JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

PROCESS PARAMETER OPTIMIZATION ON FRICTION STIR WELDED 5 MM DOUBLE SIDE PURE COPPER PLATE FOR TENSILE STRENGTH ENHANCEMENT

BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF RESEARCH AND GRAUATE STUDIES

Faculty of Mechanical and Industrial Engineering
Department of
Manufacturing Engineering
BY

BESUFKAD FEYISA ALEMU

Under the supervision of

Associate Professor –Dr. ASSEFA ASMERA

ABSTRACT

This study tried to investigate the process parameters optimization of Friction Stir Welding on 5 mm similar double sided butt welded pure copper plate to enhance tensile strength. To overcome the problem of fusion welding of copper in joint brittleness, oxidation, solidification and large distortion and to optimize the process parameters it needs adequate information of the tool dwell time, tool rotational speed, and traverse speed without this it was difficult to use the special properties of copper with its excellent resistance to corrosion, high electrical and thermal conductivities ,and the favorable strength and ductility for many industrial applications. The study applied scientific methods, specifically statistical methods of both Taguchi and Gray relational & coupled with Principal component analysis and selected universal milling machine as welding machine. Throughout the study, multiple quality features like ultimate tensile strength and percentage of elongation are focused. The process parameters, namely Tool rotational speed, Traverse speed, and Dwell time are selected to *optimized with respect to ultimate tensile strength and percentage elongation and chosen the Taguchi quality design concept, and L_9 Orthogonal Array table for the experiment, and grey relational grade obtained based on Gray relational analysis method and a value of optimum level of process parameters was identified. Furthermore, significant contributions of process parameters have been determined using analysis of variance. The confirmation tests are carried out to verify the results. The findings of the study confirmed that the selected process parameters were greatly influenced towards optimizing the quality characteristics of ultimate tensile strength & percentage elongation and the optimal process parameters was determined successfully so as to benefit quality weld through this approach and it showed that there exist a relationship between process parameters and responses besides all the considered factors are statistically significant in enhancement of tensile strength. And with the conclusions it was possible to get enhanced tensile strength of pure copper using friction stir welding, the process parameters optimized at tool rotational speed 400 rpm, traverse speed 30 mm/min and dwell time of 5 sec., and dwell time was much affecting the tensile strength. The implementation of friction stir welding process plays a vital role in successful quality improvement of pure copper and this method should further researched.*

Key words *Tensile strength, Taguchi, Gray Relational: FSW, Copper, Analysis*

CHAPTER ONE

INTRODUCTION

This chapter gives a brief description of the background to this work. It also presents the statement of problem, the objectives of the study, significance of the study, scope of the study and organization of the chapters.

1.1 Background of the Study

Friction stir welding (FSW) is said to have many advantages over fusion welding; It is used to weld alloys, welding defects are few and the process is environmentally friendly. Initially, FSW was used for aluminum, but later the FSW method was also used for other metals such as copper and copper alloys (Mishra and Ma, 2005). According to Nandan et al., 2008, friction stir welding (FSW) has become an important technique in joining aluminum alloys and other soft materials into materials used as tools in forging. Fusion welding and brazing are often used to weld copper, but these methods produce smoke and waste and have proven to be ineffective due to some limitations (Xue et al., 2010). Mousavi and Neknijad, 2009 said that pure copper is not suitable for welding using welding techniques such as fusion welding due to the presence of oxygen and rapid work of welding heat. Conventional fusion welding is said to produce problems such as joint brittleness, oxidation, solidification cracking, porosity and large deformations (Minton et al., 2006).

Copper and its alloys are the most important engineering materials due to their good ductility, corrosion resistance, electrical and thermal conductivity (Chain Welding Association, 2001). This property makes it useful in many industrial applications seeking greater electrical and thermal conductivity, as well as high ductility, creep resistance and corrosion resistance, and considers copper materials to be cutting-edge in carriers. However, copper is not suitable for use due to its high purchase price and high material consumption. With this in mind, copper connections are not only more expensive than steel, but also need to be optimized in terms of parameters. ; There are limitations when trying to join conventional rules and the tensile strength needs to be increased due to its great potential in many applications (Bargel et al., 2016).

Xu et al. (2011) and Akınlabi (2010), most of the studies conducted in the field of copper FSW provide evidence and focus on the effects of tool strength and non-stationary process on the final mechanical and micro-structural joint strength.

The reason why we choose this research topic was nowadays FSW have advanced and received the interest of researchers dedicated to identifying findings which have potential sound joining techniques to ultimately commercial uses. In light of this, optimizing process parameters of FSW copper have prominent effect in enhancing the tensile strength of the joints to best suit. In 2010, Sun and Fujii said they examined the influence of welding parameters on the microstructure and mechanical properties of welded joints to determine the appropriate process for commercial pure copper in terms of welding speed, spindle speed, and product load. For this purpose, a mathematical model was developed to predict the tensile strength of the connections using the response surface and four variables such as spindle speed, feed rate, forging force, and tool (Heidarzadeh et al., 2012). Therefore, the best FSW method should be investigated for similar double-sided butt welded copper sheets of 5 mm to increase the tensile strength**.**

There are few studies conducted in the field yet in Ethiopia. So this research will help to see the gaps in the friction stir welding of pure copper plate and optimization process parameters for the material under study and that will help to fill same. Most of the studies conducted on FSW of copper plate ranging between thickness 5 mm and above are only few (N. Srirangarajalu et al., 2016). Hence in this thesis the detail investigation in the Process Parameter Optimization of Friction Stir Welded of 5 mm similar double sided butt welded pure Copper for Tensile Strength enhancement , and the effect of tool rotational speed, traverse speed, and dwell time will be taken.

1.2 Statement of the Problem

Copper and copper alloys can be joined in many ways, including gas welding, arc welding, resistance welding, brazing and brazing. Copper fusion welding is difficult due to its high thermal diffusivity and high oxidation rate at its melting temperature. In traditional fusion welding, there are problems such as joint brittleness, oxidation, solidification cracks, pores and large deformation (Minton et al., 2015) .with little information concerning the optimization process parameters on FSW 5 mm similar double sided butt weld copper plate. This was a problem to overcome this fusion welding and to optimize the process parameters and exploiting copper's special properties, such as electrical and thermal conductivity, good combination of strength and ductility, and excellent corrosion resistance, requires sufficient knowledge to be useful for many industrial applications (IJEDR, 2015). In same token, the procurement cost of copper being higher than steel then it needs the process to be optimized to use for different applications with quality joint.

The problems investigated related to the process optimization of 5mm similar double sided butt weld copper plate were lack of clear optimized process parameters to enhance the tensile strength of the weld and lack of clear procedure for an overall effectiveness of the quality weld of 5mm similar double sided butt weld copper plate and it was quite known about the FSW within the metal industries of the country. This may told that FSW were not clear to apply to the metal industries of the country, with no applying of FSW technology the selection of process parameters, optimization, and enhancement of tensile strength for quality weld of copper and copper alloys were impossible.

Moreover the availability of information help researchers and industries to be motivated for further focusing to solve the problems related to fusion welding of copper and cooper alloys. Therefore, the main purpose of studying the optimized parameters of 5 mm uniform butt welded copper sheets is to promote the use of friction stir welding (FSW) or solid-state welding technology, which has already been linked in the domestic metal industry and academia. FSW has many industrial applications, such as the production of ship panels, air frames fuel tanks and in the aerospace body work and engine support frames in the automotive industry (Selvam, 2013). FSW is used in applications where the original metal material must be kept as unchanged as possible. However, it was noted that research and industrial application of FSW are two separate processes that the student researcher need to accomplish an experimental works. In this regard, the industries support the researcher to realize his/her results, taking into account that the industries are the best evaluators.

It is known that strong connection is the most important thing to create copper connections for electrical use. Connections are preferred over cross and force connections due to their better electrical properties (Eslami et al., 2018). However, copper is generally difficult to weld with conventional fusion techniques due to its high thermal diffusivity (401 W/m.K). This high thermal conductivity makes it difficult to obtain good welds (Carlone et al., 2015). Instead, the solid state joining processes has attracted much attention, friction stir welding (FSW) also known as a solid state joining technology, and many authors have published the suitability of this process for joining copper products (Celik et al.,2016).

Also find new ways and methods to innovate the best solutions to create products that differentiate from the current method. The current welding process, tungsten inert gas welding (TIG), is not suitable for butt welding aluminum or copper sheets due to reduction. It is not possible to weld different materials because the difference in chemical properties is also bad. If some questions are answered, FSW seems to be one of the best methods for this application. FSW has many other advantages that have nothing to do with weld quality. It has been proven to reduce pollutant emissions to almost zero and reduce the energy used in the welding process, thus having a lower environmental impact than other welding methods. This technique can be used in any direction because the effect of gravity is negligible during FSW. Due to the large amount of energy, the process is usually completely automatic, which increases the cost of the equipment and reduces the skills and costs of the user (D. Lohwasser and Z. Chen, 2009).

Although they have many advantages of friction stir welding and friction stir processing (FSP) in Ethiopia. Many industries can benefit from improving knowledge of optimizing FSW processes. The FSW of copper is very interesting because it will be used in the nuclear, electrical, and electronics industries. It is also important to understand the factors affecting copper FSW to ensure the best possible weld quality and visibility.

This issue has indicated the need of paradigm shift in the joining of copper and copper alloys from a focus on conventionally welding process to a wider focus on FSW. And this has highlighted the importance of optimizing the process parameters in enhancing the tensile strength of the joint. But to do this, task requires better understanding of the theories of FSW, principles, experimental works and confirmation of the experimental works.

The first gap shows in revisiting the scarcely available materials concerned with the FSW of similar 5mm butt weld copper plate and the overall industrial applications in Ethiopia, one can understand that there is less work done in the field and there exists a gap in the knowledge regarding the portion of the FSW that can be utilized to weld copper and copper alloys. In other words: the problem appears more serious when it comes to industrial applications.

Although the potential has been proven, as the authors of this study know, there is currently no enough application in the domestic industry for electrical and electronics joining by means of FSW. To achieve this goal, many things need to be further investigated. This study investigates the optimization of process parameters to the use FSW for the production of copper connection in the experimental work.

The very little information exists concerning FSW used by the metal industries of the country is a serious problem, because without sufficient knowledge, many of the industries who are directly involved in the process were not knowing what to expect from the process. Therefore, this study was design to ascertain what process parameters to perform on the enhancement of the tensile strength of the weld and within this lack of sufficient knowledge in the metal industry on FSW may reduce. Since the information on the demand for FSW at the industries and academic sectors of the nation has not yet been established, poor information may continue to persist. When the researchers give adequate information, poor information may decrease. And this study helped to answer this information what are important for FSW of similar 5mm butt weld copper joint.

The second gap related to how to optimized process parameters and improve the tensile strength, and there will be experimental research that conducted in examining the relationship between them. But this is not clearly analyzed for similar double side butt weld of 5mm pure copper plate and this suggests unresolved area of studies to know to what parameters influence more

Many researchers have studied the FSW of aluminum and its alloys, but only some research reports are available for copper and its alloys (Hwang, 2010). Although there are few studies and proposed process optimization methods to predict suitable process parameters which affect the performance of aluminum -copper FSW joints. The views of the experimental work, specifically, on process parameter optimization and mechanical property were on the work of (Hasan et al., 2015; K.M.Dawas et al, 2018; Tansel et al, 2014; and Livan, 2020; A.K. Lakshminarayanan, 2019 V. and Balasubramanian , 2010) , but no experimental study has been conducted to examine the optimized process parameters on similar 5 mm double sided butt weld copper plate using Taguchi and GRA coupled with PCA method . Apart from this, most of the studies on FSW of copper have been done on 1 to 4mm thick plates. However, there are few studies on FSW of copper plates with thickness of 5mm and above (N. Srirangarajalu, and A. Rajadurai, 2016).

This study differs from others for two basic reasons. First, the study advanced the application of FSW by examining similar 5mm double sided butt weld copper plate and the effect of optimum process parameters as part of quality characteristics. Second, this research and its basis may eventually provide tools for the analyzes of FSW copper plate and enable better design of experiments and analyzes for better matching of mechanical properties. Finally, for making it applicable the experimental information on the FSW of 5mm similar double sided butt weld copper plate that needs more emphasis. The purpose of this study is to examine the optimum process parameters on the enhancement of tensile strength, and on its relationships to determine whether the optimum process parameters enhance the tensile strength of the joint or not from industrial application point of view.

With this background the present study can be stated as Process Parameter Optimization of FSW on similar 5 mm double side butt weld pure copper plate to enhance Tensile strength.

1.3 Research Questions

Based on the above problem definitions, the following basic research questions will be addressed:

1:-What are the effects of process parameters for the study?

2:-What are the trends between welding parameters and tensile strength?

3:-What are the process parameters that give optimum tensile strength?

1.4 Research Objectives

1.4.1 General Objectives

The purpose of this study was to investigate the Optimizes Process parameters of FSW on 5 mm similar double sided butt welded pure copper plate to enhance tensile strength.

1.4.2 Specific objectives

The Specific objectives are as follows:

1. Examine the effect of process parameters to enhance tensile strength.

2. Finding the optimal parameters, through a Taguchi and GRA coupled with PCA in order to achieve and transfer the correct know-how and technology to our industry.

3. Important indicators were determined using ANOVA.

4. Validate the results by conducting confirmation experiments.

1.5 Significance of the Study

Friction stir welding (FSW) is a method developed to join aluminum and its alloys. Efforts are going to expand the use of FSW to materials which are harder and more difficult to weld, such as copper, steel, stainless steel, Ni-alloys, and titanium. The great potential of FSW can be used for a wide range of applications from joining plates of various thicknesses to manufacturing complex structures. Application examples include magnetic resonators, heat exchangers, air conditioners, furnace coolers, electrolytic bus bars, and superconductors. Apart from some good work, studying FSW of pure copper and especially Friction Stir Welding of copper alloys has been very limited (N. Srirangarajalu et al. ,2016).

In the present industrial arena of friction stir welding, the ability to translate the research of different materials into application through experimental work will be important. Analyzing and understanding how this can be used in academic or scientific institutions and the metal industry is one of the most important aspect in manufacturing engineering academic research. The papers in this issue attempt to evaluate the important implication of FSW for economic and business development. They provide a more competitive FSW for copper and copper alloys subjected to fusion welding.

Due to the widespread use of existing copper and copper alloy FSW in the industry, improvements were evaluated by testing the performance of the products. This new focus has diverted attention away from the main role of creating engineer as industrial expert in to research and knowledge generating , and the possibility of joining the commercial pure copper plates by friction stir welding have demonstrated the effectiveness of joint (Dhananjayulu Avula et al., 2011) .

Benefits to researchers/research industries resulting from competitiveness to their products and should be expected to be primarily financial, even though any revenues resulting from improved product can help fund additional research activities, in addition to the financial benefits. The main benefits are direct and should be considered in the long term. In helping and develop mutual trust between the researchers/research and industry, It establish long-term strategic partnerships (as opposed to one-off contracts), it build strong experimental application for researchers/research.

Irrespective of the extent and complexity of experimental work, deploying the basic principles of FSW brings multi-faced benefits to the industry involved in the process, the academia, and the market/customers. The process can help industries to reduce their time and cost required for quality weld of copper and copper alloys. Furthermore, it facilitates the application of improved products and technologies (W. B. Lee et al., 2004).

This research has important implications for research student and industry that uses copper and copper alloys for different applications. The research student understood the actual experimental study on FSW of 5mm butt welded copper plate; this will also help to determine best techniques on enhancement of the tensile strength. On the other hand, this study tries to reveal how to create FSW test process and the importance of the methods. Finally, this study forms the basis for in- deep research and analysis by interested researchers.

1.6 Scope of the study

This research has the following important limitations. Experimentally, this research only use pure copper sample to investigate the process parameters that optimizes friction stir welding for tensile strength enhancement of 5 mm similar double sided butt weld copper plate. Thematically this study tried to uses Taguchi and GRA coupled with PCA method and ANOVA to assess Process parameters that optimizes friction stir welding. Even if there were a lot of concepts related to optimization methods, the main purpose of the research is to investigate optimization process parameters to enhancement the tensile strength of 5 mm double sided butt welded copper plate using Taguchi and GRA together with PCA methods.

1.7 Limitations of the study

Like every research this study also has limitations. To achieve their research goals, the research student uses 5 mm thick butt-welded copper plate or C101/CW004A (which is 99.9% pure copper used in many engineering applications).

There are a lot of factors that can be investigated by FSW process parameters. Even in this specified study there may be other untouched factors, so the researcher suggests for further study on the area. In experimental studies, the researcher encounter problems with experimental materials and having proper testing laboratories and methods were critical. Experimental materials may not available as what we need. However, to reduce the impact of these shortcomings, great care must be taken in selecting material and reviewing all evidences before problems arises.

1.8 Organization of the Thesis

This paper divided into five parts and chapters. It constitutes the content of the first part, which includes the introduction, background, statement of the problem, general and specific objectives, and research questions, significant of the study, the scope of the study, limitation of the study and the organization of the work. Chapter two contains the review of the various experimental methods on process parameter optimization of tensile strength done on FSW, types of materials and various methods of determining the optimum process parameters. Chapter three describes the methods, materials, procedures and experimental setups. Chapter four discusses the experimental results and discussion. Chapter five gives the conclusions and recommendations from the study.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, we will interpret and discuss the features of this thesis from various perspectives with related topics based on scientific articles, journals and books, in order to give our readers a multi angle view over the topic, and try to keep it simple and understandable.

2.1 Friction Stir Welding (FSW)

The friction stir welding technology was first introduced by the Welding Institute (TWI) in 1991 and is the result of many years of welding research in light metal alloys (mainly aluminum alloys)(W.M Thomas et.al, 1996). In the joint welding process (MMA), (TIG), (MIG), (MAG), etc. the materials are combined according to the diffusion process in the turbulent zone (HAZ). This process requires heating the connection to a temperature that makes difference, but on the other hand, it requires a lot of energy. This heat causes defects or some significant deformations, residual stresses, porosity, irregular and coarse-grained HAZ structure.

2.1.1 Principle of FSW Operation

The working principles of FSW are as follows. A non-consumable rotating tool is placed between on stable work pieces to be welded. The heat generated due to friction and plastic shear deformation between the tool and the base material softens but does not melt the material. Frictional heat dominates in the upper region of the weld, and heat from plastic work dominates in the lower region (Song and Kovecevic 2003; Colligan and Mishra 2008). As the tool is moves along the mating line, the mating surfaces are “stirred” together by the rotating tool. The tool moves the plastic material from the front of the tool to the back of the tool, similar to extrusion or forging processes. The welded material cools down at the back of the rotating tool and forms a solid weld. Figure 1 shows a schematic diagram of the FSW process and its main components (Thomas et al., 1991).

The FSW process has four phases: 1) entry phase, 2) holing phase, 3) welding phase, and 4) exit phase. The process begins with the first stage, where the tool gets close to the material, and then penetrates the material to generate the initial heat.

The second stage is characterized by the process of reaching the temperature required to start the welding process. This involves a constant pressure that creates the necessary energy (friction) to between the tool and the material, which creates the required mechanical (friction) energy. This process continues until the elastic modulus of the material (i.e. the pressure of the tool and the material) decreases; This indicates that the required temperature has been reached, and the welding process has started.

The welding stage (third stage) is done by a complex thermo-mechanical process involving a combination of heat and plastic deformation. Performing welding in the FSW process involves mixing the “doughy” material of the work piece along the mating line. Given that the temperature generated by this heat is not exact to form complete diffusion, the material that needs to be welded has to be mixed in their mating line using the tool.

In the entire process mechanical work plays an important role: it affects both the thermal energy and the mixing of base materials in their “doughy” stage to achieve the quality of the weld joint. In the last stage (fourth) the tool leaves the material (with vertical movement) and completes the welding cycle. The FSW process is most often used for butt and lap welds but can also produce corner joints. Heat is generated by a special tool that has a steeped shaft shape body with a larger diameter (shoulder) and a smaller diameter (pin), that have a technical advantage in the welding process , see Figure 1(P. Prasanna et al., 2013.).

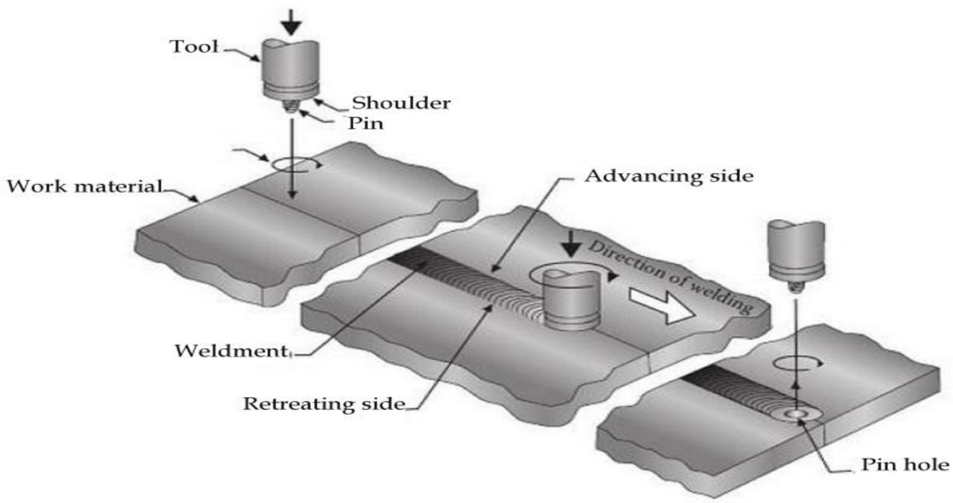


Figure 2.1 Operational principles of FSW. (Source: ISSN 0543-5846)

2.1.2. Friction Stir Welding of Copper

FSW is a new welding method developed by the British Welding Institute (TWI) in 1991. It is a solid state joining method and it eliminate defects of fusion welding that arises due to their liquid state (such as solidification). Cracking is reduced or completely prevented. It has excellent weld quality and its mechanical properties are often equal to or better than the parent material, especially when compared to fusion welding methods. It is also safe, clean and environmentally friendly. It does not require expensive welding filler rods or a high level of skill or training, and can be performed in any position, from down hand to overhead. It is currently used primarily for joining aluminum alloys, although it is suitable for use in many materials, including

iron,
copper, nickel, and titanium alloys (Dawes et.al, 1995).

2.2 Process Parameters

The process parameters of friction stir welding is roughly divided into three groups: (a) Related to tools: shoulder and pin , shoulder diameter, pin length, pin diameter, characteristic of tool geometry (b) Related to machine: welding speed, cutting force or depth, spindle speed, tool tilt angle, etc., and other parameters related to the welded materials (Lohwasser and Chen, 2010).

2.2.1 Tool Related Parameters

The tool is the most important factor in FSW along with the correct welding parameters. The functions of the tool include heating and softening the base metal, dispersing the oxide layer, compressing the base metal from the front to the back of the tool and from the top of the weld to the bottom, and finally consolidating the softened materials to form a solid state joint. The tool ply an important role in the weld production (Mishra and Ma 2005).

2.2.1.1 Tool Geometry

The tool shaped in stepped shaft from to hold a shoulder and a probe. The length of the probe is related to the thickness of the material to be welded (Dawes 1995). In general, both the shoulders and the probes have features (threads, grooves, flat surface, etc.) that will improve the welding performance. The shoulder effect is more important in thin section welds, but as the section thickness increases, the effect of the probe will be greater .According to Savolainen et al. , noted that three flat surfaces were sufficient for FSW of thin -section copper's. Thicker sections require more complex geometries (Dawes and Thomas 1999).

Tool geometry is very important because it affects the microstructure and size of the weld as well as the breakdown of oxides. Tool geometry also supports tool strength. Efficient tool geometry produces error-free, undercut-free and burr-free welds. Additionally, the geometry should be easy to manipulate. Unfortunately, current tool design is based on observational and experimental data, which limits understanding of the underlying mechanisms (Dawes 1995; Nelson 2005).

2.2.1.2 Tool Dimension:

Tool size is very important for friction stir welding. Tool size will vary depending on work-piece thickness and material. No specific design of copper-copper connections has been reported in previous literature. The length of two points is very important in FSW tools. One is the shoulder and the other is the probe. It directly affects the mechanical properties and microstructure of the weld. The FSW tool shoulder was generally reported the concave or flat for Copper joint. In the past, pins used for copper materials included cylindrical pins and conical pins, while pins used for copper materials included toothless and threaded pins. It has been reported that the tool pin length is generally 0.2 mm shorter than the substrate thickness to ensure the required force and full penetration into the joint. Shoulder-pin diameter is shown in the range 3 to 4; this is slightly higher compared to the shoulder used for aluminum and its alloys. For copper FSW connections, it has been reported that the diameter from shoulder to pin is higher because the copper material has high thermal conductivity and high melting point, thus it should have more heat (W. B. Lee, S. B. Jung, 2004 and H. Khodaverdizadeh, et al., 2012).

2.2.2 Machine Related Parameters

2.2.2.1 Welding Speed

Welding speed is also a very important parameter for friction stir welding of copper materials. Welding speed directly affects welding performance, when welding speed increases, heat input decreases; when welding speed decreases, and heat inputs increase. The combination of rotation speed and welding speed ensures a good joint. Previous article (W.B. Lee, S.B. Jung, 2004 and Y.F. Sun, H. Fujii, 201).

2.2.2.2 Tool Rotational Speed

The rotation of the tool is directly related to the welding power source, which directly affects the welding quality. Rotational speed plays a 41% role in FSW quality. According to all previous reports, the 800-1200 range is the best recommended range for copper FSW connections. The increase in tool rotation speed causes more heat, which causes the TMAZ and HAZ to expand, resulting in a decrease in tensile strength. However, the rotation is fast enough to generate friction and heat (P. Xue et al., 2011 S. Kallee et al., 1998).

2.2.2.3 Tool Dwell Time

Welding service shall include time on tool after depth is reached and before starting to move. Dwell time affects the initial heat input and can affect the quality of the weld. A standard dwell time of 3 seconds should be used but can be adjusted depending on source characteristics s (Justin. M.E , 2014).

2.2.3 Other Parameters

2.2.3.1 Copper as Base Material in FSW

FSW of copper is more difficult compared to aluminum, copper is more difficult process due to the melting point, thermal conductivity, and flow stress. According to Mahoney (2003), the flow stress at the welding temperature determines the friction stir weldability of the given material.

2.2.3.2 Properties of Copper

Copper has a face-centered cubic (fcc) crystal structure and it does not undergo phase changes after solidification. The melting point of copper is 1084 °C compared to aluminum other properties of copper include high thermal and electrical conductivity, formability, and corrosion resistance (Mc Nelley et al. 2007).

2.2.3.3 Mechanical Properties of the Copper Welds

There is very little information in the literature about the mechanical properties of copper FSW welds. Overall, the results show that the electrical properties of copper FSW welds are similar to those of the parent material when appropriate welding equipment is used. Mechanical properties appear to directly affect material flow during FSW (Zettler et al., 2006).

2.3 Tensile Properties

The yield strength and tensile strength of friction stir welded samples are often evaluated to compare the strength and ductility of the welded samples with the base metal. This is mostly done with harshness. Many researchers report the tensile strength of FS welded joints as a percentage of the base metal, and some also investigate the relationship with process parameters. Tensile samples were wire cut using EDM and prepared according to ASTM standards for small sample (Kumbhar et al., 2011).

2.4 Advantages of FSW

The advantages of friction stir welding are:

1. The process creates no smoke and splashes , requires no gas shielding , and is requires and no consumable tool , makes it environmentally friendly.

2. Since the weld is obtained in the solid phase, gravity does not play a role; hence the process can be performed in any position (vertical, horizontal, overhead or orbital).

3. Because the temperature involved in the process is very low, there is less shrinkage during solidification.

4. The Welds made using FSW are good quality, have excellent properties and have better microstructure than traditional welding methods.

2.5Application of Copper and copper alloys

Copper and copper alloys are widely used in many products to improve our daily life. They have excellent electrical and thermal conductivity, good strength and durability, corrosion and fatigue resistance, and are generally non-magnetic. They can be easily soldered and brazed, and many can be welded with a variety of gases, arcs and processes. They can be polished and polished to almost any texture and shine. Pure copper is widely used in wires and cables, electrical contacts, and many other items that need to carry electric current.

Copper and some types of brass, copper and copper-nickel, are widely used in car radiators, electrical appliances, home heaters, solar products, and many other applications where rapid heating is required across or across metal profiles. Because of their excellent resistance to corrosion, copper, brass, bronze and copper-nickel are also used in pipes, valves and fittings in machines that transport potable water, process water or other aqueous liquids as well as gases.

Copper alloys are also the best alloys to reduce contamination in contact areas. More than 280 copper alloys have received health registration from the US Environmental Protection Agency (EPA) for being able to kill 99.9% of bacteria within two hours.

2.6 Taguchi and GRA coupled with PCA Implementation Procedures

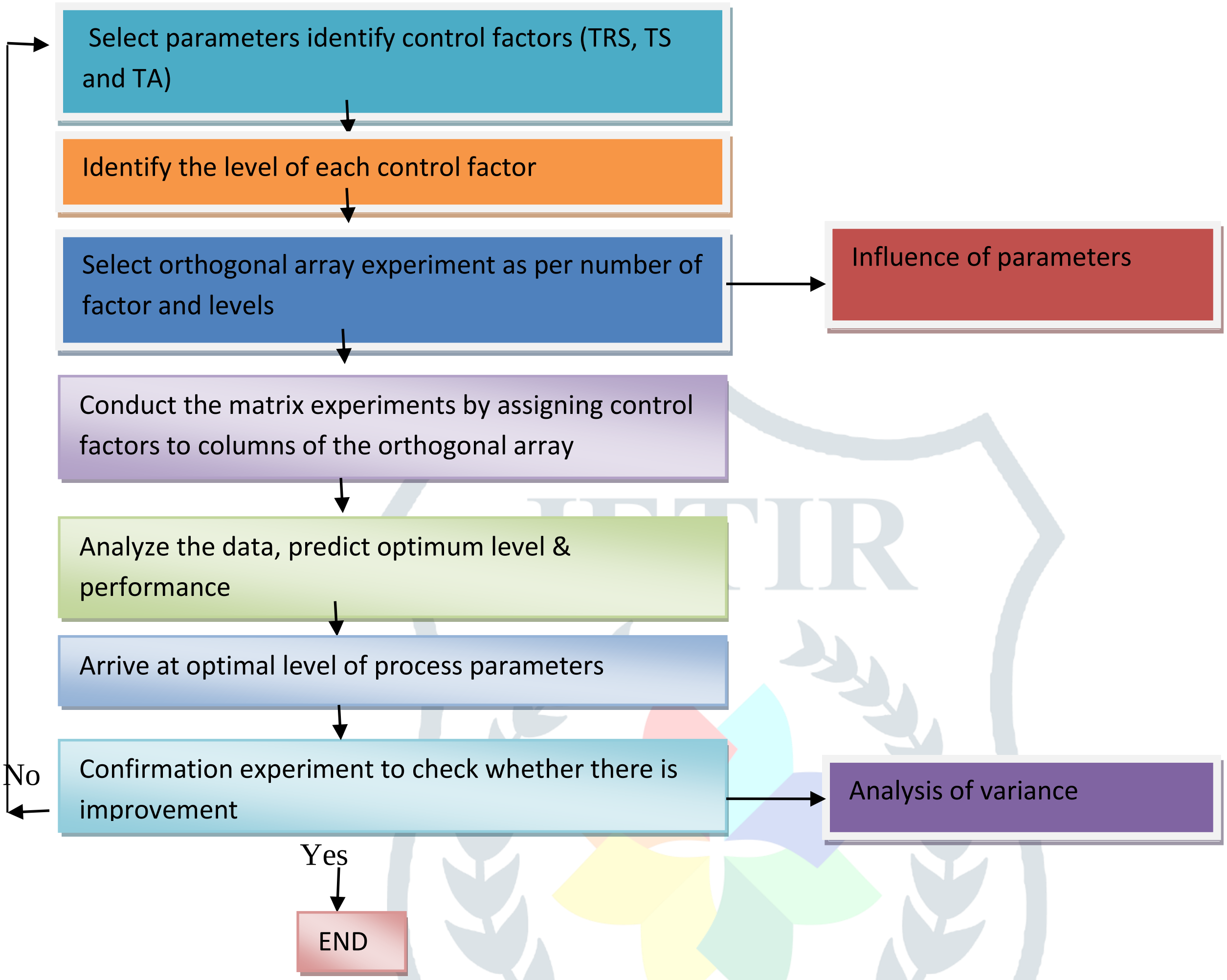


Figure 2.2-. Procedures for Taguchi and GRA analysis

Empirical Studies

According to Khodaverdizadeh et al. , 2012 investigated the work hardening behavior of pure copper alloy FSW joints. The tests were carried out on two different rotation speeds and a feed system that was not recommended and was switched between the machines and small connections of copper connections. In SZ and HAZ, the grain size decreases with increasing rotation speed and also decreases with decreasing welding speed. As a result of its hardening ability, the stain hardening index decreases.

About Lin et al., 2014 compared the efficiency of friction stir welding of pure copper sheets with TIG and found that the FSW welding efficiency of copper was 13% higher than that of tungsten inert gas welding (TIG).

According to H. Bisadi et al., 2016 they used FSW to analyze research papers of AA5083 aluminum alloy and pure copper. The tests were carried out at different rotation speeds at welding speeds of 15 and 32 mm/min. It has been found that too low or too high welding temperature can cause many joints, and the best joint tensile shear performance is achieved at a high rotational speed of 825 rpm and a welding speed of 32 mm/min.

According to Galvaoa et al., 2016 the aim of this study is to examine the effect of shoulder geometry on friction stir welding of 1 mm thick copper-DHP (deoxidized copper phosphorus, high residual phosphorus) plates. Three shoulder geometries are used for this purpose (flat, tapered and rolled) and the rotation and travel speed of the tool can be changed. It turns out that the flat shoulder tool is not sufficient for welding, while the rolled shoulder tool is better than the shoulder tool in terms of reducing defects. However, both geometries require minimum rotation speed to avoid defects.

Y.M. Hwang et al., 2010 attempted to investigate the thermal history of friction stir welded (FSW) work-pieces using pure copper C11000 for joints. For this purpose, K-type thermocouples are used to record the temperature history in different parts of the workplace, and this information allows the determination of welding success along with pre-heating, device rotation speed and tool movement speed.

According to Nandan et al., 2008, it is accepted that the most important factor in welding is not the rotation speed, but the movement speed and depth are also important. Rotational speed determines the heat and temperature as well as the shear strength from the FSW weld. Therefore, it affects the microstructure and mechanical properties of FSW welds. Other welding parameters also included like tilt angle, spindle power, torque, Z force, and the distance between the FSW weld and the side of the plate.

According to Savolainen et al., 2012 the use of H13 tool steel, nickel-based super-alloy, sintered TiC /Ni/W (2:1:1), hot melt TiC/Ni/Mo (3:2:1) ratio appeared, pure tungsten and PCBN. They report that tools made from nickel-based super-alloys are made only for pure copper and for 10-11 mm thick copper alloys, and they also stated that the PCBN tool can be used to weld Cu-Ni alloys.

K. Sureha, A. Els-Botes., 2011 The authors report on friction stir welding of high-strength, high-conductivity 3 mm thick copper at a travel speed of 50 to 250 mm/min and a rotation speed of 300 rpm. The tests were carried out at different welding speeds of 50, 100, 150, 200 and 250 mm/min and a constant 300 rpm. The authors reported that grain size and micro-hardness increased with increasing welding speed. The authors also reported that the yield strength (YS), ductility and ultimate tensile strength (UTS) in the machined area were higher than those of the base metal, and YS and UTS increased with increasing speed. At a constant rotation speed, as the rotation speed increases, energy consumption and efficiency decrease, making the equipment more efficient.

H. Khodaverdizadeh et al., 2012 the authors reported the FSW of 5 mm thick copper (Samples R600T25 and R600T75) at constant rotation of 600 rpm at two speeds of 25 and 75 mm/min to study the effect of welding speed. The authors reported that the properties of the samples at 75 mm/min welding speed were better than those at 25 mm/min welding speed, because as the welding speed increased, grain size and power consumption decreased, thus hardness and tensile strength also increases.

J.J. Shen et al., 2010 reported the study of FSW of 3 mm thick copper plates at different welding speeds from 25 to 150 mm/min and constant rotation of 600 rpm. The effect of welding speed on the microstructure and mechanical strength of the joint shown good The FSW was performed at a rotation speed of 600 rpm and different welding speeds of 25, 50, 100, 150 and 200 mm/min.

G.M. Xie et al. In 2007, FSW consisting of 5 mm thick copper sheet was reported at three different speeds: 400, 600 and 800 rpm. And the welding speed remains constant. In this article, the authors examined the welding tests, no welding defects were detected in the weld, good mechanical properties were obtained at 800 rpm, and it was also reported that the weld was not made with fine-grained low-energy material. . - no copper source. At a rotation speed of 400-800 rpm and a travel speed of 50 mm/min, the microstructure is 3.5-9 μm. As the rotation speed and grain size of the FSW copper ingot field increases, the hardness decreases. As the grain size of the nugget region decreases, the micro-hardness and yield strength of the nugget region increases and its ductility decreases.

H. Khodaverdizadeh, et.al, 2012 the authors reported the FSW of 5 mm thick copper material in two different dimensions. To examine the effect of rotation speed, the rotation speed was 600 and 900 rpm and the cutting speed was 75 mm/min (models R600T75 and R900T75).

The authors reported that in FSW joints, the stiffness of the SZ was lower than that of the HAZ and BM at all rotational speeds. As the FSW material temperature increases (rotational speed increases and travel speed decreases), the lower hardness area expands. FSW produces two competing factors that affect SZ hardness. Thermal exposure has a softening effect, thereby reducing the hardness of SZ. On the other hand, the importance of grain refinement produced by FSW increases the hardness of SZ. At higher temperatures, for example in the R 900T75 model, the softening effect prevails. Therefore, the hardness value of SZ is lower than that of standard R600T75 and shows a large area of low hardness. The yield strength (YS), ultimate tensile strength (UTS) and hardness of the friction stir welded structure decreased compared to BM. This may be due to the decrease in dislocation speed during re-crystallization. A lower dislocation rate requires less energy to deform the material.

Y.F. Sun, H. Fujii, 2012 Authors reported FSW consisting of 2 mm thick pure copper sheet at rotation speed from 200 to 1200 rpm. Welding speed is 200 to 800 mm/min and axial loads are between 1000 and 1500 Kg. The author found that at a load of 1000 kg, when the rotation speed decreased to 700 rpm, a groove-like weld defect appeared in the whip area due to inefficient plasticity.

P. Xu et al. In 2011, the tool inclination angle provides high clamping force to increase the axial force. Friction stir welding of copper materials requires high temperature equipment because the copper content is 1083 °C, so there must be friction pressure to generate sufficient heat, and the friction increases with the increase of axial force. Using appropriate tool rake angle can increase the axial force, resulting in better joint strength in FSW. To obtain the axial pressure for copper-to-copper FSW connections, the tool rake angle is between 1° and 3°. The bevel angle tool with shoulder design gives better results on copper products.

According to the research of Surekha and Els-Botes, 2011; and Xie et al. 2007 Heat input welding and resulting grain size affect the tensile strength of copper FSW welds. Lower electrical properties (tools with lower rotational speed or higher movement) and smaller grains result in higher strength, tensile strength and lower ductility. The tensile strength of a weld compared to the base metal depends on the condition of the base metal (annealed or work hardened) and the heat input to the weld. The welding equipment used when examining the FSW of pure copper uses low-power and rapid cooling water at the edge of the tool. The resulting welds exhibit nearly identical tensile strength (elongation at break and the yield and ultimate tensile strength) as compare to the parent material.

According to Sun and Fujii, 2010 the report on welded a 2 mm thick commercial pure copper they stated that increasing the applied force reduces the grain size rather than reducing the tool rotation speed. It implies by increasing the load in achieving a higher hardness of weld than the base metal.

Experimental study by Andersson and Andrews, 1999, compared 10 mm thick phosphorus-doped copper FSW that can be welded in different positions (beginning, middle and end of the weld) and base materials. The tensile strength values of the welds were similar but lower than the base metal (216-218 MPa and 280 MPa, respectively).

According to T.K. Bhattacharya et al., 2017 studied the relationship between electrical properties, joint strength and welding strength, and by heat testing FS butt welding of Al-Cu, different data were found to be both axial and axial. force and torque decrease. The study also found that increasing the rotation speed from 800 RPM to 1000 RPM, thus increasing the heat input, made the joint stronger. This is true for the two feed rates they used in their research , 20 and 40 mm/min.

Study: H. Bisadi et al., 2013, Effect of rotation and feed speed on FS lap welds copper. They found that both low and high welding temperatures led to many joint defects. In their tests, higher welding temperatures resulted in decreased joint quality and increased burr formation. Lower temperatures may cause defects near the bonding layer, as well as some gaps. It highlights the importance of temperature control during FSW of Al-Cu to obtain a good weld.

Experimental study by Akinlabi et al., 2010 showed that the resistance of FSW Al-Cu connections increases as the amount of power increases. This may be due to the increase in the number of IMC and P.K. Sahu et al. When welding FSW AA1050 to copper in 2016, it was found that increasing the rotation speed to

1200 RPM provides more welding power, while the power decreases when the rotational speed exceeds 1200 RPM.

Research by Liu et al., 2011 found that tool speed has a significant effect on the distribution of Cu in the FS butt welding test of Al-Cu. They found that at a rotation speed of 1000 rpm, the roots consisted mostly of Cu and the equilibrium structure. They found that when the rotation speed decreased to 600 RPM, large copper particles accumulated on the aluminum alloy side, and the distribution of copper particles in the weld was very dense.

According to different authors, the quality of welds decreases as the rotation speed increases, which shows the importance of the balance between rotation and other friction stir welding processes did not increase the tensile strength of the weld. In addition, they said that as the rotation speed increases, the IMC layer thickness in the weld becomes uneven, indicating that the weld quality decreases.

2.8 Conceptual Framework of the Study

In this study, the conceptual framework was based on the following independent variables: determining the optimum process parameters and maintaining balanced signal noise control which were assumed to have effects on the dependent variable tensile strength. The researcher deliberatively did not use an intervening variable as the relationships were assumed to be linear. However, This study used control and uncontrolled process parameters as De Vuyst et al., 2006 typology to define the principle of FSW mechanisms and the formation of the weld that need to be enhanced and according to the author the flow of material during FSW depended on the parent material, tool deign, and the selected welding parameters. And the enhancements of tensile strength are influenced by these factors. And the assumed relationship between the variables was shown in Figure 2.3.

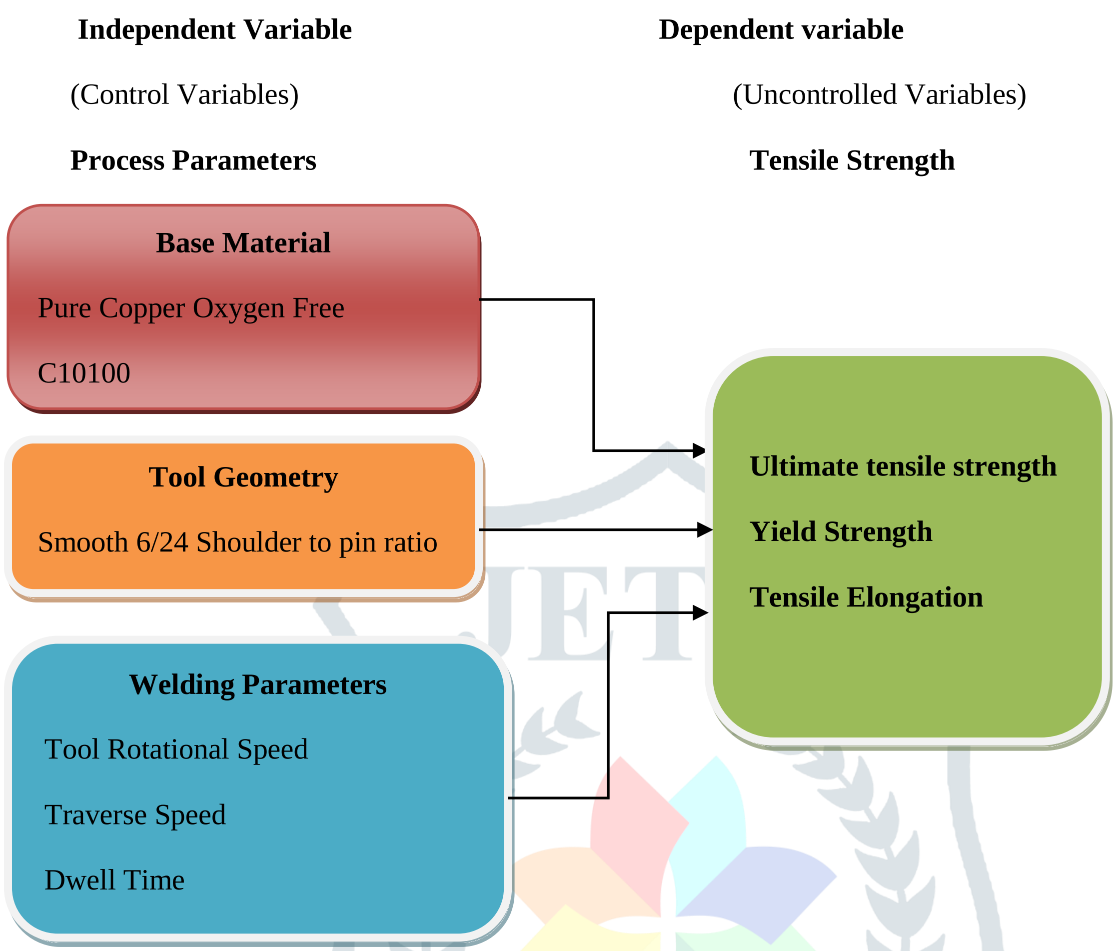


Fig 2.3 conceptual Framework of The study

CHAPTER THREE

MATERIALS AND METHODS

The chapter discusses what material , instruments and equipments were used in welding and testing of the experimental specimen with explaining why different FSW process parameters were selected and the methodology for the flow of the study.

3.1 Methodology

The research methodology of this study were indicated in flow chart started from the use of Taguchi, and GRA methods, as Figure 2.2 shown ,and it begun with how the objective of the study to be performed up to the optimum parameter confirmatory tests as indicated in the flow chart Figure 3.1. According to C.R.Kothari, 2004 it is necessary for the researcher to know not only the techniques but also the methodology to systematically solve the research problem. And at various steps that are generally adopted by a researcher in studying his research problem along with the logic behind them.

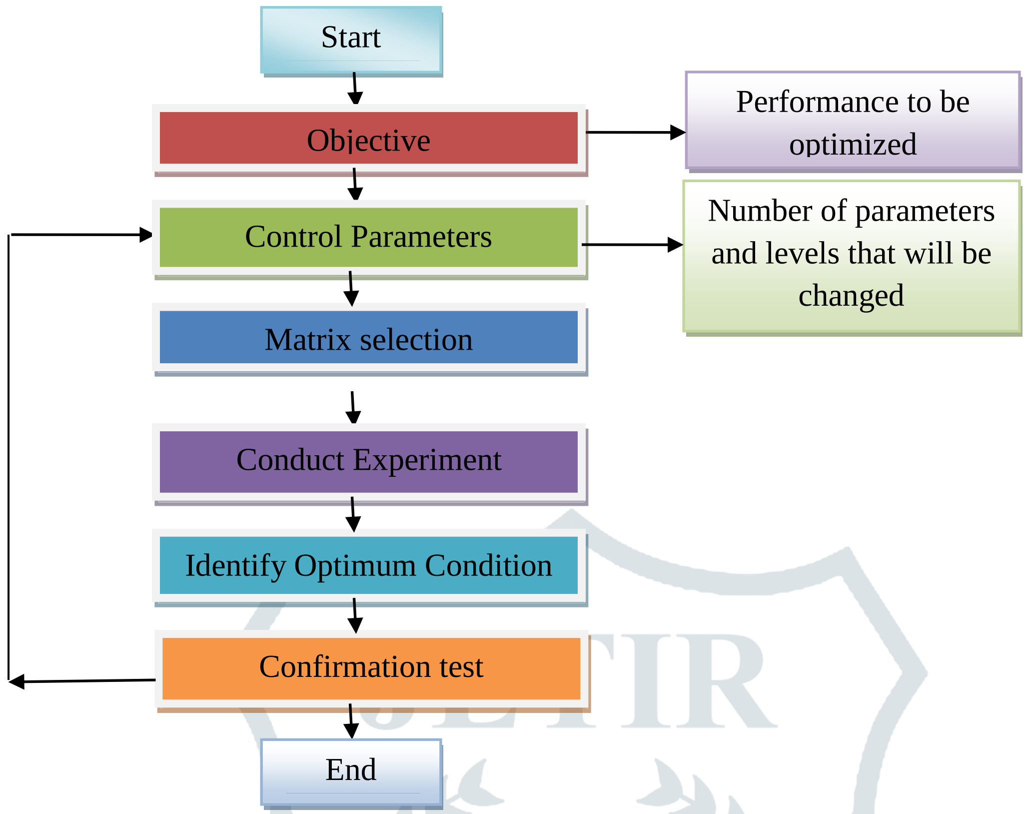


Figure 3.1 The Experimental Flowchart of the Study.

3.2 Materials

3.2.1 Welding Materials

The material used in this study were pure copper as a base material .According to Mahoney, 2003 FSW of copper is more difficult as compared to aluminum, due to copper's has higher melting point, thermal conductivity, and flow stress. The stress of welding temperature determines the friction stir weldability of the material in question. In this experiment, we used similar double sided butt welded pure copper with plate of 100 mm, 50 mm, and 5 mm (length, width and thickness) respectively, as shown in figure 3.2 below. In this study, pure oxygen free copper was used as a double side butt joint welding model. An optical emitted spectrometer machine (appendix II) was used to check the chemical composition of the metal and the results are summarized in Table 3.1. In order to minimize the stress caused during cutting, all models are cut to the same size using a hand machine.

(A) (B)

Figure 3.2 Material chemical composition tests A) Before the Test and B) After the Test

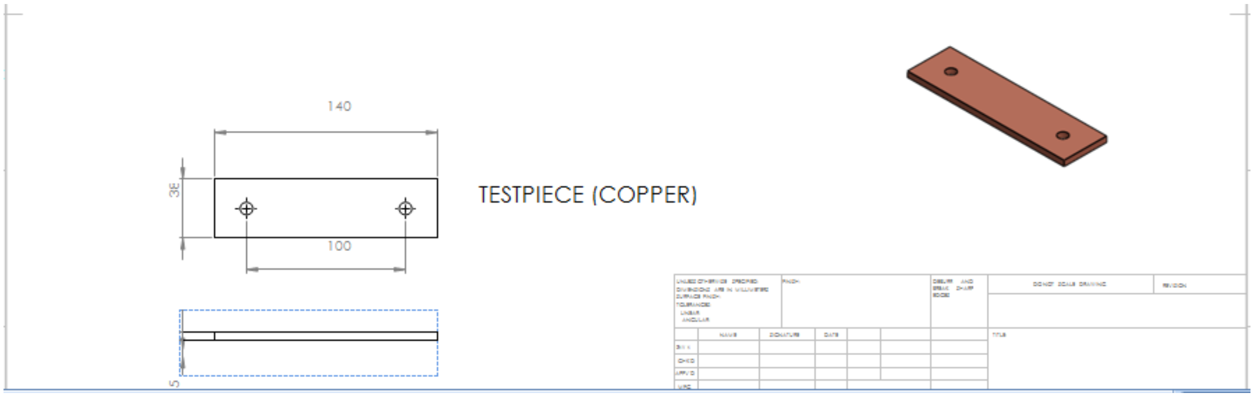


Figure 3.3 Pure copper Cu-OF (Oxygen free Cu)

Table 3.1 The chemical composition of oxygen -free pure copper (Wt %)(Appendix II)

Element Material	Percentage Composition (% Wt.)
Cu	99.90
Zn	0.0100
Pb	0.0250
Sn	0.0100
Mn	0.0020
Fe	0.0079
Ni	0.0050
Si	0.0112
Mg	0.0005
Cr	0.0020
Al	0.0005
Be	0.0022
Ag	0.0030
Co	0.0318
Bi	0.0318
Cd	0.0010

The melting point of pure copper is 1084.62°, its atomic weight is 63.55 u, its density is 8.96 g/cm and it is in the 29th place in the periodic table of elements (S. Pappas Facts about copper (www.livescience.com)). The tensile strength of pure copper depending on if how it is made, the alloy inclusion , and after the heat treatment the alloy has the tensile strength of 836 MPa and ductility 13.4 % Strength is measured at room temperature by a tensile tester Z100 (Zwick).or how it is casted, annealed or cold-worked. Cu is not only an important engineering material but also it is an important disinfectant. Bacteria, yeasts and viruses die quickly on copper surfaces, a phenomenon known since ancient times. Ancient Egyptians used it to heal chest wounds and drink water; this process described in the Smith Papyrus, written between 2600 and 2200 B.C. (H. Dollwet and J. Sorenson, 1985).

Table. 3.2. General Mechanical Properties (S. papers and facts/www/livescience.com)

Density(g/cm^3)	Hardness, Vickers	Yield strength, Mpa
8.95	50	70

3.2.2. Tool Material

Ideally, non-consumable tools are used in order to prevent contamination of the weld with tool material. Required properties of the materials include adequate strength , wear , and sensitivity of welding temperature, fracture toughness at ambient and welding temperatures, inertness of the material to be welded, thermal stability, and good friction compatibility with the base material. Most information says that the tool steel performs well as FSW tool material for up to 3mm thick copper plate.

The general choice of research materials is hot work steel tools with a good balance between wear resistance, strength and fracture toughness levels. For FSW of thicken copper material (higher than the 4mm), the tool material used for FSW should be stronger and more strong than the tool steel. Tungsten carbide and tungsten alloys are also considered as suitable tool material for thick copper material (K. Surekha , A. Els-Botes, 2011 and Y.F. Sun, H. Fujii, 2010).

It is also important to choose the tool, which should be made of good materials and process technology, but should also maintain strength and tension during welding to avoid damages, rapid wear and failure of the tool. Most tools used for welding aluminum are made from tool steel. Tool steel, high speed steel and other hardened steels are a popular choice and are also used for welding some dissimilar materials such as aluminum to magnesium and aluminum to copper. However, for welding other required materials, materials such as polycrystalline cubic boron nitride (PcBN) and tungsten materials are good choice (R. Rai. et.al, 2011). Therefore, H13 tool steel was chosen for this study because it was frequently used by others and according to Savolainen et al, 2010 it was investigated that a double sided friction stir butt-welded oxygen-free pure copper and other two copper-alloys with a thickness of 10–11 mm were used tools made of H13-type tool, and similarly for this experimental work it was selected to weld the specimens. Since the mechanical properties of the tool are higher than that of the mechanical properties of the welded specimen. For this reason, the H13 welding tool was safe for joining the specimen without breakage and tool wear as well as due to its ease of fabrication it was chosen for this study. Therefore, feature of H13 tool steel contributed to its selection in this study (Muhamad Tuah , 2015).

3.3 Experimental Setup

The experimental setup is one of the most important setups when studying the effect of process parameters to the quality of the welds, because if all experimental conditions are different from trial to trial it will not possible to establish a relation between results and those tests. Therefore, to avoid lack inconsistencies between the experimental and the test results, certain common conditions must be setup for the study or between the welded specimens and to the worktable. And to do this experimental study the welding machine, worktable, tool and fixture, and the experimental and testing procedures were set.

3.3.1 Friction Stir Welding Machine

All friction stir welds in this work are made using universal milling machine, (Model HM 1668, No. 1308016 Maanshan Wanma-Machine Building Co Ltd) as shown in Figure. 3.2. FSW equipment with automatic transversal and longitudinal movements of the table helps in welding control, it can be done in horizontal position control, also it is very important and useful in force control than CNC milling machine. The machine can perform monitoring parameters in addition to force control, and has the advantages over conventional milling machine.

Figure 3.4 Universal Milling Machine. (Courtesy: Workshop ETU, WTT Center)

3.3.2 Tool and Fixture Design

The lathe machine was used to machine solid cylindrical bar of 27 mm diameter high carbon steel into tool bit for the adaptive FSW tool. The fabricated tool bits have a 6 mm probe diameter and 24 mm shoulder to weld 5 mm similar double side butt weld copper plates.

It is stated that the pin length of the tool is generally 0.2 mm smaller than the base material thickness, which can provide reasonable plunge force and full penetration in the joint. In this study a 5 mm thick copper plate was butt-welded on both side and to get a total of 0.2 mm less pin length in between of the welded sides the designed tool pin length was 2.4 mm. And the shoulder to pin diameter ratio in the range between of 3 to 4 shown in different studies , but the material used for this study was slightly higher when we compare with shoulder to pin ratio studies that was used for aluminum and its alloys as figure 3.5 shown. In copper FSW connections, higher shoulder to pin diameter are also reported in different papers due to its higher heat input , high thermal conductivity and higher melting point (H. Khodaverdizadeh et al. , 2012).

In this study, a special non-consumable tools made of hard tool steel with pin diameter (D) equal to 6 mm was selected to weld a double sided similar 5 mm copper plate. The pin profile was tapered with initial diameter equal to D (6 mm) and the final diameter of d (3 mm) with the pin length of 2.4 mm., and a shoulder to pin ratio was 1/4 with a steeped shaft profile and a height of 70 mm that connected the pin to the main tool body as shown in figure 3.5

A well-designed tool can change the welding characteristics and reduce the size deficiency. If the machine is not rigged, tools such as threaded pins can create down force at different rpm i.e. the threads rotating and stirring the metal create forces which must be countered by the machine and there will be a case where the threaded pin is running in reverse to push material away from the shoulder; therefore the forces will be greater and causing more deflection in a cold weld as opposed to a hot weld. Even if the machine rigidity is good to withstand this and will not indicate deflection, it will affect the quality of the weld. Therefore, in this study a proper pin/shoulder tool design were taken for good mechanical properties (Fujii, H., et al. 2006).

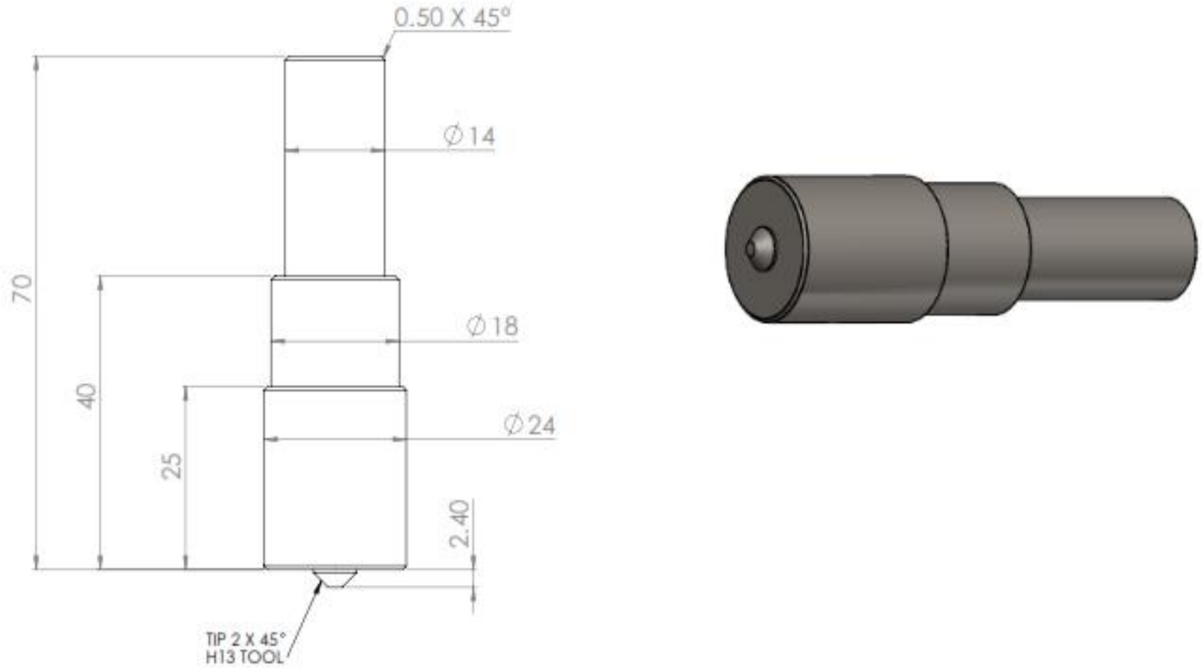
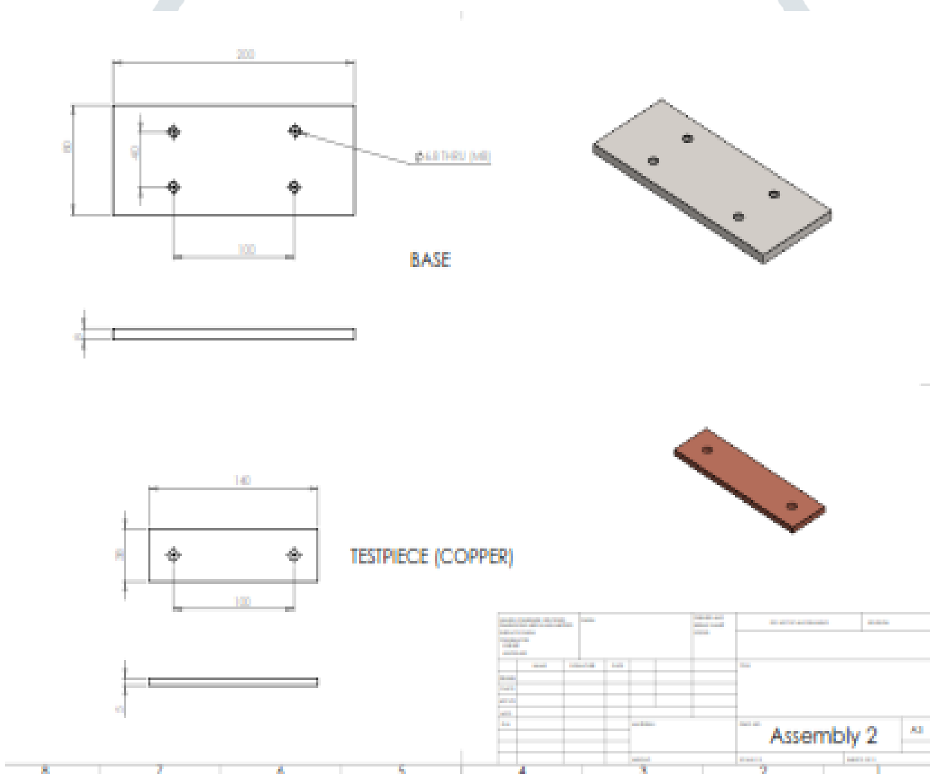


Figure 3.5 Design of straight cylindrical pin

Figure .3. 6 The H13 Cylindrical Probe

The designed fixture used in this FSW process consists of a small metal with dimensions of 140 *mm 80 *mm 8 mm (L W T), drilled with the hole larger than 11mm and ended on its back with a countersunk to hold the hexagonal bolt head and the threaded part of the bolt will be on the upper side of the plate to firmly fixed with the plate. In addition to that the Universal milling machine table fixtures were used for the attachment of the work as work holding devise as shown in the Figure 3.7 After welding the bolt and nut will be loosen, and the welded part are disassembled, and removed easily from inside the copper plate specimen (Appendix I)

A fixture was developed to weld in a universal vertical milling machine, and the design of the fixture was adapted to fix the material best fit in the FSW process (Siddique et al., 2014 and Titilayo et al., 2012). And the designs of the fixture that are used for this study are depicted in Figure. 3.7. And the design of the tool bit shown in Figure.3.6, these designed mechanical clamps were used to fix the welded copper plate in the worktable of the machine, and the double side butt joints were welded perpendicular to the rolling direction (Appendix I).



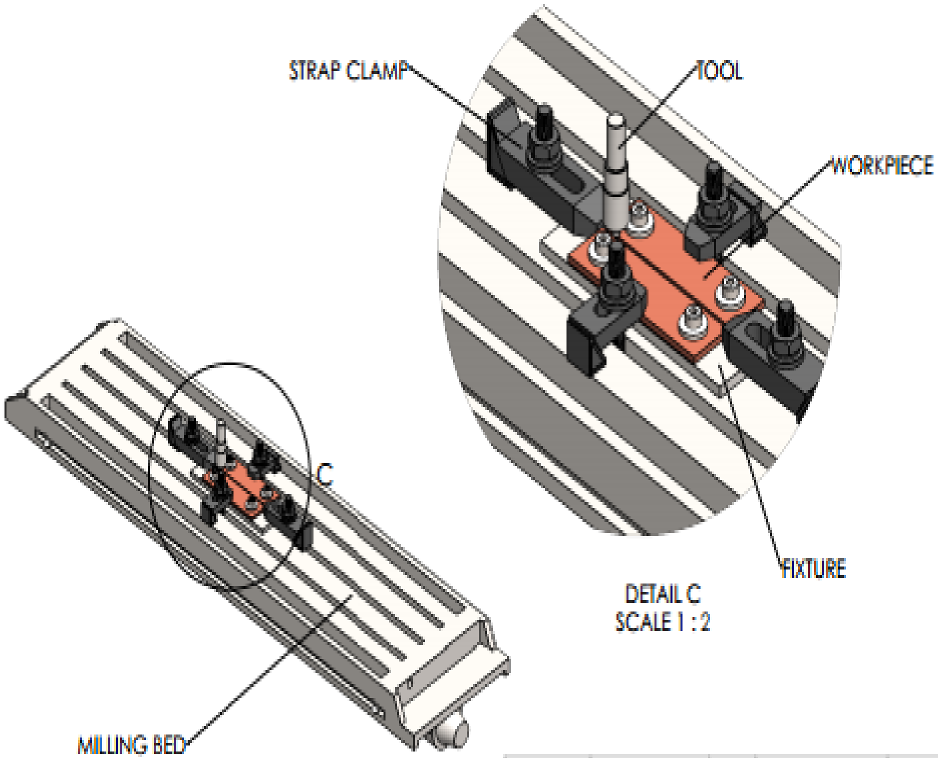


Figure 3.7 Fixture to hold the plate

3.4 Experimental Procedures

In this study, 5 mm pure copper plate was used for the friction stir welding process, which can be considered as both side welding of similar materials. The dimensions for the plate were 100 X 50 X 5 millimeters. And three different parameters were used during this process with three values for each. Those parameters included rotation speed, travel speed, and dwell time. According to those parameters, nine specimens were welded and investigated with tensile test. And the best and worst specimens from these nine specimens also investigated using the universal testing machine. The process flow chart of the experimental process of this study is shown in Figure 3.8, which shows the general plan and arrangement of pure copper plates during the friction stir welding process.

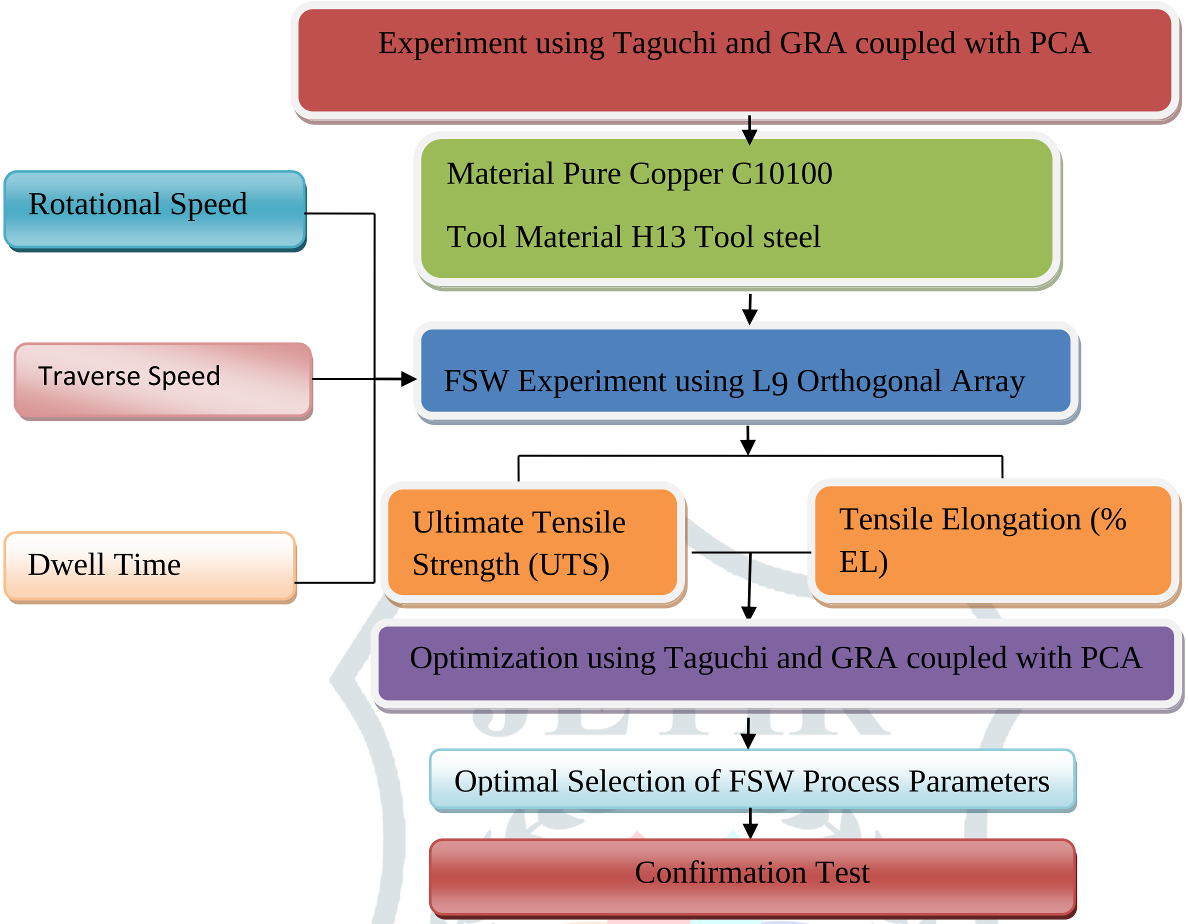


Figure 3.8 Process flow chart of experimental procedures.

3.5 Tensile testing

The small standard-size tensile test specimens was prepared with gage length 32 mm, width 6 mm, total length 100 mm and fillet radius of 6 mm were machined (Figure 3.9) and test them according to American Standards. The Society for Testing and Materials (ASTM E8M) Standard states that the initial strain rate at room temperature is 1.67 × 10-2 mm/s. The tensile properties of the joints were evaluated using three tensile specimens prepared from the same joint. All samples were mechanically polished before testing to eliminate the effects of surface defects. The fracture structure is shown in Figure 3.9. The tensile test was performed using a universal testing machine), and the specimen before and after fracture are shown in (appendix III). According to Taguchi's L9 orthogonal array method, tensile tests were performed on nine (9) tensile samples to evaluate the ultimate tensile strength, and tensile elongation.

In general, the effectiveness of friction stir welded the double sided butt mating parts is measured by tensile strength. The ultimate tensile strength and percentage of elongation implement the destructive test methods using universal tensile testing machine as Figure 3.11 , and it shown and the procedural arranged result of the machine test used to measure the tensile strength of the tests as shown in Figure 3.10. The ultimate tensile strength and the percentage of elongation values were calculated and recorded for each test. The values of UTS and % EL for each experimental test are given in Table 4.1.

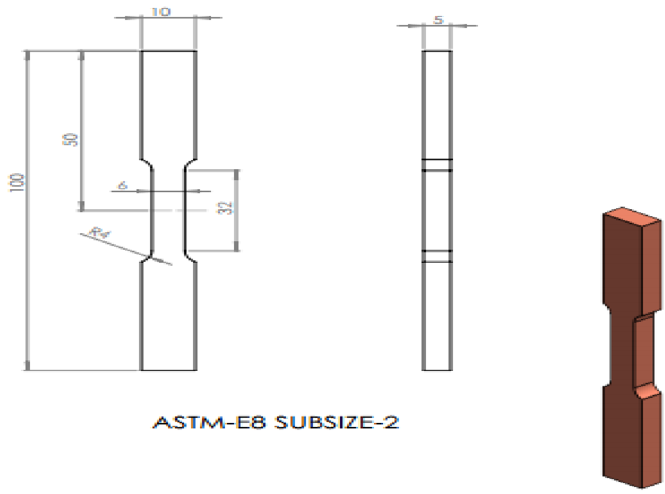


Figure 3.9 Dimensions of the tensile specimen according to ASTM E8M

Figure 3.10 The tensile specimens after the test in (before the taste shown in appendix I)

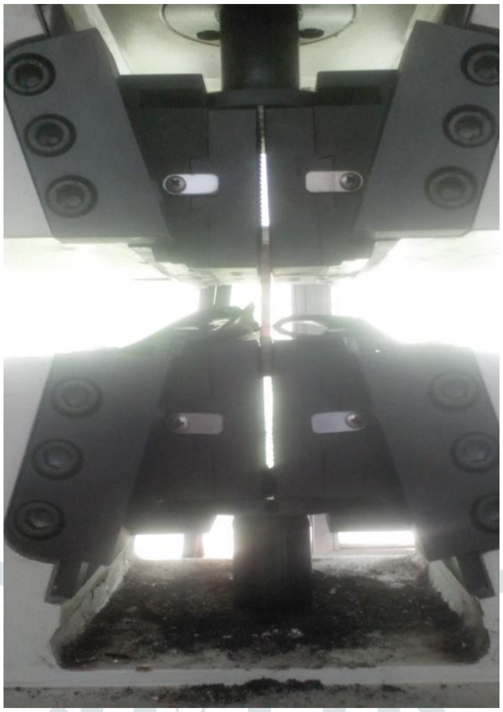


Figure 3.11 Universal Tensile testing machines (Full image shown in appendix II)

3.6 Methods

3.6.1 Introduction

The experimental plan used a scientific methods combined with a systematic approach and design to efficiently conduct the experiments. Usually, in engineering there are two ways to approach the problems, a mathematical approach and statistical analysis; the mathematical methods include many different equations and models. When choosing mathematical method, if the problem is difficult, getting results from that method will take time and significant amount of resources. And that was the reason why, the majority of the real-time problems are solved using statistical approaches.

Therefore, in the present study, we selected the statistical approach to solve the problems, and the design the experiment was well planned and carried out. The appropriate data were collected from the experiment and analyzed toward the objective. And, if complex problems are involved in the experiment and data subjected to this experimental error are considered, then statistical method is the only purpose of analyzing the problems. This statistical method has many advantages, which are explained below:

1. The number of attempts decreases.
2. Key decisions that control and improve product or process performance can be identified.
3. The best place for those who can't find it.
4. The parameters can be estimated well.
5. Trial and error is predictable.

6. The effect of parameters on the characteristics of the process can be calculated (D.vijayan, 2017).

In applying the methods, it is important to focus on purpose of the research, because it is necessary to develop the tensile properties (ultimate tensile strength and elongation of the welded material), and then it is important to have a complete control over the selected relevant process parameters. And to control this process choosing proper process parameters play an important role.

3.6.2 Determining the process parameters

The FSW process involves two main movements, rotation and advancement, along the connection of joined materials we considered the two basic parameters of this technological process which are the rotation speed of the tool (rpm) and the welding speed (mm/min). These parameters affect the heat generated during the process, the quality of the weld and the tensile properties. Therefore, for the tool geometry, the tensile properties of FSW joints are affected by the above parameters applied to the process as confirmed by numerous examples papers (Mishra R.S et.al, 2014, Threadgill P.L et.al, 2009, Liu H.J.et.al, 2009 and Xue P.et.al, 2010).

Few papers showed the effects of rotational and traverse speeds on the copper weld performance of FSW. The rotational and welding speeds control the heat input during the FSW, which is studied in detail with few papers and correctly selecting the parameter values helped paramount to the outcome of the weld, and generally to express the heat input also affected by the high thermal conductivity and high melting temperature of copper. And also a dwell time for the tool after it has reached plunge depth and before it begins to weld affects the initial heat input and can even more affect the weld quality. Therefore, this study selected the welding process parameters of rotational speed for the tool, welding (traverse) speed, and dwell time. These process parameters are considered to have important effect on the friction stir weld properties.

3.6.3 Determining the rotational and traverse speed limits level

In this study, it was determined that the selected welding process parameters such as tool rotational speed, and welding (traverse) speed are considered to have an important effect on the weld performances. In the selection of this process parameters the minimum and maximum range of the tool rotational speed and traverse speed were found by many trials. This experiment or preliminary experiment is based on previous experimental done in this field. And this previous experimental works that are used to select this factors or various parameters along with their range are presented in the Table 3.3, Table 3.4 and Table 3.5

Table 3.3- Effect of rotational speed

Article	Material	Thickness	Rotational speed	Remarks
Sahu et al., 2016	Pure Cu	4	600-2400	Medium rotational speeds produce Better welds. Higher welding speeds lead to more flash formation and more Material interaction.
Liu et al. ,2011	Pure Cu	3	600-1200	Better Cooper particle distribution with Higher rotational speeds. Lower rotational speeds promotes less Material mixing and cavity defects of the weld.
Bhattacharya et al. , 2017	Pure Cu	3	800-1000	Better weld quality acquired with higher Rotational speeds. Lower rotational Speeds promoted less material mixing of the weld.
Celik and Cakir ,2010	Pure Cu	4	630-2440	Medium rotational speeds promote a composite structure and high tensile Strength in the weld quality. Higher speeds Supports more inter metallic compound formation.
Xue et al.,2011	Pure Cu	5	400-1000	Thinner and more uniform inter metallic compound (ICM) layer achieved at lower speeds. Weld Surface quality loosen and IMC formation Increased with higher speeds.

According to the above tabulate data (Table 3.3) the selected significant range of parameters for the rotational speed of the tool is in the range of 400 rpm up to 1000 rpm. Because according to Xue et.al. 2011 studies supported the material thickness of this study as 5mm thick pure copper plate and the desired quality of weld to be achieved.

Table 3.4 Effect of Traverse speed

Article	Materi	Thickne	Traverse	Joint	Remarks

	al	ss	speed		
Tan et al.,2013	Pure Cu	3	20-40	Butt	Higher welding speeds supports weld cavity defects and Insufficient mixing of materials in the weld joint. Lower speeds promote less flash formation; quality weld appearance and proper weld joint material Mixing.
Bhattacharya et al.,2017	Cu	3	20-40	Butt	Better welds acquired with Lower welding speeds. Higher speeds induced less Smooth material flow.
Saeid et al, 2010	CU	3	30-375	Lap	Higher welding speeds have lower vertical transport of material and initiates cavity defects. Lower welding speeds increase the mixing of Materials.
Akinlabi et al.,2011	Cu	3.175	50-300	Butt	Lower welding speeds improved mixing of joining materials. Higher welding speeds did not achieve coalescence and proper mixing
Al-Roubaiy et al.,2014	Cu	1	160-250	Butt	Higher welding speeds let low material mixing. Lower welding speeds enlarge the mixing area and increase IMC Formation.

And according to the above Table 3.4 it was shown different traverse speed that are used in the study with their remark as the highest quality of weld that we desired to achieve and this was coherent with this study .However to select significant traverse speed limits we conduct pilot experiment within the described ranges that shown improve quality of weld in the remark and according to this we are determine (30 mm/min.) as an average value of traverse speed to be selected.

Table 3.5 The different levels of rotational and traverse speed of FSW copper

Article	Rotational Tool speed (rpm)	Welding (Traverse) speed (mm/min)	Material Thickness (mm)
Sakthivel T. et al., 2007	1000	30	2
Liu et al. ,2009	400	100	3
Lee w.B. et al. , 2004	250	61	4
Okamoto k. et.al ,2014	1300	170	6
Xue et al.,2010	≥400	50	5
Khodaverdizadeh et al., 2011	600-900	75	5
Khodaverdizadeh et al., 2011	600	25	5

In addition to the information listed above , Table 3.5 shows the different level of parameters of copper friction stir welding; It is important to determine important process parameters in order to obtain best possible tensile strength of the joint. For this purpose, in Table 3.5 different data on the mechanical tests of butt joint samples of electrolytic copper (99.998% Cu) with a thickness of (T) = 5 mm made by FSW that are applying different rotational and traverse speeds are listed. Therefore, based on these it needs to fully analyze on different range the effects of the applied process parameters in the enhancement of the tensile strength of the joints. Since there are different variables that are specified in Table 3.5.

In addition, the above selection was studied by Xie et al., 2007, FSW of 5 mm thick copper with constant welding speed of 50 mm/min and with different rotation speeds of 400, 600, and 800 rpm indicates that a defect free copper welds were achieved. Therefore, under relatively low heat input conditions a fine grained microstructure being produced at a rotation speed of 400 rpm and a traverse speed of 50 mm/min. Hence to determine the level limits for the selected parameters the minimum 400 rmp and the maximum 1000 rmp tool rotational speed for 5 mm copper plate are taken and similarly for the levels range of intervals for the traverse speed in this study the minimum range selected was 30 mm/min as depicted in the table 3.4 and 3.5.

And in consideration of table 3.5 we selected the values for pilot experiment the maximum tool rotational speed (1000 rpm) and minimum tool welding speed (30 mm/min) and for the ease of the analysis all the selected limit levels was divide in equal magnitude gaps as Low (minimum) , medium , and High (maximum) . And according to this limit levels the parameters was equally divide in the above level of gaps with an interval of 300 rpm for rotational tool speed and with 30 mm/min for welding (traverse) speed and this levels are considered as the level limits for this study. Generally, in this study the acceptable parameters were found with rotational speed between 400 rpm up to 1000 rpm and travel speeds between 30-90 mm/min.

And additionally according to Gaohui Li, 2019 it was studied the effect of dwell time on mechanical properties taking with a dwell time of one (1), five (5), and nine (9) seconds. Since the material used in this study was copper and one of the problems of this FSW of copper was its high thermal conductivity, it was very important to consider the tool dwell time in the welding process. Therefore, the dwell time influences the initial heat input of the process and can greatly affect the weld quality. And the dwell time was set 3 seconds for most materials up to 5 mm thick butt friction stir welded, and this can be modified depending on weld characteristics, and the selected dwell time for this study ranges from 5 up to 9 seconds (Justin M.E, 2014)

In addition to that above mentioned literature and other extensive literature study, it was considered that in FSW tool rotational speed, traverse speed, and dwell time as the primary process factors that are influencing the tensile properties such as Ultimate Tensile Strength and Tensile Elongation (Lakshminarayanan & Balasubramanian, 2008; Rajakumar et al., 2013; Vijayan et al., 2010). Therefore, this study conducting pilot experiments with considering only parameters of tool rotational speed, traverse speed, and dwell time. And each process factors are categorized into three levels as low, medium and high and the selected ranges regarding to this pilot experiment used to select parameter values. Therefore, the range of the preliminary work of friction stirs welding process parameters are shown in the table .3.6.

Table: 3.6 Parameters used in the tests.

Parameter	Value
Rotational Speed	400 – 1000 rpm
Transverse Speed	30– 90 mm/min
Dwell Time	5-9 sec.

From this preliminary experiments that was done on the specimen using random values the suitable values parameters were selected. Therefore, the tool rotational speed, traverse speed and dwell times in this study are considered the important factors or parameters of interest with the above equal magnitude gap of limit levels.

3.7. Optimization Techniques

Therefore, to achieve the purpose of the study various prediction methods were assessed, namely Response Surface Methodology (RSM), Grey Relation Analysis (GRA), and Artificial Neural Network (ANN) Combined with Principle Component Analysis (PCA) and Taguchi methods. And all of them can be applied to define the desired output variables. And all this systematic methods were classified under two categories depending on the objective function, namely single objective optimization and multi objective optimization (D.vijayan., 2017)

This study have selected Taguchi and Grey Relation Analysis (GRA) combined with principle component analysis (PCA) statistical techniques among other statistical methods namely Response Surface Methodology (RSM), and Artificial Neural Network (ANN) , to obtain an optimal setting of process parameters of friction stir welding of a similar double sided butt welded 5 mm copper plate . In addition to that the main goal of this study was to get optimized tensile strength of the process, and to get maximum values of ultimate tensile strength and percentage of elongation applied a single objective optimization methods and to conflicting objectives of UTS and % EL that can be solved using multi objective optimization methods, and within this study there will not be a single optimal solution.

Therefore, this study employed Taguchi method was used to obtain optimal solution for each case, since the purpose is to optimize a single performance characteristic.The Grey relational analysis (GRA) is used to effectively resolve the complicated interrelationships among multiple performance characteristics of the process. The aim of this study was to determine the best FSW parameters to enhance tensile strength under these conditions. Taguchi method was also used to explain the effect of the FSW process characteristics. In addition, Grey relational analysis is also used to find the best FSW process parameter that meets various characteristics of the FSW process, becoming a useful tool for solving many multi optimization problems (Deng Julong, 1989).

3.7.1 Taguchi Method

As mentioned above, all designs must be subjected to many tests. It works and gets complicated if the number of things increases. To overcome this problem, Taguchi proposed a special method called the use of orthogonal arrays to examine the entire parameter space with small experiments. Therefore, Taguchi suggests using loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss is converted to signal-to-noise ratio (S/N). In general, performance characteristics for signal-medium analysis fall into three categories. These are: nominally best, bigger is better, smaller is better. The Taguchi method is also implemented using MINITAB software, which includes signal-to-noise ratio and variance analysis. By analyzing the differences, the contribution of each parameter to better FSW welding can be determined. Signal-to-noise ratio (S/N) response provides the most impact. Finally, optimal parameters were determined by mean plots of signal-to-noise ratio and mean response (Srinivas et al., 2012).

3.7.2 Design of Experiment

Design testing is considered one of the best methods in product/process development. It is a statistical method that attempts to provide information about complex, multivariate processes through small experiments. The following are the main procedures of DOE (Srinivas et al., 2012).

3.7.3 Selection of Orthogonal Array (OA)

There is special standard experimental design (Orthogonal arrays (OA)) are that requires only a small number of tests to find the main factors that affects the output. Therefore, before selecting an orthogonal array, the minimum number of tests to be examined could be fixed based on the given G. Taguchi formula below

N Taguchi = 1+ NV (L – 1)

N Taguchi = Number of tests to be examined

NV = Number of parameters

L = Number of levels

In this work, the selected parameters and level are given as:

NV = 3 and L = 3, Hence

N Taguchi = 1+ 3 (3-1) = 7

According to this empirical formula at least seven (7) tests are to be tested, and based on the orthogonal array (OA) it has at least seven (7) rows i.e., it holds at least seven (7) tests. And the selections of this orthogonal arrays or rows are selected based on the number of parameters and the levels which are used for this study in according to its standards (G. Taguchi., 1986).

The standard orthogonal arrays are commonly used to design the tests:

2-Level Arrays: L4, L8, L12, L16, L32

3-Level Arrays: L9, L18, L27

This research carried a large numbers of tests or twenty seven (27) experimental tests need to be examined. Therefore, when number of process parameters increases its trials also increases. And, to solve this problem the selections of a special experimental standard or OA are important in determining and reducing the number of experimental trials (Hakan .A et al., 2010)

This study selected welding process parameters such as tool rotational speed, traverse speed, and dwell time. And these selected three (3) parameters of friction stir welding are considered as controlling factors that were tested with three (3) levels of degrees, namely low, medium , and high, they are also denoted in this research low as (I), medium (II) , and high values with (III) respectively as shown in table 3.7.

Table 3.7 shows the selected parameters and their levels considered for the experimentation.

Process parameters	Units	Level I	Level II	Level III
Rotational speeds	Rpm	400	700	1000
Traverse speed	mm/rev.	30	60	90
Dwell time	Sec.	5	7	9

In this research to select an orthogonal array that are important for experimental work uses the degrees of freedom that are to be computed and the total degree of freedom in this experimental work was eight (8) and from the standard OA, L_9 were selected. According to the Taguchi method this was sufficient to optimize the parameters, if three (3) parameters and three (3) levels are selected the L_9 orthogonal array (OA) as standard tool employed , and the arrangement of the standard L_9 are shown in table 3.8 and 3.9 respectively.

Table 3.8 Levels of process parameters used L_9 Orthogonal Array

Trial No.	Levels		
	I	II	III
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3.9 Experimental design using orthogonal array

Trial No.	LEVELS		
	Tool Rotation Speed	Traverse Speed	Dwell Time
1	400	30	5
2	400	60	7
3	400	90	9
4	700	30	7
5	700	60	9
6	700	90	5
7	1000	30	9
8	1000	60	5
9	1000	90	7

3.8 Ethical Issues

In planning an Experimental research the experiments are performed by in laboratories or workshops in virtually all fields of inquiry, usually to discover something about a particular process or system, and in this study an experimental test is conducted. More formally, we employed an experiment tests or series of tests to obtain a purposeful changes that are made from the input variables of a process. Therefore, what we observe and identify as the reasons for changes may be observed in the output response (Montgomery, Douglas C., 2001). Therefore, due to this reasons in this study a particular consideration was given to ethical principles that were developed by different researchers.

The purpose is to develop a strong process, that is , one that allows minimal interference from other sources of change. All information in this study will be kept confidential and ethical issues , and as much as possible effort are made while performing this experiment.

CHAPTER FOUR

RESULTS AND DISCUSTION

4.1 Introduction

The purpose of this research was to study process parameters optimization 5mm similar double sided butt friction stir welded pure Copper plate to enhance the tensile strength. With this aim this study proffering sustainable solutions to insufficient FSW issues of 5 mm pure copper using Taguchi and GRA coupled with Principal component analysis method. This study also set out to determine the impact of using Friction stir welding as an option in metal fabrication industries in Ethiopia. For this purpose , the friction stir welding theories of De Vuyst et al., 2006, and Colligan and Mishra , 2008 was taken in to consideration in the study, and to developed a conceptual model showing the relationships between the influence of welding parameters on the FSW process , with different welding parameters and their effects. Hence most welding parameters within the field of FSW are not incommensurable, i.e that they can compare each other to see if they are optimum or not.

Therefore, the researcher decided that it was necessary to talk about the selected welding parameters that used to answer the research questions in this study, and not a detailed analysis of among other problems that are described in the theoretical framework.

Therefore, I conducted my research using the following research questions as a guide**;**

RQ1:-What are the selected process parameters that give optimum tensile strength?

RQ2:-What are the trends between the selected welding parameters and tensile strength?

RQ3:-What are the effects of the selected process parameters of this study?

In addition , this chapter deals with results and discussion of the experimental observation and findings of the study .And they are further presented in four sections: Section-I: - deal with single objective optimization using Taguchi to identify predominant factors; .Sections -II: - Multi objective optimization uses GRA; Sections -III: - Present the results of confirmation tests, and Section IV:-Discussion of the effect of Process parameters using contour plots of FSW.

RQ1:-What are the selected process parameters that give optimum tensile strength?

Section-I: - Single objective optimization using Taguchi to identify predominant factors.

4.2 Single response optimization using Taguchi to identify predominant factors

The Taguchi method in quality optimization of FSW was powerful tool, it selected the pre dominant factors as depicted in 3.6.2 and makes use a special design of orthogonal array (OA) through a minimal number of experiments , and can also used effectively to optimize process parameters of single performance. Because the purpose of this study was to determine which experiment of the double sided butt pure copper FSW to produce higher or enhanced tensile strength. In addition, this study analyzed the effects of deferent process parameters responses of UTS, and % EL. Further it was done by applying the grey relational method, which helps to convert in the optimization of multiple qualities in to single quality optimized process variables to produce the best combination of improved tensile property.

Table 4.1.Taguchi L_9 OA with multi-response results and signal to noise (S/N) Ratio.

Exp Run	Control Factors			Response Values		S/N Ratios (dB)	
	TRS	TS	DT	UTS (Mpa)	% EL	UTS (Mpa)	% EL
1	400	30	5	852	13.7	58.5884	22.73441
2	400	60	7	836	12.9	58.44413	22.21179
3	400	90	9	815	12.1	58.2338	21.65571
4	700	30	7	832	12.7	58.4129	22.07607
5	700	60	9	815	11.9	58.20181	21.51094
6	700	90	5	829	12.9	58.37109	22.21179
7	1000	30	9	814	11.9	58.21249	21.51094
8	1000	60	5	827	12.7	58.36061	22.07607
9	1000	90	7	817	11.9	58.22315	21.51094

4.3 Effect of the Parameters on Ultimate Tensile Strength (UTS)

The application of Minitab-18 statistical software (appendix VI) used to convert the experimental data of ultimate tensile strength in Table 4.1 into S/N ratios. The main process parameter was identified from the delta statistics in the response table for S/N ratios as shown in Table 4.2. Based on the difference between the highest and the lowest average value of each factor the delta statistics was computed, and according to the delta value ranks was assigned. The highest value of delta was assigned the first rank and represents the predominant process parameter for the tensile strength. Hence table 4.2 indicated that the dwell time with a delta value of 0.22 was the most influential factor. The second most contributing factor was the tool rotational speed with a delta value of 0.16, followed by the traverse speed of 0.13.

Table 4.2 Response Table for Signal to Noise Ratios of UTS

Level	TRS	TS	DT
1	58.42	58.40	58.44
2	58.33	58.34	58.36
3	58.27	58.28	58.22
Delta	0.16	0.13	0.22
Rank	2	3	1

According to the answers in Table 4.2 we obtain the required process parameter levels, and as the main effects plot for S/N ratios was generated as shown in Figure 4.1, and the trend of the graph that indicated the UTS was greatly influenced by variations in the dwell time similarly seen in Table 4.2, particularly in the case of similar double side butt 5 mm pure copper FSW, the ultimate tensile strength normally decreases with an increase in the dwell time. One of the reason for this study was the formation of the initial stage heat input and that was greatly affect the quality of welding (Justin. M. E , 2014).The radical decreasing trend of S/N ratios for UTS from 5 seconds to 7 seconds in Figure 4.was additional observation that shown the quality of response was deteriorated when the applied dwell time increases

RQ2:-What are the trends between the selected welding parameters and tensile strength?

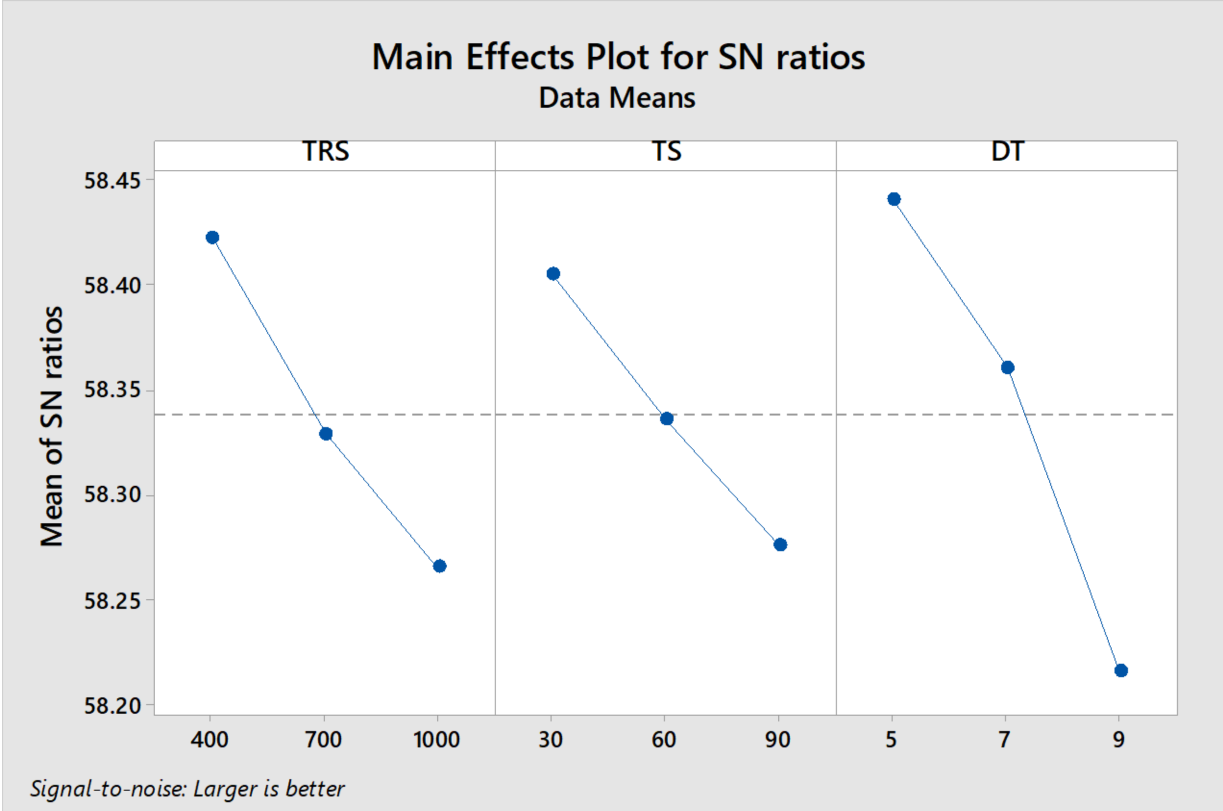


Figure 4.1 Main Effects Plot for S/N Ratio of UTS.

The plot of the main effect for S/N ratio of UTS indicates the optimum values of the experimental results. In addition, the relationship between tool rotational speed, traverse speed, and S/N ratio are also indicated in Figure 4.1. It shown a drastic decreasing trend of tool rotational speeds from 400 rpm to 1000 rpm ,and the plot of traverse speed also similarly shown a drastic decrease of S/N ratio from 30 mm/min to 90 mm/min , and a too much decrease of traverse speed from 60 mm/min up to 90 mm/min. Subsequently, it were indicated that the response values were considerably decreases when the process parameters increased. Therefore, in this study the S/N ratio analysis regardless of the quality characteristic indicates that a higher S/N ratio corresponds to better values of experimental results , and in this instance it shows higher ultimate tensile strength. The response table presented in Table 4.2 and main plot effects for S/N ratios in Figure 4.1 suggested that TRS 1, TS 1, and DT 1 are the desired factor levels in order to achieve higher S/N ratios and UTS values.

Table 4.3 Analysis of Variance for S/N ratios

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**% Con**
TRS	2	0.037286	0.037286	0.018643	509.53	0.002	22.4 %
TS	2	0.024843	0.024843	0.012421	339.49	0.003	17.8%

DT	2	0.077310	0.077310	0.038655	1056.47	0.001	55.4%
Residual Error	2	0.000073	0.000073	0.000037			
Total	8	0.139511					

Once the levels were determined, analysis of variance shown in Table 4.3 was performed to obtain the percentage of contribution and the significant of each factor in the UTS impact. And it was determined the dwell time with a contribution of 55.4 %, with the highest influence on the UTS, followed by Tool rotational speed with 22.4 %, and then Traverse speed with 17.4 % . At 95% confidence level, factors having a p-value less than 0.05 are considered significant. Since the p-values of tool rotational speed, traverse speed , and dwell time are less than 0.05 they are considered significant in UTS change. Additionally, it can be seen from Table 4.3 that the values of $R^2$and R^2adj are high and comparable with each other. And this indicates the goodness of fit of the model (appendix VII)

4.4 Effects of process parameters on Percentage of Elongation.

To determine the factors affecting the percentage of elongation (% EL), the S/N ratio test data required to calculate % EL are shown in Table 4.4.. Similar to that of UTS analysis, Larger-the better characteristic of the Taguchi method was selected to examine factor effects (appendix VII). The response table for the S/N ratios of % EL was then generated as shown in Table 4.4. The results indicate that the dwell time with a delta of 0.78 has the highest effect on % EL, followed by tool rotational speed and traverse speed, with the result values of deltas of 0.5 and 0.31 respectively.

Table 4.4Response Table for Signal to Noise Ratios of % EL

Level	**TRS**	**TS**	**DT**
1	22.20	22.11	22.34
2	21.93	21.93	21.93
3	21.70	21.79	21.56
Delta	0.50	0.31	0.78
Rank	2	3	1

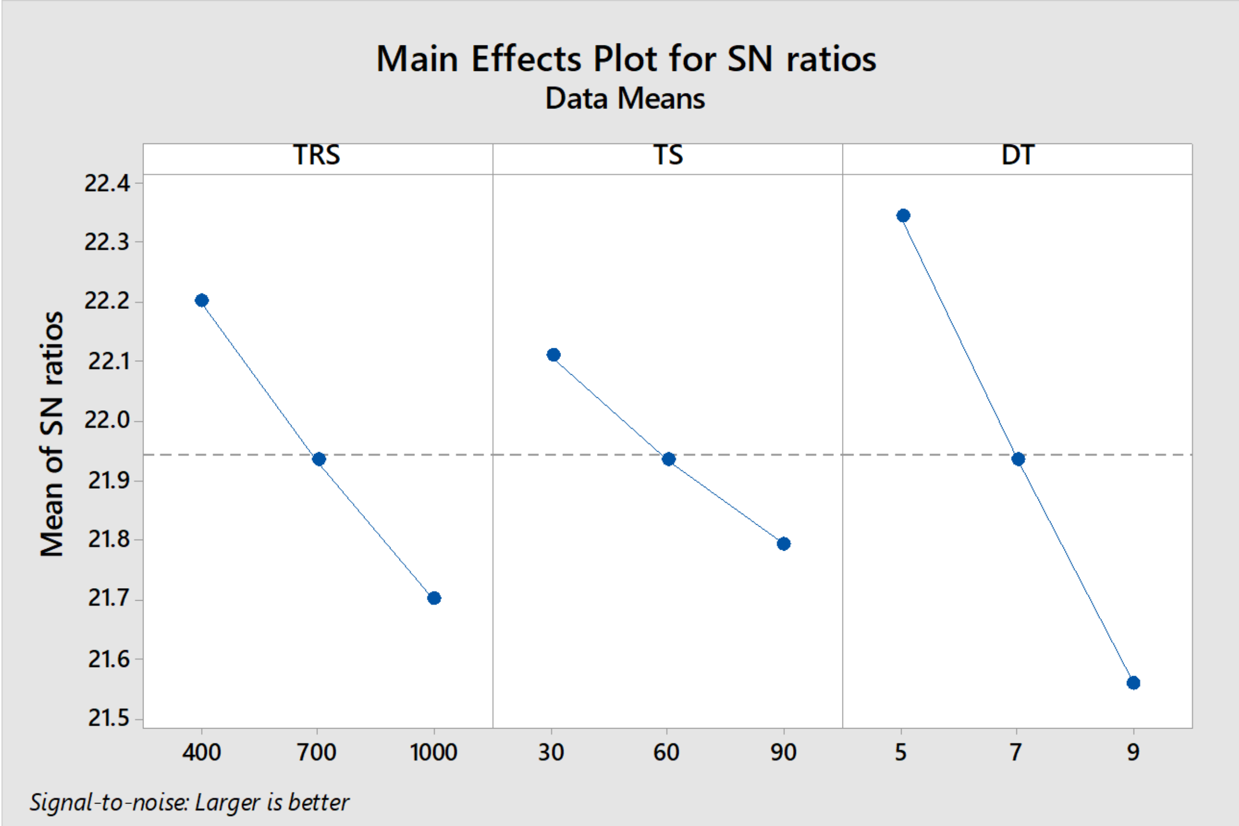


Figure 4.2 Main Effects Plot for S/N Ratios of EL

Then use the response of the signal-to-noise ratio to obtain the key value of %EL as shown in Figure 4.2. It showed that the ratio decreases with increasing in the dwell time , rotational , and traverse speed. In the case of rotational speed, there was a sharp drop in the ratio between 400 and 1000 rpm as Figure 4.2 shows and also indicates that desirable values of S/N ratios of % EL are achieved at the first level of tool rotational speed level one (1) or at (TRS 1) , traverse speed level-1 (TS 1), and dwell time lebel-1(DT1). The results of S/N ratios in Table 4.4 also specify the same levels for the variables. Further, the delta statistics in Table 4.4 reveal that % EL primarily affected by dwell time, followed by tool rotational speed , and traverse speed.

Table 4.5 ANOVA for S/N ratio of % EL

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**% Con.**
TRS	2	0.37756	0.377563	0.188782	67.32	0.015	26.1 %
TS	2	0.14878	0.148784	0.074392	26.53	0.036	10.2 %
DT	2	0.91685	0.916846	0.458423	163.48	0.006	63.2 %
Residual Error	2	0.00561	0.005608	0.002804			
Total	8	1.44880					

Similarly, to % EL as that of UTS an ANOVA was performed (Table 4.5). To determine the significant factors and the percentage contribution of each factor. It was inferred from Table 4.5 that, at the 95% confidence level, the dwell time were the highest percentage contribution of 63.2 % , followed by tool rotational speed of 26.1 %.,and traverse speed of 10.2 % .Additionally, as the p value of the all was less than 0.05, and this indicates the they are significant factors. The high R values indicate 99.61% of the variability of the model and it confirms the validity of this model (appendix VII).

However, in real-world applications, it is essential to determine a single combination of optimal parameters for multiple responses. Therefore, this study, GRA is deployed for multi-response optimization to determine the three factors and two responses. Whereas, the S/N ratio approach detailed above generates two sets of optimal input parameters for each of the two responses.

Sections -II: - Multi objective optimization uses GRA.

4.5. Multi-Response Optimization Using GRA

This section discusses the multi-objective optimization technique that was employed to select the best levels of the design results. Therefore, solutions that are between known with all the information and unknown with no information Grey relational analysis (GRA) technique provides best. The grey relational analysis technique was used in different studies to obtain the bestl operating levels associated with multiple performance characteristics (Prasanna, J et al., 2014). This study use Gray relational analysis to obtain the best process parameters associated with multiple quality characteristics of similar double side butt friction stir weld of 5 mm pure copper (appendix VIII). It is used generally to approximate the behavior of uncertain systems with no black and white solution, and in this case black implies having no information and white signifies having all information. Therefore, in this study GRA has been applied to optimize problems involving multiple factors and responses (Kasemsiri. P, 2017).

The steps of GRA techniques that are used in the study are as follows :(Khan, Z.A et al., 2010).

1. Data normalization
2. Deviation sequence;
3. Determination of the grey relational coefficients;
4. Determination of the grey relational grades;
5. Determination of the optimal process levels (ranking);

In this study, "Larger-the-better" method was preferred in determining the effect levels of experimental factors to evaluate the larger values for ultimate tensile strength (UTS) and percentage of elongation (% EL) , as Taguchi analysis explain there are three (3) methods, these are smaller-the-better, Larger-the-better and Nominal-the-better. And as initial step in GRA the transformation of the original response values in to S/N ratio values were carried out on the basis of the larger-the-better S/N ratio equation (4.1). And Table 4.6 show this values of the S/N ratio of the experimental results with the larger-the-Better quality characteristic of S/N ratio.

$\frac{S}{N} ratio = -10 \log(1/n \sum_{n=i}^{j}(1/y2)$..........Equation 4.1

Table 4.6 The Experimental S/N ratio values

Ultimate Tensile strength(UTS)(Mpa)	Percentage elongation (%) EL
58.609	22.734
58.444	22.212
58.223	21.656
58.402	22.076
58.223	21.511
58.371	22.212
58.212	21.511
58.350	22.076
58.244	21.511

UTS= Ultimate tensile strength and % EL= Percentage elongation

4.5.1 Data Normalization

The first stage of GRA techniques was data normalization , and this data normalization avoid problems of different scales, units, and targets. Usually, tests of data normalized between zero and one, and normalization was performed on both responses (Yunus.K et al., 2018). The normalization performed for the present investigation was presented in Table 4.7. Since, the outputs such as ultimate tensile strength and percentage elongation are needed to be maximized. This study chosen the higher the better characteristic and normalization of experimental results of each response were done and rated between 0 and 1 using Equation (4.2) with the higher the better attributes or criterion.

The selected quality performance type were "large-the-better" , and it applied to calculate the Grey relational generation Equation (4.2) below.

$(xi)^o(K) = xi(k) - \min xi(K) / \max xi(k) - \min xi(K)$.........Equation (4.2)

Table 4.7 The Normalization of S/N ratio

Ultimate Tensile strength(UTS)(Mpa)	Percentage Elongation (%) EL
1	1
0.584	0.573
0.027	0.118
0.479	0.462
0.027	0.000
0.400	0.573
0.000	0.000
0.347	0.462
0.081	0

4.5.2 Deviation Sequence

The deviation sequence obtained after data normalization and the deviation sequence were used equation (4.3). And before the analysis of Gray relational coefficient it is important to get the deviation sequence data for the reference and comparability sequence and these were given in Table 4.8 below.

$\Delta_0(k) = \|\|x_{0*}(k) - x_{i*}(k)\|\|$ Equation 4.3

Table 4.8 The Deviation Sequence for the Reference

Deviation Sequence	
Ultimate Tensile strength(UTS)(Mpa)	Percentage elongation (%) EL
0	0
0.416	0.427
0.973	0.882
0.521	0.538
0.973	1.000
0.600	0.427
1.000	1.000
0.653	0.538
0.919	1.000

4.5.3 Gray relational coefficient

The grey relational coefficient was calculated to express the relationship between the ideal (best) and actual normalized experimental results as shown in Table 4.9 . Moreover, the Grey relational coefficient can be expressed in equation (4.4), and within the formula Ɛ is a distinguishing coefficient and usually assumed to be 0.5 (Pradhan 2012).

$\sum (k) = \frac{\Delta \min + \varepsilon \Delta \max}{\Delta i + \varepsilon \Delta \max}$ Equation 4.4

Where; Ɛ= 0.5

Table 4.9 The Gray relational Coefficient (GRC)

GRC	
Ultimate Tensile strength(UTS)(Mpa)	Percentage Elongation (%) EL
1	1
0.546	0.539
0.339	0.362
0.490	0.482
0.339	0.333
0.455	0.539
0.333	0.333
0.434	0.482
0.352	0.333

4.5.4 Principal Component Analysis (PCA)

To calculate the gray relational grade (GRG) , the Equation (4.5) estimated GRG by assuming the weighting characteristics of w_1+ w_2 = 1. However, for the practical applications it may not be appropriate, hence to use equation (4.5) and to estimate the GRG's weighting quality characteristics the PCA were used to estimates the lost quality of the variable (UTS and % EL). The PCA data are used to estimate the correlation coefficient matrix and corresponding Eigen values for the equation (4.5) by squaring each principal component of Eigen values (value of in equation) the weighting quality characteristics of w_1 and w_2 to estimate. The Eigen values listed in Table (4.10) , Eigen vectors Table (4.11), and Eigen quality characteristics are listed in Table (4.12) respectively. Therefore, by squaring each principal component of Eigen values for the equation of GRG can be found.

Table 4. 10: Eigen values and explained variation (appendix IX)

Principal Components	Eigen values	Explained variations
UTS	1.9037	95.2 %
% EL	0.0963	4.8 %

Table 4. 11: The Eigenvectors for principal component

Quality Characteristics	Eigen Vectors	
	First Component 1	Second Component
UTS	0.707	0.707
% EL	0.707	- 0.707

Table 4.12 Quality Characteristic Contribution

Quality Characteristics	Contribution
UTS	0.4999
% EL	0.4999

The GRG Equation (4.5) use w_k as the weighting factor of k. In the present study, the weighting value k was estimated through PCA analysis. And the value for, the grey relational coefficients are taken $\xi = 0.5$.

4.5.6 Gray Relational Grade

The Grey Relational Grade (GRG) shows the association between the reference and comparability sequences. And a large Grey Relational Grade means the corresponding parameter combination close to optimum. The important process factor was also identified from the mean GRG values. Therefore, GRG's from each test was determined by equation (4.5). And Table 4.13 shows the GRG's corresponding to the combined process parameters and the graphical representation of the GRG's as shown in Figure 4.3. The larger Ultimate Tensile Strength and Elongation for all welded specimens are desirable values. Therefore, largest GRG was obtained in the 1stexperimental run, and this 1stexperimental process parameters are closest to optimum.

$x_i = 1/n \sum w_k \xi_i(k)$ Equation 4.5

In addition, the Grey Relational Grade was determined by averaging the grey relational coefficient that are corresponding to each performance characteristic . Additionally, the overall performance characteristics of the multiple response process depends on the calculated grey relational grade.

Table 4.13 Gray Relational Grades (GRG)

Run	Tool Rotation Speed (rpm) R	Traverse Speed (mm/min) T	Dwell Time (Sec.) S	Grade
1	400	30	5	0.778
2	400	60	7	0.489
3	400	90	9	0.567
4	700	30	7	0.455

5	700	60	9	0.400
6	700	90	5	0.454
7	1000	30	9	0.379
8	1000	60	5	0.434
9	1000	90	7	0.389

4.5.7 Gray relational Rank

Lastly, determination of the Optimal Process Parameters and its Level was analyzed by ranking Gray relational grade as shown in Table 4.14 and Figure 4.3. And this Grey relational grades ranking indicate the maximum ultimate tensile strength (UTS) and the Percentage Elongation (% EL) of the initial parameter that are set in this study. And the mean Grey relational grade of each level of the experimental in this experimental FSW process parameters are also summarized and shown in Table 4.15.

Table 4.14 Gay Relational Rank (GRR)

Run	Tool Rotation Speed (rpm) TRS	Traverse Speed (mm/min) ST	Dwell Time (Sec.) DT	Grade GRG	Rank
1	400	30	5	0.778	1
2	400	60	7	0.489	3
3	400	90	9	0.567	2
4	700	30	7	0.455	4
5	700	60	9	0.400	7
6	700	90	5	0.454	5
7	1000	30	9	0.379	9
8	1000	60	5	0.434	6
9	1000	90	7	0.389	8

TRS = tool rotational speed, TS =traverse speed, DT= dwell time

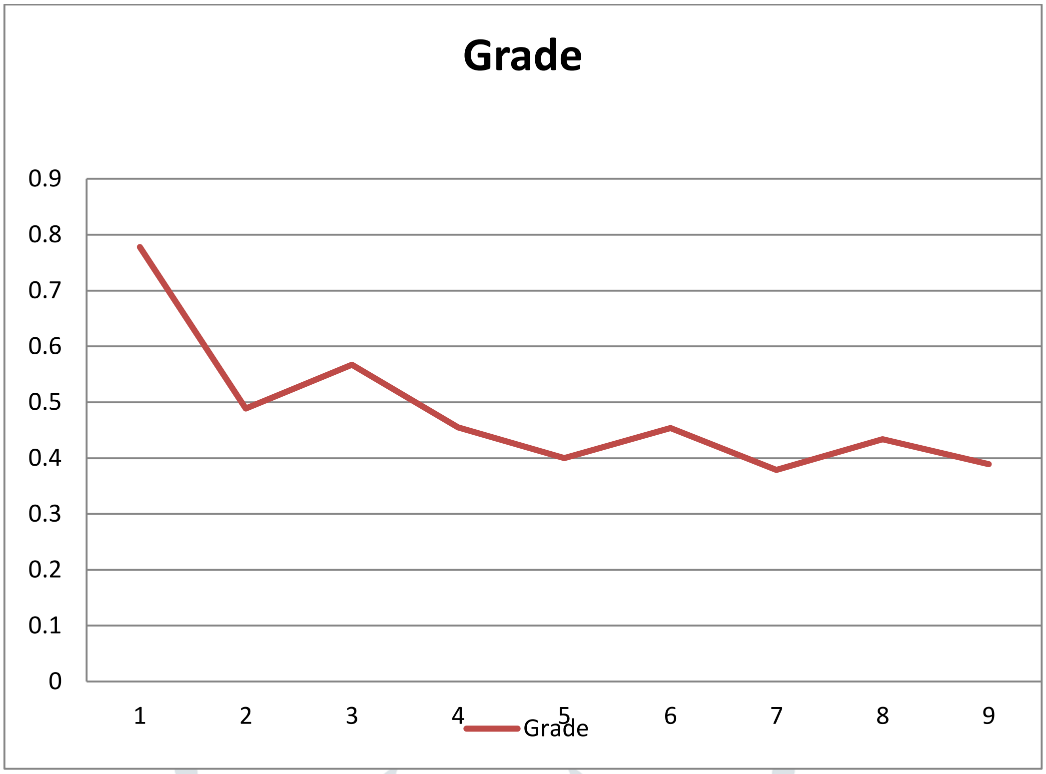


Figure 4.3 Experimental Vs grade for GRG maximum UTS and % EL

Table 4.15 Response Table for Means of GRG

Level	TRS	TS	DT
1	0.4252	0.4087	0.4390
2	0.2981	0.3021	0.3108
3	0.2548	0.2671	0.2283
Average Grade	0.3260	0.3260	0.3260
Max.-Min.	0.1704	0.1416	0.2107
Delta	0.1704	0.1416	0.2107
Rank	2	3	1

Additionally, applying the Grey relational method used to calculated selected GRGs mean, and that helped to convert the optimization of multiple qualities into single quality optimization process variables to produce the best combination of tensile properties as shown in Table 4.15.The higher values of the mean of GRG's indicated a strong correlation. Therefore, from the response table of GRG's in Table 4.15, it was possible to arrive at the combination of optimal parameters which maximize overall response. And the Grades in the response table serve as a measure of the correlation between the reference sequence and comparability sequence of GRA, and the maximum grey relational grades exist at TRS 1, TS1 , and DT 1. Therefore, in this research to conclude the optimal settings of similar 5 mm double side butt friction stir welded pure copper was with tool rotational speed (TRS) (400 rpm), traverse speed (TS) at 30 mm/min , and with dwell time (DT) at 5 seconds.

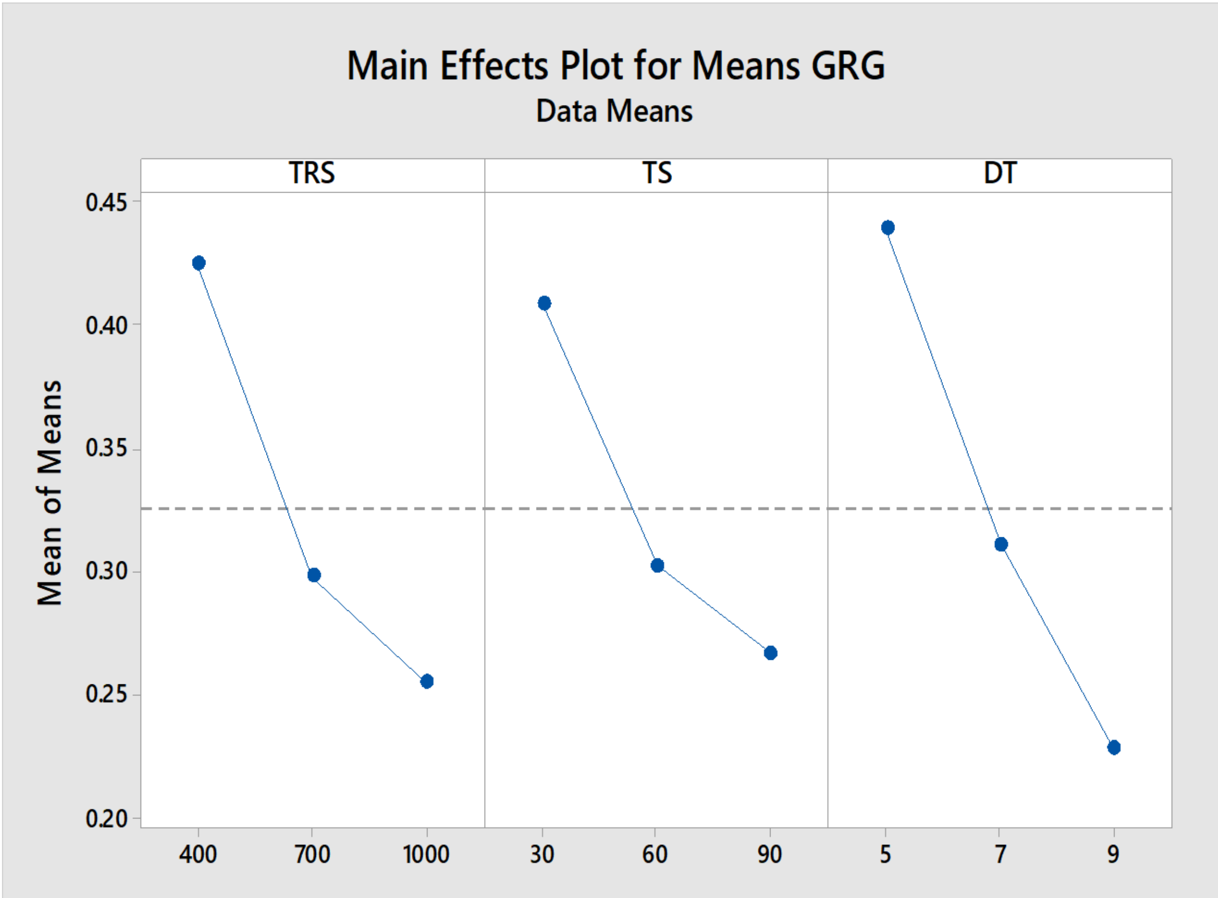


Figure 4.3 The main effects plot for means of GRG

As it was indicated in the Figure 4.3 the larger the Grey relational grade indicated the better the multiple process parameter . Besides, the relative importance among the FSW process parameters for the multiple quality characteristics still needs to be known. However, the initial optimal process parameter combinations of the FSW levels can be determined more accurately from Gray relational rank (GRR), and that was supported with Figure.4.3, and Table 4.15. The optimal process parameter combination was determined as TRS 1 (Tool Rotational speed, 400 rpm), TS1 (Traverse Speed, 30 mm/min) , and DT1 (Dwell Time, 5 seconds). This obtained initial process parameter settings used for the estimation of optimal process parameter that was done together with using Taguchi and Minitab analysis methods. The present investigated optimized complex multiple response characteristics needed to be transformed into simple optimization or single Grey relational grade. And for single response optimization in form of Grey relational grade Taguchi approach is best suited , and employed.

4.6 Analysis of Variance (ANOVA) for GRG

In this study to examine the significance and percentage contribution of each factors , ANOVA was performed for the Grey relational grade at a 95% confidence level in considering the multiple responses of UTS and % EL.

Table4.16 Analysis of Variance for GRG

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
TRS	2	22.150	22.150	11.0749	20.21	0.047	29.4 %
TS	2	13.367	13.367	6.6836	12.20	0.076	175 %
DT	2	39.830	39.830	19.9151	36.34	0.027	52.1%
Residual Error	2	1.096	1.096	0.5480			
Total	8	76.443					

From the ANOVA table 4.16 it was shown the values presented F-value were more for dwell time, followed by tool rotational speed , and traverse speed. The value F for dwell time were 36.34, tool rotational speed 20.21, and traverse speed with 12.20. This means that dwell time was much affecting the tensile strength. And the analysis was performed at 95 % confidence level. The parameters are highly statistically important when appropriate P value is less than 0.05.

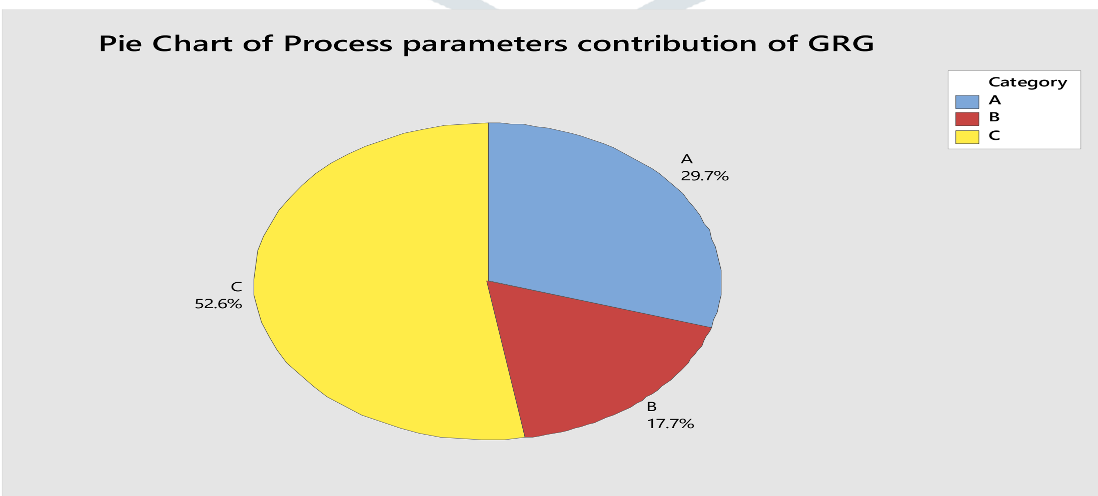


Figure 4.4 contributions of process parameters on ANOVA of GRG.

The last column in the Table 4.16 and Figure 4.4 showed the percentage contribution of each factors for enhancement of the tensile strength. And from the ANOVA analysis, it were concluded that the greatest influence for enhancement of the tensile strength of 5 mm similar double sided butt friction stir welded pure copper were with dwell time 52.1 %, followed by tool rotational speed with 29.4 %, and at end with traverse speed 17.5 %. And the factor interactions are not considered in this analysis for it was assumed to be statistically irrelevant according to P value. Hence it can be concluded that all considered factors are statistically significant for considered enhancement of the tensile strength of similar double sided butt FSW of 5 mm pure copper.

Sections -III: - Present the results of confirmation tests

4.7 Confirmation Test

In this study the final step were conducting the confirmation tests and it used to validate the conclusions. Besides , the confirmation tests need to be carried out in order to ensure that the theoretical predicted combination of parameter to optimum process parameters of the test results. Therefore, the initial optimum parameters used in the confirmation test suggested by Grey relational analysis, and again this initial optimum process parameters confirmation test performed on using universal milling machine with three (3) specimens of similar 5 mm double side butt Friction stir welded pure copper plate at levels of tool rotational speed (TRS1) 400 rpm, Traverse speed (TS1) 30 mm/min, and Dwell time (DT1) 5 seconds. Finally. the result of the confirmation tests indicates UTS (850 M pa), and % EL (13.75) (appendix V). This study , used a 95% confidence interval for the predicted mean of Grey relational grade (μ_{GRG}) , and a confirmation test was calculated using the following equations (Kumar, 2013, Kuo et al., 2007):

μ_{A1B1C1} = A1 + B1+c1 - 2*($\acute{\Gamma}_{GRG}$) Equation .4.6

μ_{A1B1C1}= 0.4252+0.4087+0.4390-2*(0.3260)

μ_{A1B1C1} =0.6209

Confidence interval (CI) calculated as: $CI=\mu \pm \sqrt{F\alpha(1, Fe) * Ve(\frac{1}{Neff} + \frac{1}{r})}$

Where $Fe; (1, fe) = F_{0.05}; (1, 8)$ =5.3177 (F-Table in the Annex), α = Risk = 0.05

fe = Error *DOF* = 8 (Annex F-Table)

Ve = Error adjusted mean square (Table 4.17) = 0.00281221

Neff = Effective number of replications

R = Number of replications for confirmation experiment = 3, and also the effective number of replications *(neff)* is calculated by

$neff = Tn/1+Ts$= 27/1+8= 3

Where *neff* = is expressed in mathematical, *Tn* = Total number of experiments = 9, and *Ts* = The sum of the total degree of freedom of significant factors.

Therefore, the calculated CI was: CI=$\mu \pm \sqrt{F\alpha(1, Fe) * Ve(\frac{1}{Neff} + \frac{1}{r})}$ while the calculated value for μ= 0.6209 and that of C.I = 0.0315

Therefore 95% confidence interval of the predicted optimum condition was given by the following equation, where the Grey relational grade value after conducting the confirmation experiments with optimal setting point, i.e. A1 B1 C1

(0.6209-0.0315) < μ < (0.6209+0.0315)

(0.5894)< μ < (0.6524)

Table 4.17 Confirmation Test

	Optimum Parameters			
Parameters Setting Levels	Initial	Predicted GRG	Tested GRG	Improved
	TRS1 TS1 DT1	TRS1 TS1 DT1	TRS1 TS1 DT1	
GRG		0.6209	0.667	

RQ3:-What are the effects of the selected process parameters ?

Section IV:-Discussion of the effect of Process parameters using contour plots of FSW

4.8 Effect of process parameters

The contour plots used to study the effect of tool rotational speed (TRS) , traverse speed (TS), and tool dwell time(DT) on the tensile strength of friction stir welded of 5 mm similar double side butt welded pure copper plate joints. The results are shown in different contour plots for GRG verses TRS and TS Figure 4.5 , GRG verses TS and DT Figure 4.6 , and GRG verses TRS and DT Figure 4.7 respectively.

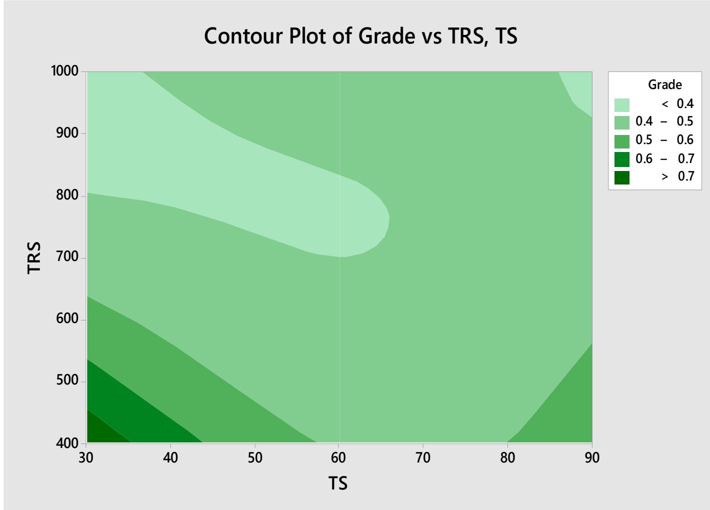


Figure 4.5 Contour Plot for GRG verses TRS and TS

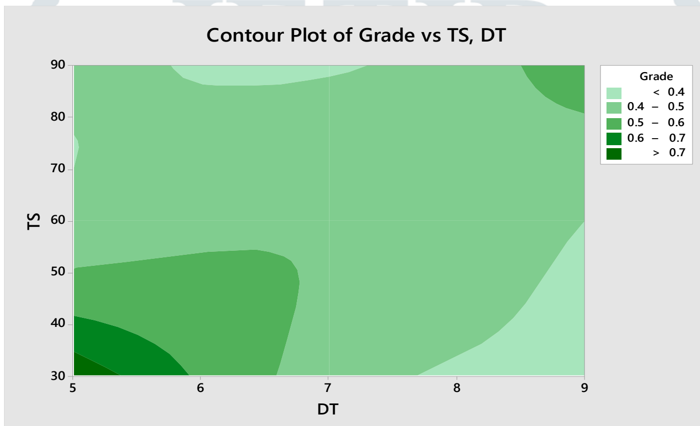


Figure 4.6 Contour Plot for GRG verses TS and DT

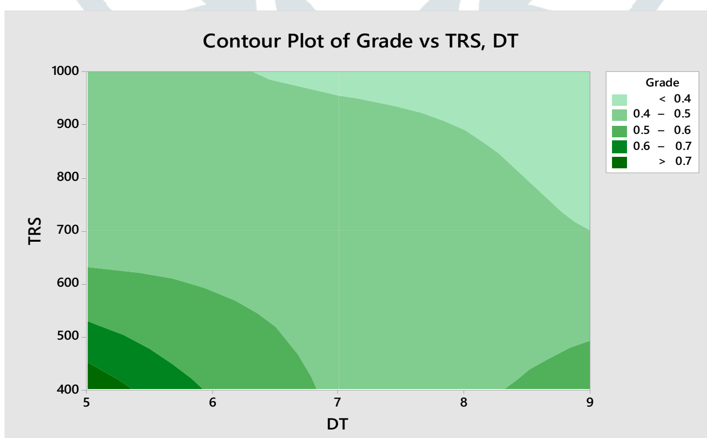
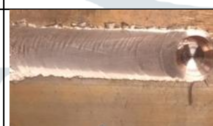
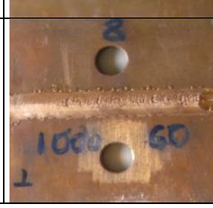


Figure 4.7 Contour Plot for GRG verses TRS and DT

The contour plot shown in figure 4.5 clarifies the evaluated response for grade regarding UTS and % EL. It shown the dwell time at 5 seconds the tool speed 400 rpm ,and traverse speed at 30 mm/min produces high grade. Further increase in dwell time the grade values was decreased. And according to Figure 4.6 shown an increase in traverse speed up to 90 mm/min , and dwell time of 9 seconds produces bad tensile strength. And Figure 4.7 illustrates as increase in tool rotational speed up to 400rpm with dwell time up to 5 seconds produces better tensile strength but further increase in this values get reduced it quality responses. Lastly further as the figures indicated that an increase in tool rational speed , traverse speed , and that of the dwell time was verified again in this contour plots to show tensile strength value get reduced.

4.9 Effect of welding parameters on the joint quality

Table 4.18 welding parameters effects on welded joint quality

Run	**TRS (rmp)**	**TS (mm/min)**	**DT (Sec.)**	**Tensile Strength**	**Welding joint**	**Observation**
1	400	30	5	UTS =852 % EL=13.7		Surface crack Nil Flash Nil
2	400	60	7	UTS =836 % EL=12.9		Surface crack and Flash, defect observed
3	400	90	9	UTS =815 % EL=12.1		Surface crack Nil Flash observed
4	700	30	7	UTS =832 % EL=12.7		Surface and Flash defects observed
5	700	60	9	UTS =815 % EL=11.9		Surface crack Nil Flash Nil
6	700	90	5	UTS =829 % EL=12.9		Booth Surface crack and Flash defect
7	1000	30	9	UTS =814 % EL=11.9		Surface crack Nil Flash little
8	1000	60	5	UTS =827 % EL=12.7		Surface crack Nil Flash small

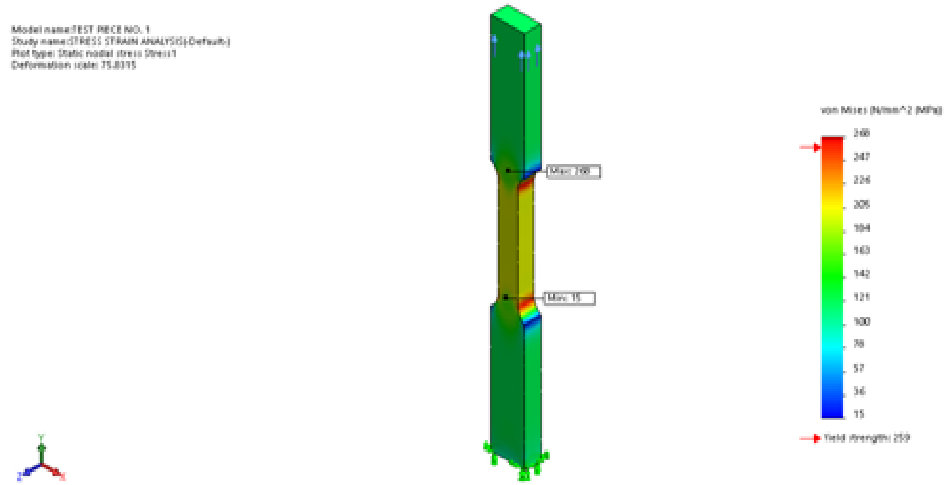
9	1000	90	7	UTS =817 % EL=11.9		Surface crack Nil Flash Nil

4.10 Simulated Tensile Specimens

Simulated tensile testing was used as a general optimization technique in which, a physical Testing process is simulated stochastically. The ANSYS generated results represents simulated stress, train and displacement effects of the tensile test specimen during testing with as assumption of one side fixed and pulling the other side with 6000 N force and with cross sectional area of (32mm*6 mm) of pure copper and . All the simulated result shown the stress , strain and displacement contours are plotted and where minimum and maximum effects of the stress, strain and its displacement was developed on the experimental works as compared to the tensile tests (appendix V) simulation results verified the selected tensile taste specimen ASTEM E8 with dog bone shape was proper.

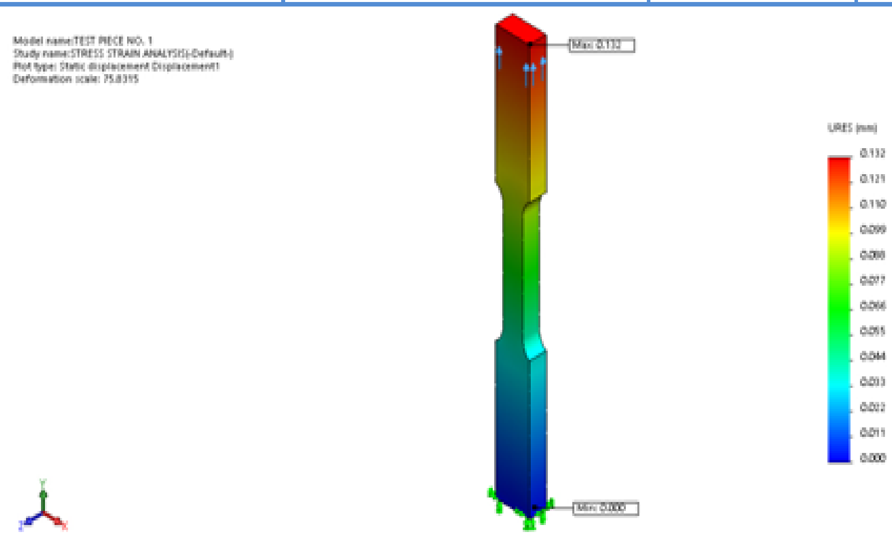
The optimization problems are solved by random generation of Copper welding and, subsequently making successive alterations at random. It indicated the simulated solution was found to have a superior fitness to its physical testing. Otherwise, the tensile test fracture still retained with probability and was not directly related to the proper selection of the specimen. And as the execution of the Tensile force continues and the stress strain and displacement values becomes large, and it indicated that the tensile test specimen fracture at the welded area was less likely to occur in probability to let in this study unfavorable solutions are accepted (appendix X). With this simulation it was sufficiently possible to loom the distribution of the stress strain and displacement where occurred. However the Parameter setting for simulated tensile testing depends on the software settings and it was achieved by trial and error to its effectiveness.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	15 N/mm^2 (MPa) Node: 8722	268 N/mm^2 (MPa) Node: 8916

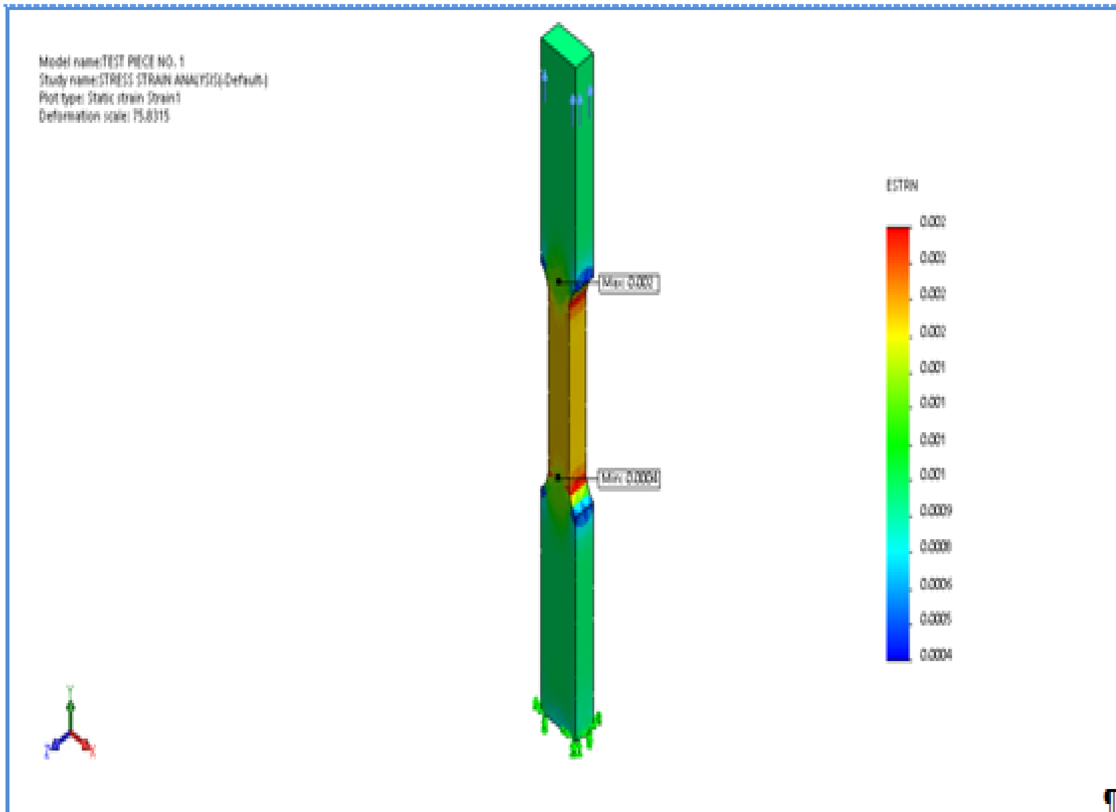


TEST PIECE NO. 1-STRESS STRAIN ANALYSIS-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000 mm Node: 1	0.132 mm Node: 205



TEST PIECE NO. 1-STRESS STRAIN ANALYSIS-Displacement-Displacement1



TEST·PIECE·NO.·1-STRESS·STRAIN·ANALYSIS-Strain-Strain1

Figure 4.8 Simulated Results for Stress, Strain and Displacement of tensile specimen

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The present study successfully applied the use of Taguchi and Grey relational statistical analysis for multi response optimization of similar double side butt friction stir welding process of pure copper using H13 tool. The main results from the present study are summarized as follows:

- The research has shown that Gray relational analysis coupled with PCA method using FSW with Taguchi can make good welds and enhanced tensile strength of copper.
- The Ultimate Tensile Strength (UTS) and Percentage of Elongation (% EL) are highly affected by weld dwell , for which the delta value of 0.22 as the most relevant; the second most relevant factor is the tool rotational speed with a delta value of 0.16, followed by the welding (traverse) speed of 0.13. Dwell time has larger impact, with an increases of delta of 0.78, followed by tool rotational speed and welding speed, with deltas of 0.5 and 0.31, respectively.
- Ultimate tensile strength(UTS) and percentage of elongation (% EL) are greatly affected by changes in the dwell time, in particular the tensile strength generally decreases as the dwell time increases. This is because initial heat formed in the friction welding process affected the quality of the weld.
- The significant effect is the dwell time , and respectively the percentage contribution of each of the ultimate tensile strength and percentage elongation is 55.4 %, the highest impact of ultimate tensile strength, followed by tool rotational speed at 22.4 %, and then traverse speed is 17.4 % . And at 95 % confidence level dwell time has the highest percentage of 63.2 % , followed by tool rotational speed of 26.1 %., and traverse speed of 10.2 %. Additionally, all p value are less than 0.05, and are considered significant factors. The high R values indicates that the model explains 99.61% of the variance, thus confirming the validity of this model.
- Optimal settings for 5 mm similar double side butt welded FSW of pure copper is tool rotational speed (TRS) (400 rpm), traverse speed (TS) (30 mm/min) , and dwell time (DT) (5 seconds) and resulting UTS 852 Mpa and 13.7 % EL .
- The factors to improve the tensile strength of the weld with their percentage contribution is dwell time with 52.1 %, followed by tool rotational speed with 29.4 %, and traverse speed at the end with 17.5 %. Therefore, it can be concluded that all considered factors are statistically significant to improve the tensile strength of similar double sided butt FSW of 5 mm pure copper.
- It indicates that an increase in the tool rational speed, traverse speed, and that of the dwell time has effects on the reduction of UTS and % of El and it was verified again in the contour plots.

5.2 Recommendations

The Final recommendation for the process parameter optimization of similar double sided butt FSW of 5 mm pure copper are briefly summed up in the following:

1. In order to develop the necessary FSW machinery furthermore proactive FSW technology automation approach and control methods should be established to meet the immediate demand of high quality industrial products. The researcher should focus on optimizing different types of process parameter and obtaining on accessible mature FSW technologies
2. Use of different FSW process parameters (tool tilt angel, different tool design ,weld force, plunge depth etc...) and analyze the experimental variations with different performance responses
3. Compare results of the friction stir welding results before and after work hardening the weld area to see how hardness increases in the base material using different FSW techniques.
4. The researchers should continue their effort to increase the efficiency and application of FSW technology, encourage metal industries of the nation to build up their own R&D capacities and to engage more strongly in joint optimum process parameter development and exchange of recent technologies with other similarly institutes. And also the university should have full flagged experimental facility and actively participate in joint FSW technology application projects with industries, preferably on light metal welding industries.

5.3 For Further Study

This research makes a difference in the commercial use of pure copper for several reasons: (1) It attempts to complement the different information regarding friction copper stir welding; (2) It can help researchers who want to study FSW technology; (3) It could help the industry, which currently uses copper for different applications, rethink FSW technology; (4) Help understand FSW machines and how to create models using FSW machines; (5) further promote the use of parameter optimization theory in higher education; (6) creates additional questions that need to be answered.

Suggestions for future research are as follows:

1. Repeat the survey using the same method and compare the results.
2. Repeat the research using other types of data and compare the results.
3. Conduct research using different FSW methods; compare results and find changes in quality characteristics with changes in FSW technology.

This study was comprehensive of process parameter optimization of 5mm similar double sided butt FSW of pure copper tensile strength enhancement. Therefore, a weak point of this study is that not enough attention is paid to micro-structural aspect and factors. Researchers can examine the micro-structural and other factors in more detail and compare the results with this study.

References

R. S. Mishra, Murray W. Mahoney, “Friction Stir Welding and Processing”, Book, ASM (2007)

G. Cam, “Friction stir welded structural materials: beyond Al-alloys”, International Materials Reviews, 2011, Vol 56. P. 1-48.

E. Scutelnicu, D. Birsan, R. Cojocaru, “Research on Friction Stir Welding and Tungsten Inert Gas assisted Friction Stir Welding of Copper”, Recent Advances in Manufacturing Engineering, ISBN: 978-1-61804-031-2

G. Raghubabu, “Influence of tool geometry and process parameters on friction stir welded aluminum-alloy an experimental investigation”, Jawaharlal Nehru technological university, Hyderabad, Thesis (2011)

R.S. Mishra, Z.Y. Ma, “Friction stir welding and processing” , A Review journal, Materials Science and Engineering R 50 (2005) ,1–78

P.L. Threadgill, “A Review of Friction Stir Welding: Part 1, Process Review”, Book, The Welding Institute (2003)

K. Park, "Development and analysis of ultrasonic assisted friction stir welding process",The University of Michigan USA, Doctoral Thesis (2009)

K. Savolainen, “Friction stir welding of copper and microstructure and property of the welds”, doctoral dissertation 13/ 2012, 17 February, 2012

S. Englera, R. Ramsayera, R. Popraweb, “Process Studies on Laser Welding of Copper with Brilliant Green and Infrared Lasers”, Physics Procedia 12 (2011) 339–346

D. Lohwasser, Z. Chen, “Friction Stir Welding”, Book, Woodhead Publishing Limited (2010),American Welding Society, Welding Handbook,Vol-2, August 27, 2000

Y.M. Hwang, P.L. Fan, C.H. Lin, “Experimental study on Friction Stir Welding of copper metals”, Journal of Materials Processing Technology 210 (2010) 1667–1672

J.J. Shen, H.J. Liu, F. Cui, “Effect of welding speed on microstructure and mechanical properties of friction stir welded copper”, Materials and Design 31 (2010) 3937–3942

K. Surekha , A. Els-Botes, “Development of high strength, high conductivity copper by friction stir processing”, Materials and Design 32 (2011) 911–916

Cavaliere , P. et al. "Effect of welding parameters on mechanical and microstructural properties of AA6056 joints produced by Friction Stir Welding", Journal of Materials Processing Technology, 180(1–3), pp.263–270., 2006.

Cavaliere, P. Squillace, A. Panella , 2008."Effect of welding parameters on mechanical and microstructural properties of {AA6082} joints produced by friction stir welding." Journal of Material Processing Technology, 200(1–3), pp.364–372.

Hirata, T et al., 2007." Influence of friction stir welding parameters on grain size and formability in 5083 aluminum alloy.", Materials Science and Engineering: A, 456(1–2), pp.344–349.

Julong, D., 1989. "Introduction to Grey System Theory". The Journal of Grey System, 1(1) , pp.1–24.

Kim, Y.G. et al., 2006. "Effect of welding parameters on microstructure in the stir zone of FSW joints of aluminum die casting alloy", Materials Letters, 60(29–30), pp.3830–3837.

Kinsey, B.L. & Wu, X ., 2011."Tailor welded blanks for advanced manufacturing", First Edit., B. L. Kinsey & X. Wu, eds., UK: Wood head Publishing Limited.

Kumar, R., Singh, K. & Pandey, S., 2012." Process forces and heat input as function of process parameters in AA5083 friction stir welds.", Transactions of Nonferrous Metals Society of China, 22(2), pp.288–298.

Mishra, R.S. & Ma, Z.Y. , 2005."Friction stir welding and processing." Materials Science and Engineering:, R: Reports, 50(1-2), pp.1–78.

Nandan, R., Debroy, T. & Bhadeshia . H., 2008. "Recent advances in friction-stir welding Process" , weldment structure and properties, Progress in Materials Science, 53(6), pp.980–1023.

Ren, S.R., Ma, Z.Y. & Chen, L.Q ., 2007."Effect of welding parameters on tensile properties and fracture behavior of friction stir welded Al–Mg– Si alloy"

Scripta Materialia, 56(1) , pp.69–72. Rooks, B., 2001."Tailor-welded blanks bring multiple benefits to car design Assembly Automation", pp.323 – 329.

Thomas, W.M. et al., 1991. "Friction stir butt welding".

Threadgill, P.L., 1997."Macro and microstructural features of friction stir welds in various materials." TWI Bulletin , pp.30–33.

Y. J. Chao, X. Qi, W. Tang. "Heat transfer in friction stir welding – Experimental and numerical studies ", Transactions of the ASME, 125 (2003), 138-145.

C. G. Rhodes, M. W. Mahoney, W. H. Bingel, R. A. Spurling, C. C. Bampton. Effects of friction stir welding on microstructure of 7075 aluminum. Scripta materialia 36 (1997) 1, 69-75.

C. M. Chen, R. Kovacevic, Finite element modeling of friction stir welding-thermal and thermomechanical analysis, International Journal of Machine Tools & Manufacture 43 (2003), 1319-1326.

H. Schmidt, J. Hattel, J. Wert, An analytical model for the heat generation in friction stir welding, Modelling and Simulation in Materials Science and Engineering, 40 (2004), 143-157.

V. Soundararajan et al., An overview of R&D work in friction stir welding at SMU, Journal of Me-tallurgy 12 (2006), 204, 277-295.

P. Prasanna, CH. Penchalayya, D. Ananda- mohana Rao, Influence of process parameters on mechanical properties of copper alloys in friction stir welding. International Journal of Engineering Sciences Research-IJESR 4 (2013) 2, 786-791

Y. N. Zhang, X. Cao, S. Larose, P. Wanjara. Review of tools for friction stir welding and processing. Canadian Metallurgical Quarterly 51 (2012) 3, 250-26

G. Padmanaban, V. Balasubramanian , Optimization of laser beam welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy, Optics & Laser Technology ,42 (2010) 1253–1260

Olivier Lorrain, Véronique Favier, Hamid Zahrouni, Didier Lawrjaniec , Understanding the material flow path of friction stir welding process using unthreaded tools, Journal of Materials Processing Technology, 210 (2010) 603– 609.

S. Cui , Z.W.Chen, J.D.Robson ,A model relating tool torque and its associated power and specific energy to rotation and forward speeds during friction stir,International Journal of Engineering Research & Technology ,(IJERT)Vol. 2 Issue 10

H. Bisadi, A. Tavakoli, M. Tour Sangsaraki, K. Tour Sangsaraki ,The influences of rotational and welding speeds on microstructures and mechanical properties of friction stir welded Al5083 and commercially pure copper sheets lap joints, Materials and Design ,43 (2013) 80–88

I. Galvão, R.M. Leala,, D.M. Rodriguesa, A. Loureiroa ,Influence of tool shoulder geometry on properties of friction stir welds in thin copper sheets, Journal of Materials Processing Technology ,213 (2013) 129– 135.

S. Gopalakrishnan, N. Murugan ,Production and wear characterisation of AA 6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method, Composites, Part B, 43 (2012) 302–308.

Michael A. Sutton, A.P. Reynolds, Junhui Yan, Bangcheng Yang, Ning Yuan ,Microstructure and mixed mode I/II fracture of AA2524-T351 base material and friction stir weld, Engineering Fracture Mechanics, 73 (2006) 391–407.

Kim Lau Nielsen, Viggo Tvergaard ,Effect of a shear modified Gurson model on damage development in a FSW tensile specime, International Journal of Solids and Structures, 46 (2009) 587–601

L. Ceschini, I. Boromei, G. Minak, A. Morri, F. Tarterini ,Effect of friction stir welding on microstructure, tensile and fatigue properties of the AA7005/10 vol.%Al2O3p composite, Composites Science and Technology ,67 (2007) 605–615.

Shafiei-Zarghani, S.F. Kashani-Bozorg, A. Zarei- Hanzaki ―Wear assessments of Al/Al2O3 nano-composite surface layer produced using friction stir processing‖ Wear 270 (2011) 403–412

Pedro Vilac¸ Lu´ısa Quintino, Jorge F. dos Santos‖ ISTIR-Analytical thermal model for friction stir welding‖ Journal of Materials Processing Technology 169 (2005) 452–465.

P. Wanjara, B. Monsarrat, S. Larose ―Gap tolerance allowance and robotic operational window for friction stir butt welding of AA6061‖ Journal of Materials Processing Technology 213 (2013) 631– 640.

M. Ericsson, R. Sandstro¨m ‖Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG‖ International Journal of Fatigue 25 (2003) 1379–1387.

L. Fratini, F. Micari, G. Buffa, V.F. Ruisi ―A new fixture for FSW processes of titanium alloys‖ CIRP Annals - Manufacturing Technology 59 (2010) 271– 274.

Kwansoo Chung, Wonoh Lee Daeyong Kim, Junehyung Kim, Kyung-Hwan Chung, Chongmin Kim, Kazutaka Okamoto, R.H. Wagoner ―Macro-performance evaluation of friction stir welded automotive tailor-welded blank sheets: Part I – Material properties‖ International Journal of Solids and Structures 47 (2010) 1048–1062.

Luis S. Rosado, Telmo G. Santos, Moisés Piedade , Pedro M. Ramos, Pedro Vilaç Advanced technique for non-destructive testing of friction stir welding of metals‖ Measurement 43 (2010) 1021–1030.

Siddiqui, M.A., Jafri, S.A.H., Bharti, P.K. and Kumar, P., 2014. Friction Stir Welding as a Joining Process through Modified Conventional Milling Machine: A Review. International Journal of Innovative Research and Development, 3(7).

Titilayo, A.E., Makundwaneyi, M.D. and Akinwale, A.S., 2012. Reconfiguration of a Milling Machine to Achieve Friction Stir Welds . In Applied Mechanics and Materials (Vol. 232, pp. 86-91).

APPENDIX I

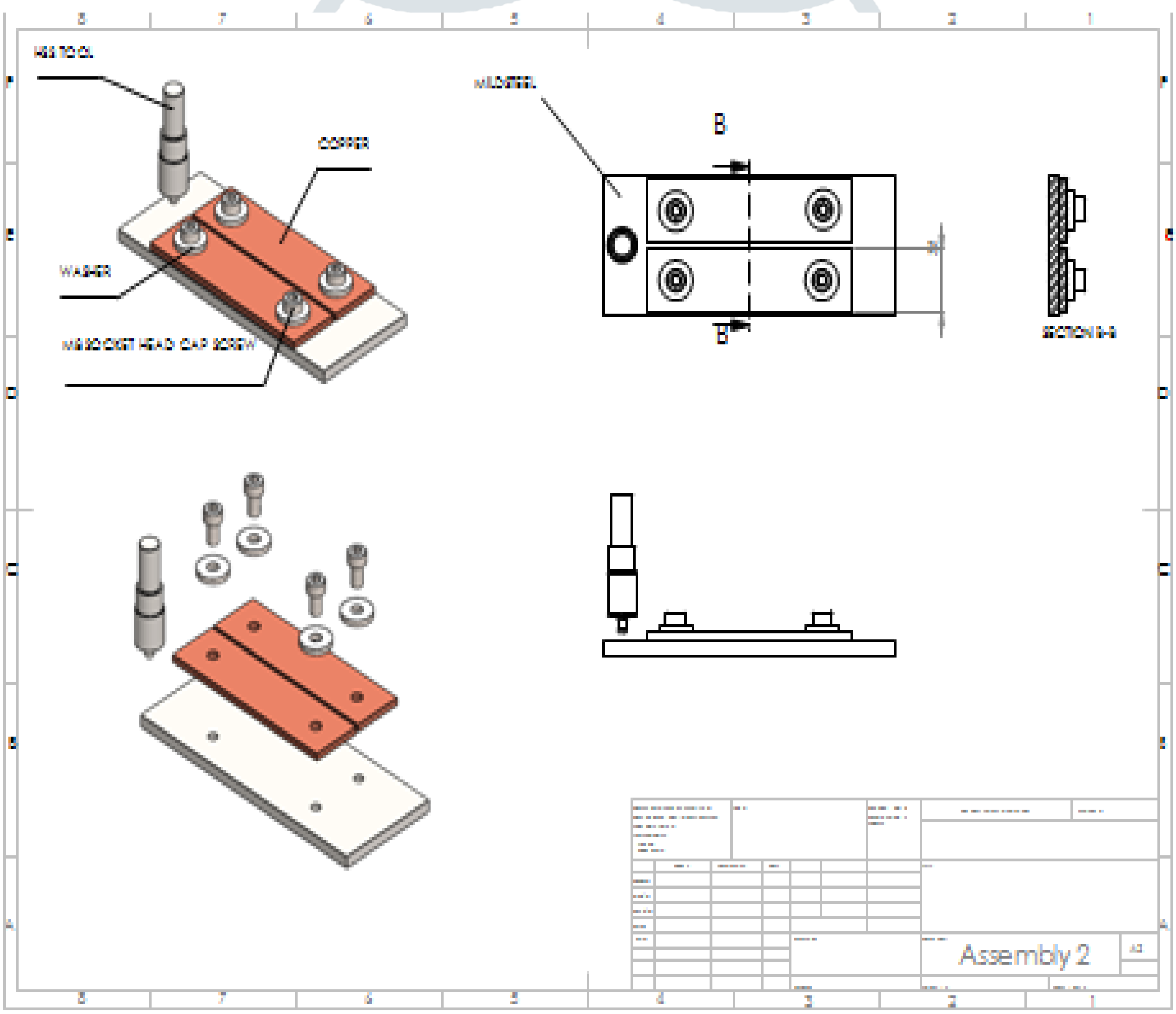
BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY

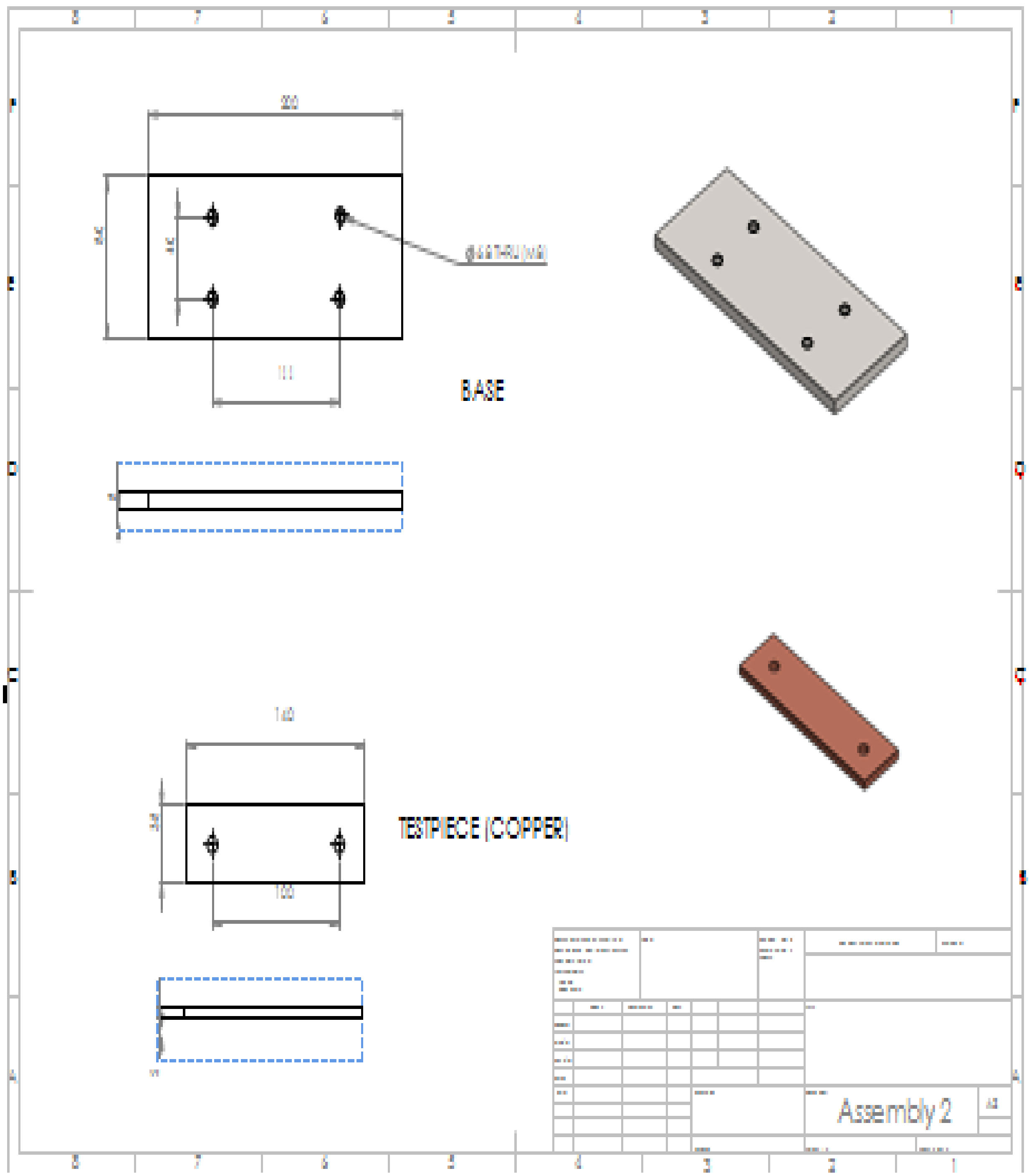
SCHOOL OF RESEARCH AND GRAUATE STUDIES

Faculty of Mechanical and Industrial Engineering
Department of
Manufacturing Engineering

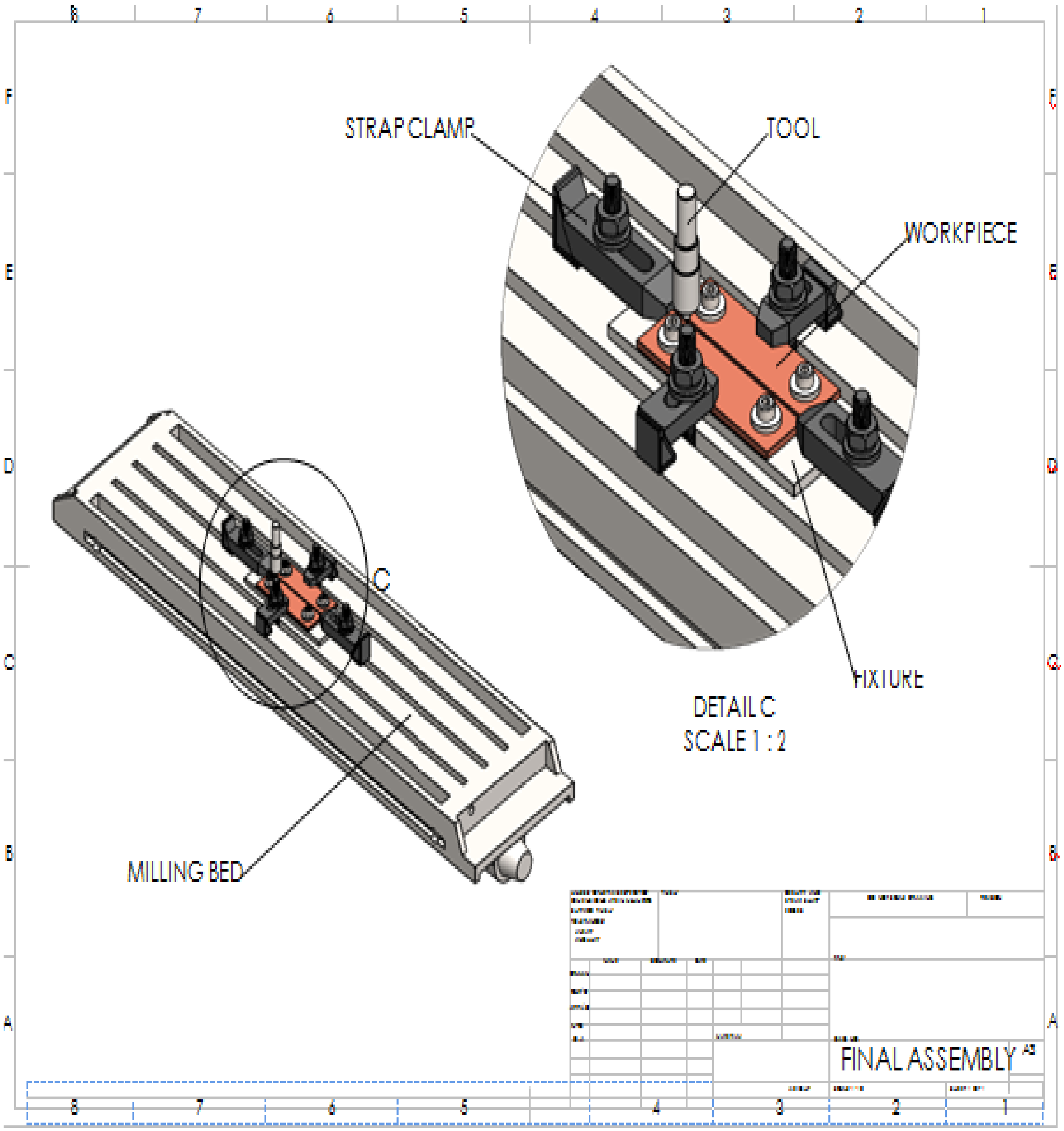
Assembly Of The Weld Specimen , Fixture , and Welding Tool



Fixture Base Plate and Work Specimen



A Fixture plate holding the work and fixed with a Machine Strap clamp



H 13Tool Design

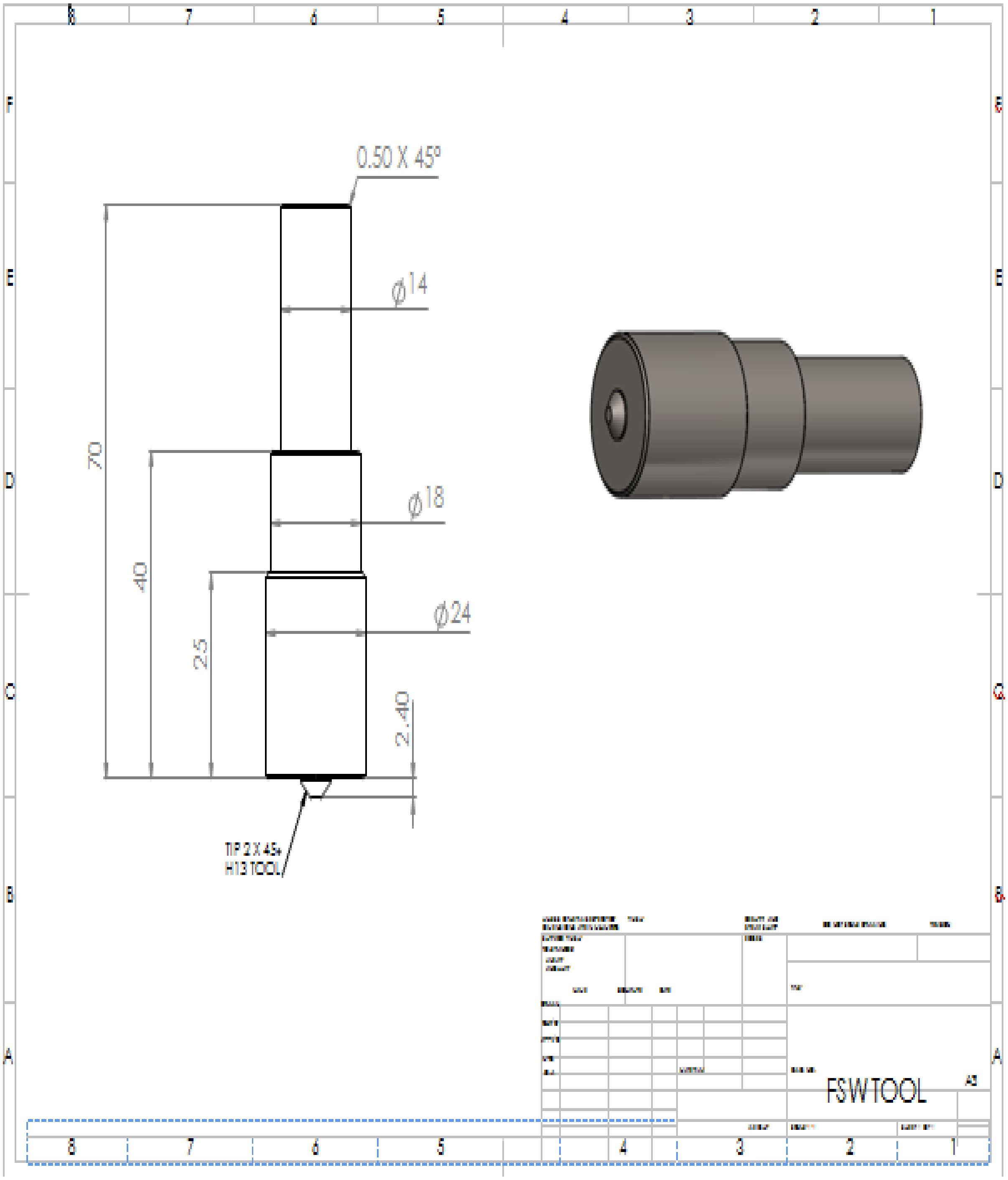
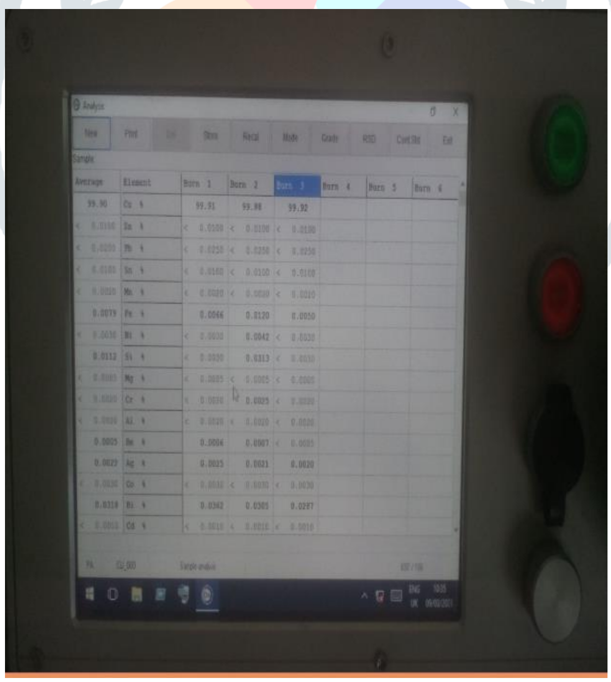


Photo for Tool Holding Fixture

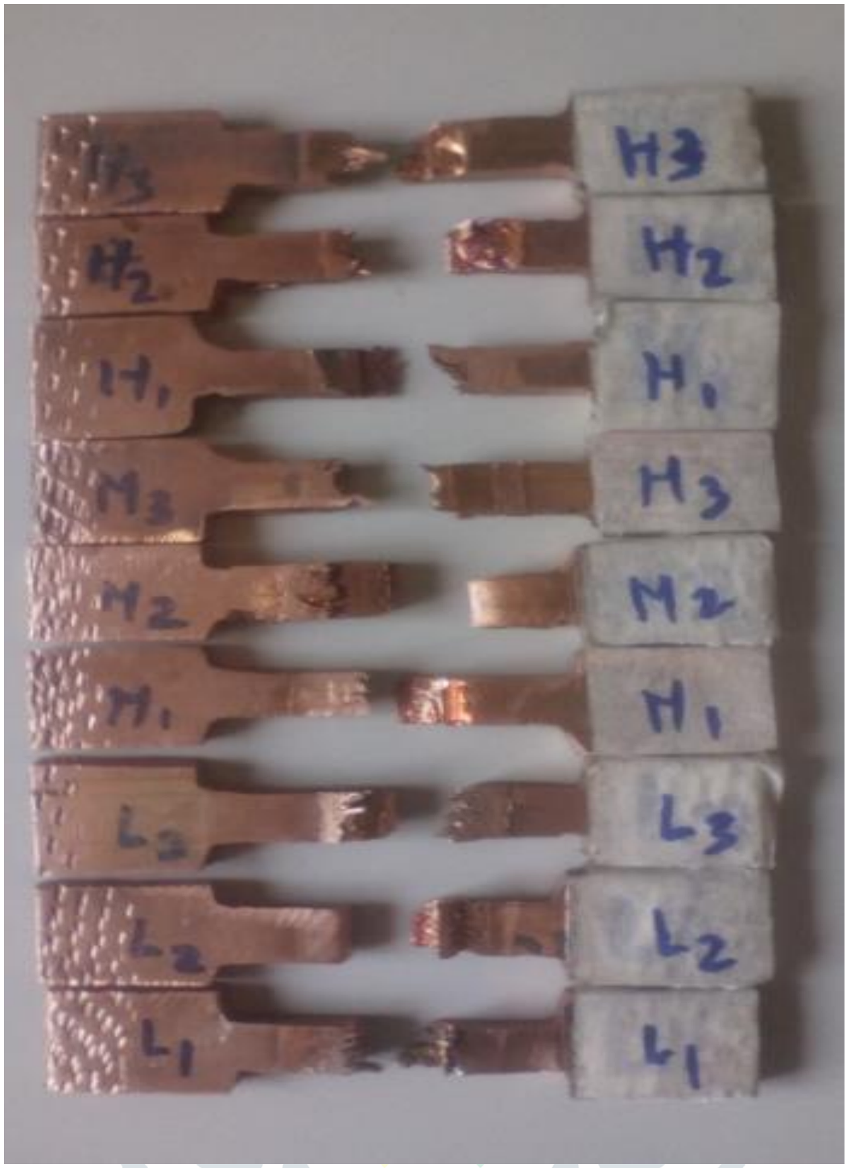
APPENDIX II



APPENDIX III

Specimen before Fracture

Specimen after Fracture



APPENDIX IV

Tensile Testing Machine

APPENDIX V

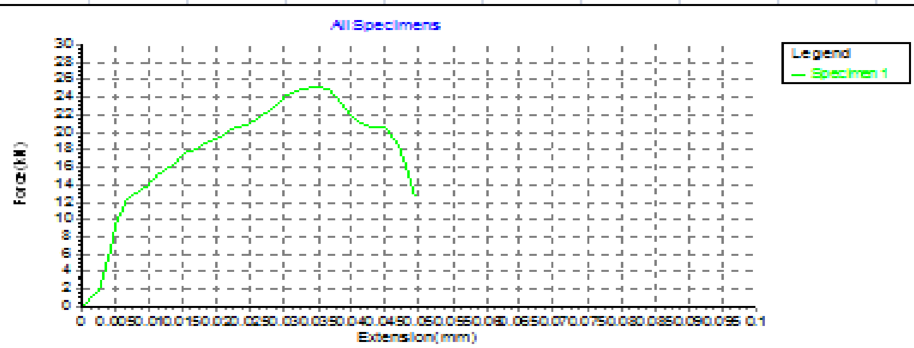
Tensile Test Results

EN-02-Metallic materials-Tensile test-2

(Test data record sheet)

Sample No.	1	Test Standard	
Laboratory	Material Testing Lab	Customer	Basufkad
Temperature	22 C	Tester	Nelson
Humidity	50	Checker	Wilson
Test Date	4/2/2021		Report 11

No.	width	thickne	Lo	Fm	FeH	FeL	Fp0.2	Ft1.0	Lu
	mm	mm	mm	kN	kN	kN	kN	kN	mm
1	6	5	32	25.2	0.0	0.0	0.0	0.0	
No.	A	Rm	ReH	ReL	Rp0.2	Rt1.0			
	%	MPa	MPa	MPa	MPa	MPa			
1	100.0	839	0	0	0	0			



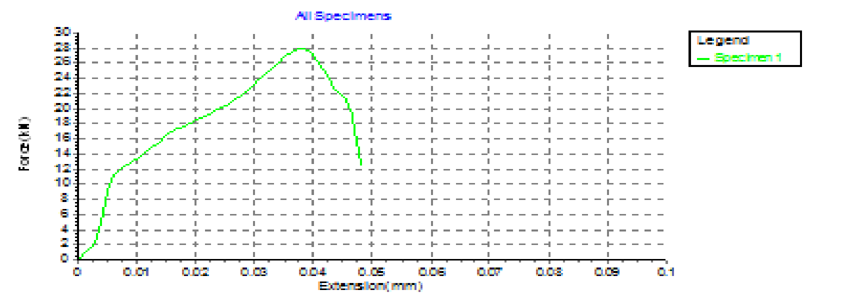
Remark:

EN-02-Metallic materials-Tensile test-2

(Test data record sheet)

Sample No.	2	Test Standard	
Laboratory	Material Testing Lab	Customer	Basufked
Temperature	22 C	Tester	Nelson
Humidity	50	Checker	Wilson
Test Date	4/2/2021		

No.	width	thickne	Lo	Fm	FeH	FeL	Fp0.2	Ft1.0	Lu
	mm	mm	mm	kN	kN	kN	kN	kN	mm
1	6	5	32	28.0	0.0	0.0	0.0	0.0	
No.	A	Rm	ReH	ReL	Rp0.2	Rt1.0			
	%	MPa	MPa	MPa	MPa	MPa			
1	100.0	934	0	0	0	0			



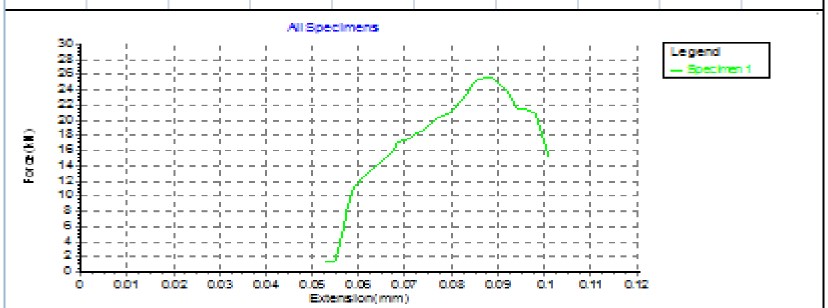
Remark:

EN-02-Metallic materials-Tensile test-2

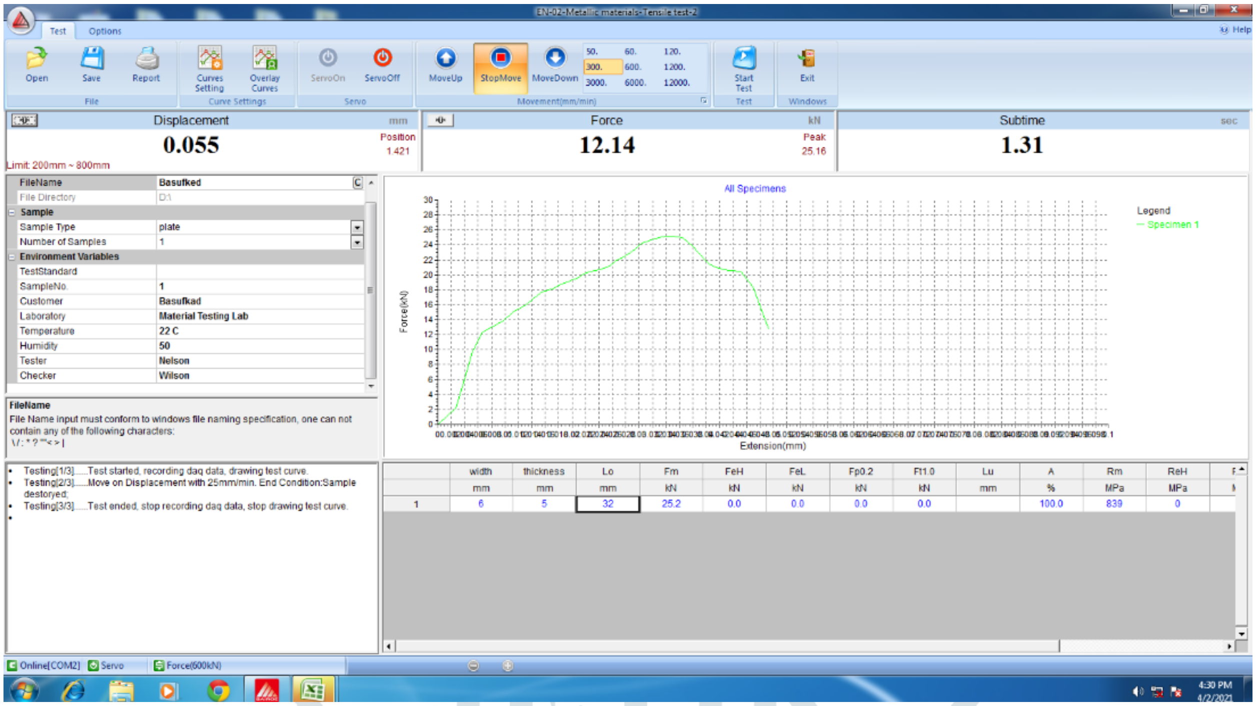
(Test data record sheet)

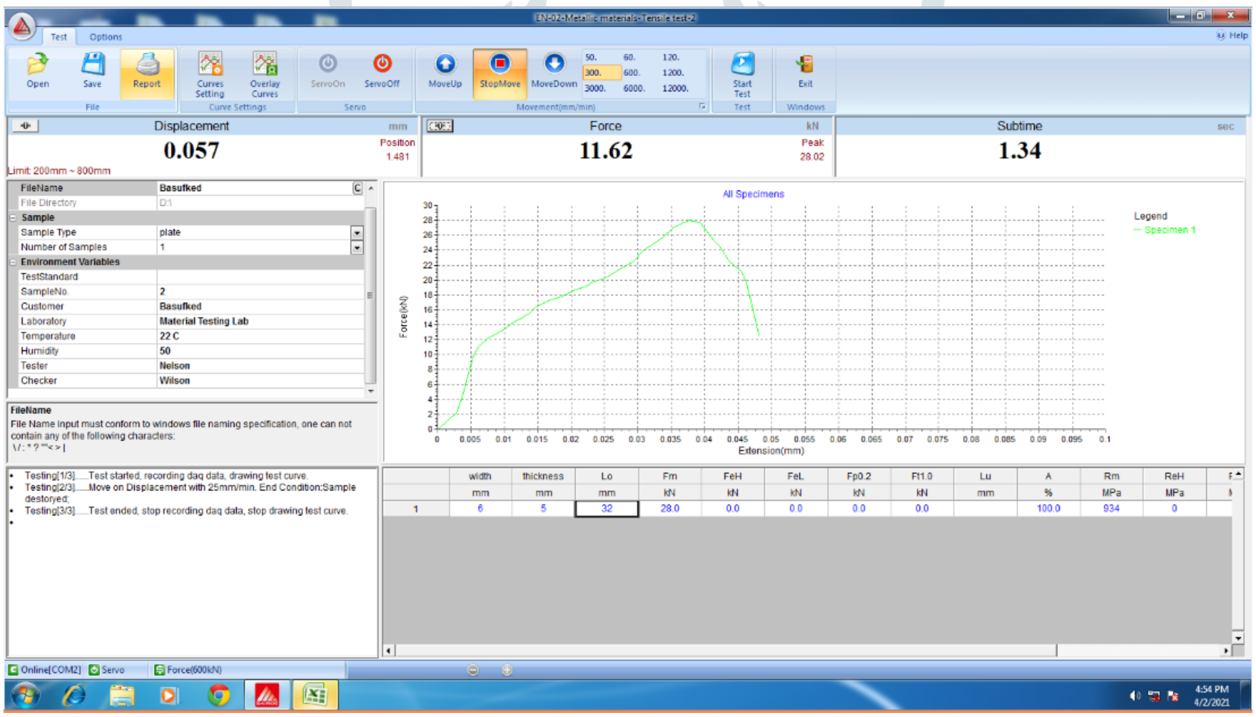
Sample No.	3	Test Standard	
Laboratory	Material Testing Lab	Customer	Basufked
Temperature	22 C	Tester	Nelson
Humidity	50	Checker	Wilson
Test Date	4/2/2021		

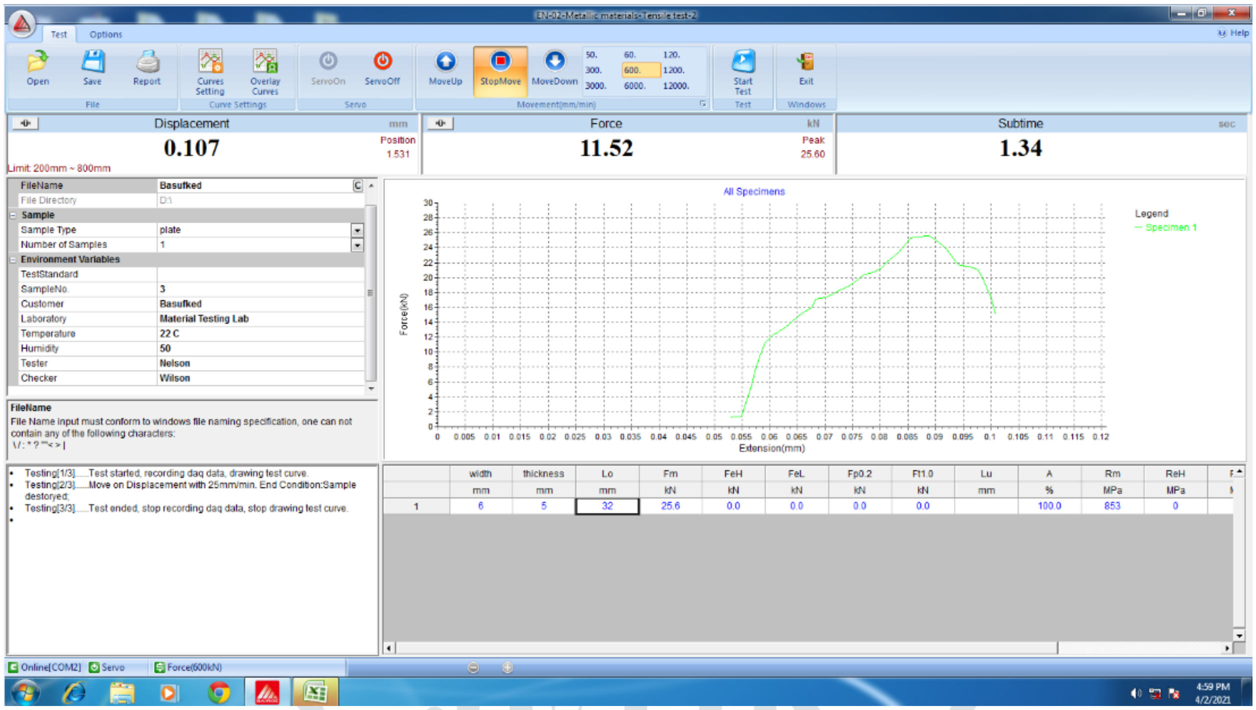
No.	width	thickne	Lo	Fm	FeH	FeL	Fp0.2	Ft1.0	Lu
	mm	mm	mm	kN	kN	kN	kN	kN	mm
1	6	5	32	25.6	0.0	0.0	0.0	0.0	
No.	A	Rm	ReH	ReL	Rp0.2	Rt1.0			
	%	MPa	MPa	MPa	MPa	MPa			
1	100.0	853	0	0	0	0			



Remark:


Test
Options
Open
Save
Report
Curves Setting
Overlay Curves
ServoOn
ServoOff
MoveUp
StopMove
MoveDown
Start Test
Exit
Displacement
mm
0.055
Position
1.421
Limit: 200mm ~ 800mm
Force
kN
12.14
Peak
25.16
Subtime
sec
1.31
FileName Basufked
File Directory D:\
Sample
Sample Type plate
Number of Samples 1
Environment Variables
TestStandard
SampleNo. 1
Customer Basufkad
Laboratory Material Testing Lab
Temperature 22 C
Humidity 50
Tester Nelson
Checker Wilson
FileName
File Name input must conform to windows file naming specification, one can not contain any of the following characters:
All Specimens
Legend
Specimen 1
Force(kN)
Extension(mm)
Testing[1/3]......Test started, recording daq data, drawing test curve.
Testing[2/3]......Move on Displacement with 25mm/min. End Condition:Sample destoryed.
Testing[3/3]......Test ended, stop recording daq data, stop drawing test curve.
width thickness Lo Fm FeH FeL Fp0.2 Ft1.0 Lu A Rm ReH
mm mm mm kN kN kN kN kN mm % MPa MPa
1 6 5 32 25.2 0.0 0.0 0.0 0.0 100.0 839 0
Online[COM2]
Servo
Force(600kN)
4:30 PM
4/2/2021


Test
Options
Open
Save
Report
Curves Setting
Overlay Curves
ServoOn
ServoOff
MoveUp
StopMove
MoveDown
Start Test
Exit
Displacement
mm
0.057
Position
1.481
Limit: 200mm ~ 800mm
Force
kN
11.62
Peak
28.02
Subtime
sec
1.34
FileName Basufked
File Directory D:\
Sample
Sample Type plate
Number of Samples 1
Environment Variables
TestStandard
SampleNo. 2
Customer Basufked
Laboratory Material Testing Lab
Temperature 22 C
Humidity 50
Tester Nelson
Checker Wilson
FileName
File Name input must conform to windows file naming specification, one can not contain any of the following characters:
All Specimens
Legend
Specimen 1
Force(kN)
Extension(mm)
Testing[1/3]......Test started, recording daq data, drawing test curve.
Testing[2/3]......Move on Displacement with 25mm/min. End Condition:Sample destoryed.
Testing[3/3]......Test ended, stop recording daq data, stop drawing test curve.
width thickness Lo Fm FeH FeL Fp0.2 Ft1.0 Lu A Rm ReH
mm mm mm kN kN kN kN kN mm % MPa MPa
1 6 5 32 28.0 0.0 0.0 0.0 0.0 100.0 934 0
Online[COM2]
Servo
Force(600kN)
4:54 PM
4/2/2021



APPENDIX VI

Data Analysis Results

Taguchi Analysis: UTS (Mpa) versus TRS, TS, DT Linear Model Analysis: SN ratios versus TRS, TS, DT

Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	58.3387	0.002016	28933.772	0.000
TRS 400	0.0834	0.002851	29.247	0.001
TRS 700	-0.0101	0.002851	-3.544	0.071
TS 30	0.0659	0.002851	23.105	0.002
TS 60	-0.0032	0.002851	-1.119	0.379
DT 5	0.1013	0.002851	35.532	0.001
DT 7	0.0214	0.002851	7.488	0.017

Model Summary

S	R-Sq	R-Sq(adj)
0.0060	99.95%	99.79%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	0.037286	0.037286	0.018643	509.53	0.002
TS	2	0.024843	0.024843	0.012421	339.49	0.003
DT	2	0.077310	0.077310	0.038655	1056.47	0.001
Residual Error	2	0.000073	0.000073	0.000037		

Total	8	0.139511

Linear Model Analysis: Means versus TRS, TS, DT Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	826.000	0.1925	4292.022	0.000
TRS 400	8.000	0.2722	29.394	0.001
TRS 700	-1.000	0.2722	-3.674	0.067
TS 30	6.333	0.2722	23.270	0.002
TS 60	-0.333	0.2722	-1.225	0.345
DT 5	9.667	0.2722	35.518	0.001
DT 7	2.000	0.2722	7.348	0.018

Model Summary

S	R-Sq	R-Sq(adj)
0.5774	99.95%	99.79%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	342.00	342.000	171.000	513.00	0.002
TS	2	228.67	228.667	114.333	343.00	0.003
DT	2	700.67	700.667	350.333	1051.00	0.001
Residual Error	2	0.67	0.667	0.333		
Total	8	1272.00				

Response Table for Signal to Noise Ratios

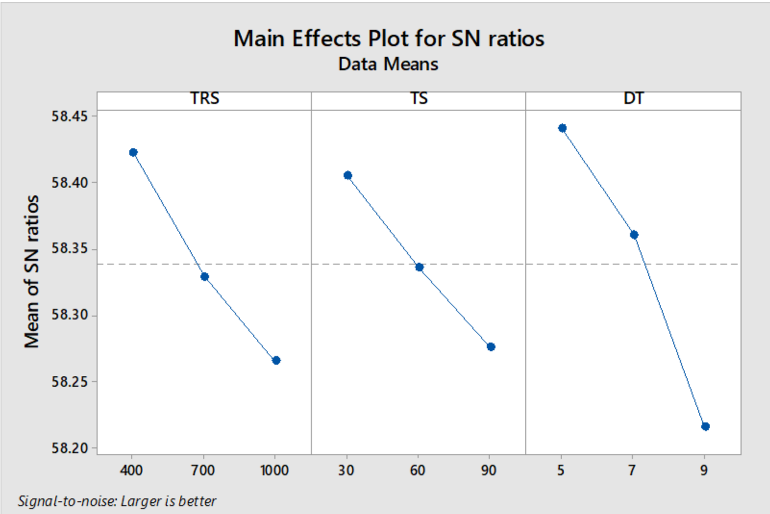
Larger is better

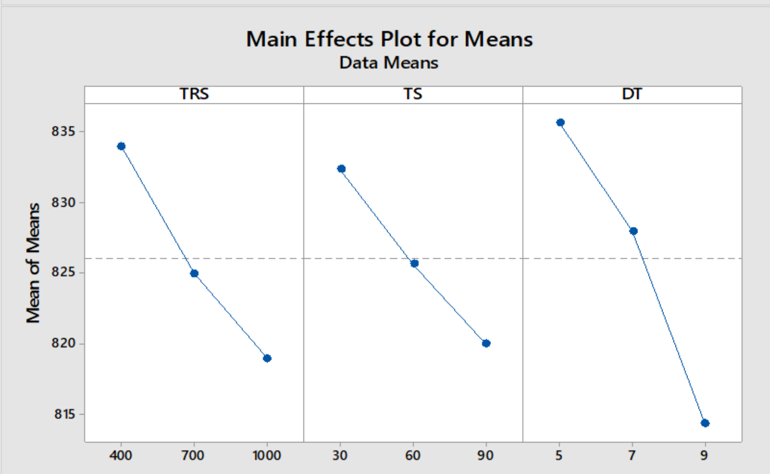
Level	TRS	TS	DT
1	58.42	58.40	58.44
2	58.33	58.34	58.36
3	58.27	58.28	58.22
Delta	0.16	0.13	0.22
Rank	2	3	1

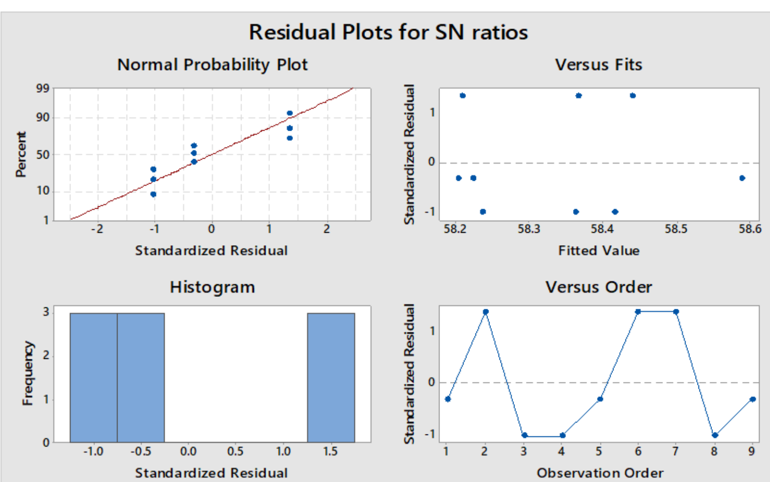
Response Table for Means

Level	TRS	TS	DT
1	834.0	832.3	835.7
2	825.0	825.7	828.0
3	819.0	820.0	814.3
Delta	15.0	12.3	21.3
Rank	2	3	1

Main Effects Plot for Means







APPENDIX VII

Taguchi Analysis: % EL versus TRS, TS, DT Linear Model Analysis: SN ratios versus TRS, TS, DT Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	21.9443	0.01765	1243.219	0.000
TRS 400	0.2563	0.02496	10.269	0.009
TRS 700	-0.0114	0.02496	-0.455	0.694
TS 30	0.1628	0.02496	6.524	0.023
TS 60	-0.0114	0.02496	-0.455	0.694
DT 5	0.3965	0.02496	15.882	0.004
DT 7	-0.0114	0.02496	-0.455	0.694

Model Summary

S	R-Sq	R-Sq(adj)
0.0530	99.61%	98.45%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	0.37756	0.377563	0.188782	67.32	0.015
TS	2	0.14878	0.148784	0.074392	26.53	0.036
DT	2	0.91685	0.916846	0.458423	163.48	0.006
Residual Error	2	0.00561	0.005608	0.002804		
Total	8	1.44880				

Linear Model Analysis: Means versus TRS, TS, DT

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	12.5222	0.02222	563.500	0.000
TRS 400	0.3778	0.03143	12.021	0.007
TRS 700	-0.0222	0.03143	-0.707	0.553
TS 30	0.2444	0.03143	7.778	0.016
TS 60	-0.0222	0.03143	-0.707	0.553
DT 5	0.5778	0.03143	18.385	0.003
DT 7	-0.0222	0.03143	-0.707	0.553

Model Summary

S	R-Sq	R-Sq(adj)
0.0667	99.71%	98.84%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	0.80889	0.80889	0.404444	91.00	0.011
TS	2	0.32889	0.32889	0.164444	37.00	0.026
DT	2	1.92889	1.92889	0.964444	217.00	0.005
Residual Error	2	0.00889	0.00889	0.004444		
Total	8	3.07556				

Response Table for Signal to Noise Ratios

Larger is better

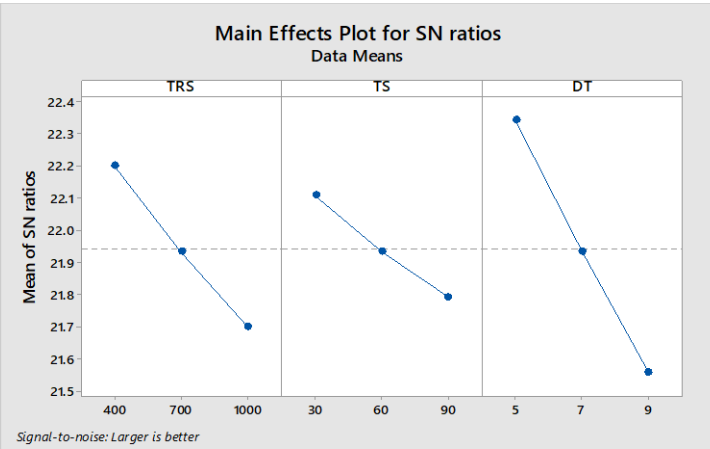
Level	TRS	TS	DT
1	22.20	22.11	22.34
2	21.93	21.93	21.93
3	21.70	21.79	21.56
Delta	0.50	0.31	0.78
Rank	2	3	1

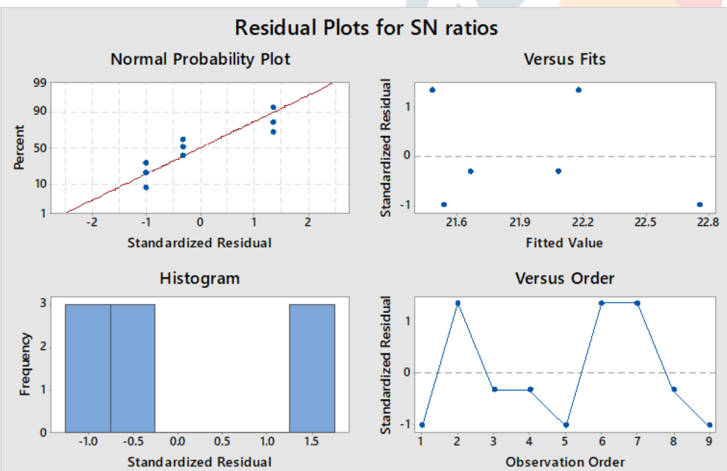
Response Table for Means

Level	TRS	TS	DT
1	12.90	12.77	13.10
2	12.50	12.50	12.50
3	12.17	12.30	11.97
Delta	0.73	0.47	1.13
Rank	2	3	1

Residual Plots for Means, Main Effects Plot for SN ratios , Residual Plots for SN ratios and Residual Plots for Means


Main Effects Plot for Means
Data Means
TRS
TS
DT
Mean of Means
13.2
13.0
12.8
12.6
12.4
12.2
12.0
400
700
1000
30
60
90
5
7
9


Main Effects Plot for SN ratios
Data Means
TRS
TS
DT
Mean of SN ratios
22.4
22.3
22.2
22.1
22.0
21.9
21.8
21.7
21.6
21.5
400
700
1000
30
60
90
5
7
9
Signal-to-noise: Larger is better


Residual Plots for SN ratios
Normal Probability Plot
Percent
Standardized Residual
Versus Fits
Standardized Residual
Fitted Value
Histogram
Frequency
Standardized Residual
Versus Order
Standardized Residual
Observation Order

3

APPENDIX VIII

Taguchi Analysis: Grade versus TRS, TS, DT Linear Model Analysis: SN ratios versus TRS, TS, DT Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	-10.2858	0.2467	-41.685	0.001
TRS 400	2.0847	0.3490	5.974	0.027
TRS 700	-0.3850	0.3490	-1.103	0.385
TS 30	1.6200	0.3490	4.642	0.043
TS 60	-0.3005	0.3490	-0.861	0.480
DT 5	2.6021	0.3490	7.457	0.018
DT 7	-0.0520	0.3490	-0.149	0.895

Model Summary

S	R-Sq	R-Sq(adj)
0.7402	98.57%	94.27%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	22.150	22.150	11.0749	20.21	0.047
TS	2	13.367	13.367	6.6836	12.20	0.076
DT	2	39.830	39.830	19.9151	36.34	0.027
Residual Error	2	1.096	1.096	0.5480		
Total	8	76.443				

Linear Model Analysis: Means versus TRS, TS, DT

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	0.32600	0.02329	13.998	0.005
TRS 400	0.09917	0.03294	3.011	0.095
TRS	-0.02795	0.03294	-0.849	0.485

700				
TS 30	0.08274	0.03294	2.512	0.129
TS 60	-0.02386	0.03294	-0.725	0.544
DT 5	0.11297	0.03294	3.430	0.076
DT 7	-0.01522	0.03294	-0.462	0.689

Model Summary

S	R-Sq	R-Sq(adj)
0.0699	93.79%	75.14%

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TRS	2	0.047067	0.047067	0.023533	4.82	0.172
TS	2	0.032647	0.032647	0.016324	3.34	0.230
DT	2	0.067645	0.067645	0.033823	6.93	0.126
Residual Error	2	0.009763	0.009763	0.004882		
Total	8	0.157122				

Response Table for Signal to Noise Ratios

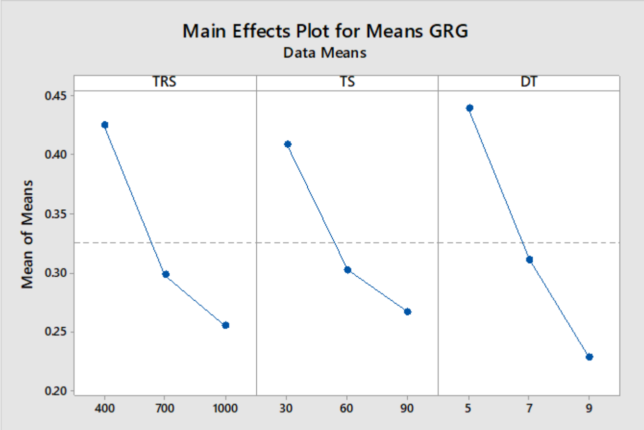
Larger is better

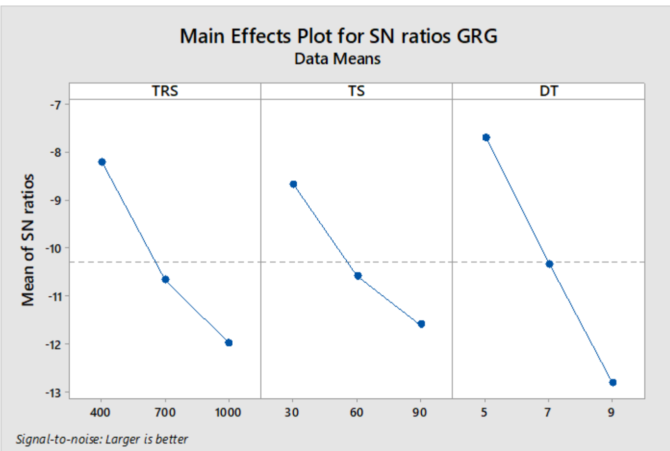
Level	TRS	TS	DT
1	-8.201	-8.666	-7.684
2	-10.671	-10.586	-10.338
3	-11.986	-11.605	-12.836
Delta	3.784	2.939	5.152
Rank	2	3	1

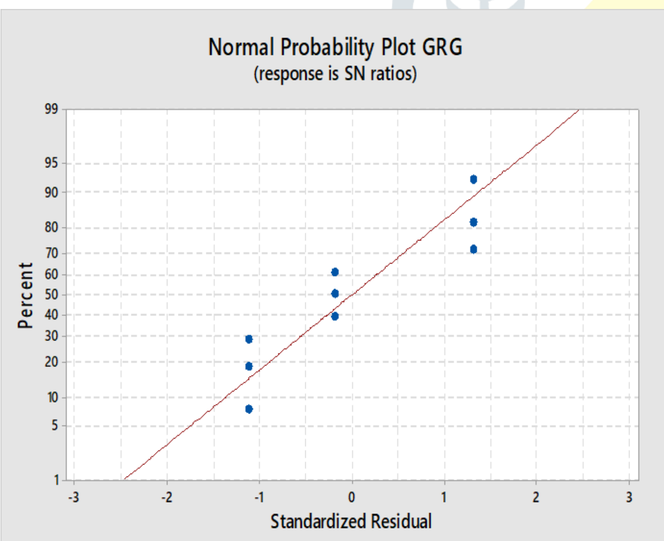
Response Table for Means

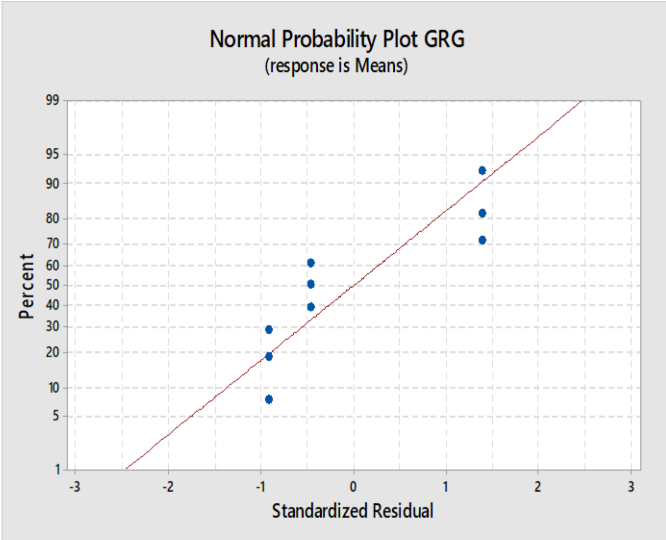
Level	TRS	TS	DT
1	0.4252	0.4087	0.4390
2	0.2981	0.3021	0.3108
3	0.2548	0.2671	0.2283
Delta	0.1704	0.1416	0.2107
Rank	2	3	1

Main Effects Plot for Means Main Effects Plot for SN ratios Normlplot of Residuals for SN ratios Residuals vs Fits for SN ratios Normplot of Residuals for Means
Residuals vs Fits for Means


Main Effects Plot for Means GRG
Data Means
TRS
TS
DT
Mean of Means
0.45
0.40
0.35
0.30
0.25
0.20
400
700
1000
30
60
90
5
7
9


Main Effects Plot for SN ratios GRG
Data Means
TRS
TS
DT
Mean of SN ratios
-7
-8
-9
-10
-11
-12
-13
400
700
1000
30
60
90
5
7
9
Signal-to-noise: Larger is better


Normal Probability Plot GRG
(response is SN ratios)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-3
-2
-1
0
1
2
3
Standardized Residual



APPENDIX IX

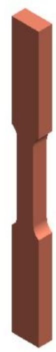
Principal Component Analysis: UTS (Mpa), % EL Eigen analysis of the Correlation Matrix

Eigen value	1.9745	0.0255
Proportion	0.987	0.013
Cumulative	0.987	1.000

Eigenvectors

Variable	PC1	PC2
UTS (Mpa)	0.707	0.707
% EL	0.707	-0.707

APPENDIX X



Simulation of TEST PIECE NO. 1

Date: Wednesday, March 31, 2021
Designer: Solid works
Study name: STRESS STRAIN ANALYSIS
Analysis type: Static

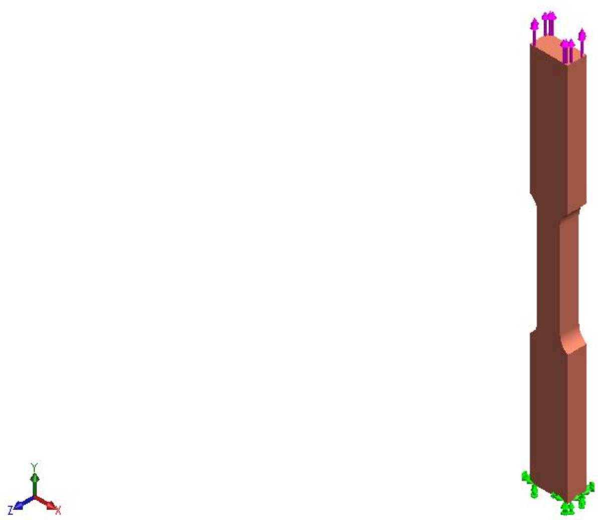
Table of Contents

Description

No Data

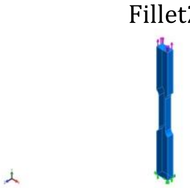
Assumptions

Model Information



Model name: TEST PIECE NO. 1
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Fillet2 	Solid Body	Mass:0.0391626 kg Volume:4.40029e-006 m^3 Density:8900 kg/m^3 Weight:0.383794 N	C:\User\BUSEFIKADU\FINAL \TEST PIECE NO. 1.SLDPRT Mar 31 12:13:47 2021

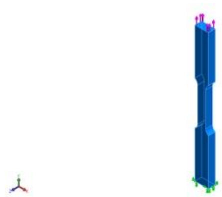
Study Properties

Study name	STRESS STRAIN ANALYSIS
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\BUSEFIKADU\FINAL)

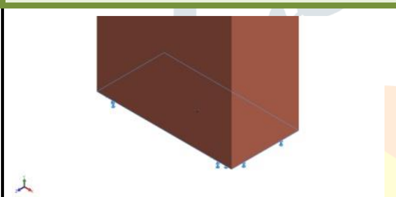
Units

Unit system:	SI (MKS)
Length/Displacement	Mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

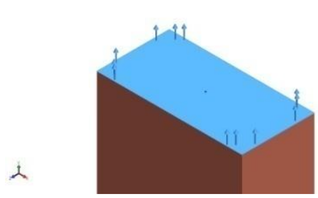
Model Reference	Properties	Components
	Name: **Copper** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.58646e+008 N/m^2** Tensile strength: **3.9438e+008 N/m^2** Elastic modulus: **1.1e+011 N/m^2** Poisson's ratio: **0.37** Mass density: **8900 kg/m^3** Shear modulus: **4e+010 N/m^2** Thermal expansion coefficient: **2.4e-005 /Kelvin**	**SolidBody 1(Fillet2)(TEST PIECE NO. 1)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.0125327	-5999.99	-0.0177879	5999.99
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** -6000 N

Resultant Forces

Reaction forces

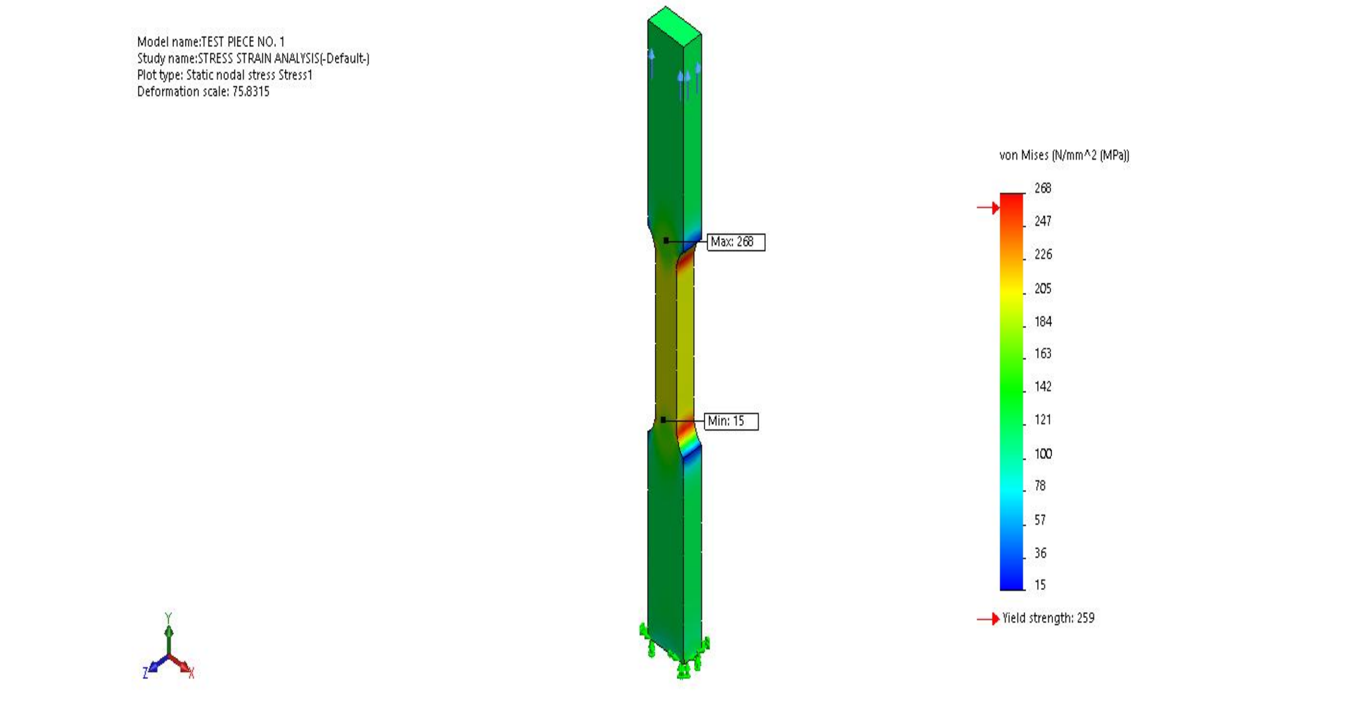
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.0125327	-5999.99	-0.0177879	5999.99

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

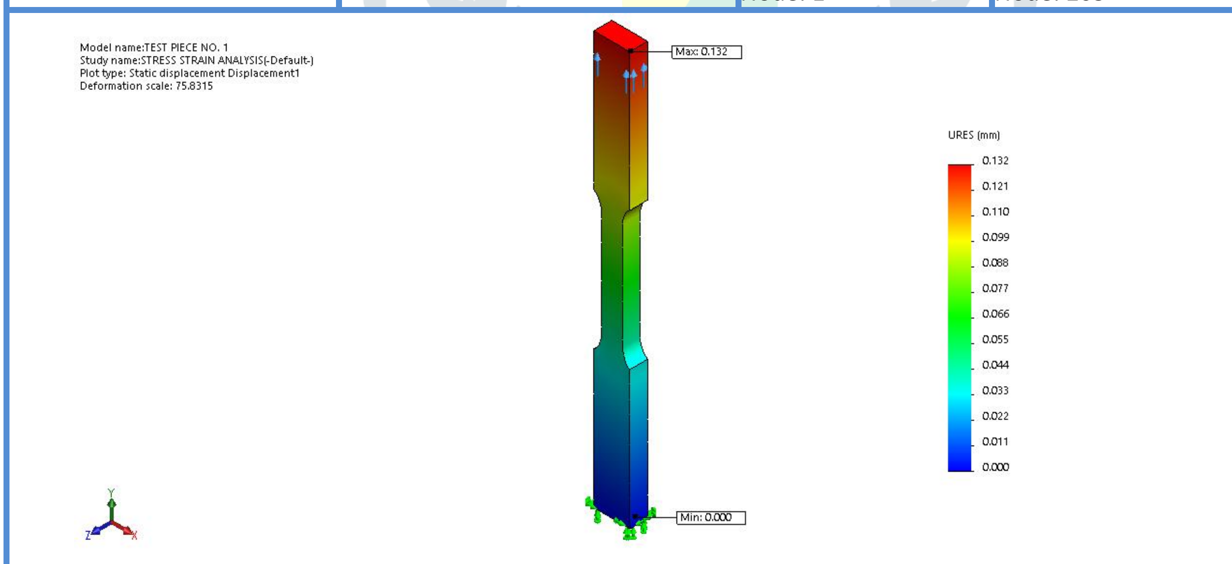
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	15 N/mm^2 (MPa) Node: 8722	268 N/mm^2 (MPa) Node: 8916



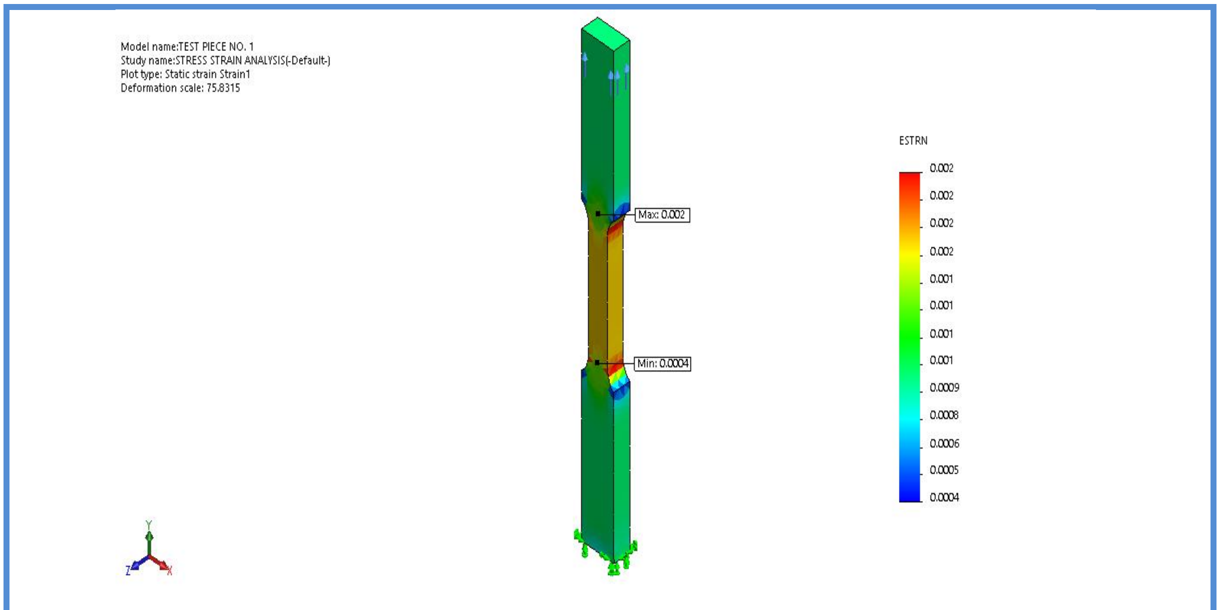
TEST PIECE NO. 1-STRESS STRAIN ANALYSIS-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000 mm Node: 1	0.132 mm Node: 205



TEST PIECE NO. 1-STRESS STRAIN ANALYSIS-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0.0004 Element: 1135	0.002 Element: 1705



TEST PIECE NO. 1-STRESS STRAIN ANALYSIS-Strain-Strain1