# Review Paper on Friction Welding of Similar and Dissimilar Metals

**Dr. Loveleen Kumar Bhagi**
Associate Professor, School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab.

## Abstract

Many industrial applications demand joining of two dissimilar metals. This may be achieved easily and with good results by using friction welding. The typically friction welded applications includes cutting tools, agricultural machinery, aerospace components, automotive parts etc. Carbon steel welded to copper is being used as the tool in EDM with copper end in contact with the dielectric medium. This greatly reduces the cost of the material used in manufacturing EDM tool.

A large volume of literature is available in journals and books explaining the phenomenon and various techniques of welding for joining similar and dissimilar metals. In this chapter, review of relevant literature has been made. The survey of the literature was based upon the different joining processes.

## 1. Introduction

The introduction of new materials and improvement of prevailing materials have led to joining of dissimilar materials employing different techniques. The joining of dissimilar metals through fusion welding is tough because of the different characteristics of each material (ASM Committee, 1971). Friction welding can be used to join metals of widely differing thermal and mechanical properties.

The first proposed use of friction in welding was perhaps contained in the American patent of 1891 when frictional heat was proposed to join a tube to a V shaped die. Friction welding was introduced for commercial application in Russia by Chudikov (1956) during 60's and it was familiarized to west by Vill (1962) in the year 1959. Friction welding does not need any filler metal, shielding gas and flux, and the joint appears to be very similar to the ones formed using electrical resistance buttwelding processes of flash and upset welding. Moreover, the energy consumption for friction welding is almost 1/10th of that required in conventional welding methods (Parmar, 1998).

Many industrial applications demand joining of two dissimilar metals. This may be achieved easily and with good results by using friction welding. The typically friction welded applications includes cutting tools, agricultural machinery, aerospace components, automotive parts etc. Carbon steel welded to copper is being used as the tool in EDM with copper end in contact with the dielectric medium. This greatly reduces the cost of the material used in manufacturing EDM tool.

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## 2. Theoretical Consideration of Friction Welding

Friction theory starts with Amontons' Laws, which states that (Vill, 1962)

a) The force of friction is directly proportional to the applied load or applied normal pressure. (Amontons 1st Law)

b) The force of friction is independent of the apparent area of contact. (Amontons 2nd Law)

c) Kinetic friction is independent of the sliding velocity and coefficient of friction is reduces with increase in normal load. (Coulomb's Law)

Based on various studies and experiments performed on the properties of friction, the relationship derived between frictional force (F) and normal contact force (L) was

$$F = \mu L \qquad \ldots (1)$$

where, $\mu$ is the coefficient of friction, and whish is in accordance with Amontons' two laws, that states that $F$ is a function of normal contact force only and does not depend upon the surface area in contact.

Friction welding of metals was first performed successfully by Chudikov and Vill, who expressed frictional force as,

$$F = \alpha S_f + \beta L \qquad \ldots (2)$$

And

$$S_f = A + BL \qquad \ldots (3)$$

Where, $F$ is the frictional force, $S_f$ is the sum of the actual areas of elementary contact, coefficient $A$ depends on the smoothness or roughness of the surface, coefficient $B$ characterizes the ability of the material to resist plastic deformation, and $\alpha$, $\beta$ are constant coefficients characterizing the material of the friction surfaces.

From equation 1.1 and 1.2

$$\mu = F/L = \alpha(A/L) + \beta \qquad \ldots (4)$$

For heavy loads, the term $A/L$ reduces significantly, so the first term in the above expression is very small and thus can be neglected.

$$\mu \approx \beta$$

Amonton's law is effectively obeyed when the value of $\beta$ is approximately equal to $\mu$.

Kragel'skiy and Vinogradova (1955) predicted that the following factors have influence on the friction coefficient during friction welding:

I. The comparative rotational speed of the friction surfaces

II. Heat produced at friction surfaces

III. Type of the material

IV. Magnitude of normal force

V. Rigidity and elasticity of friction surfaces

The value of coefficient of friction ($\mu$) varies in complex way with velocity. It also shows that there are other sources of heat in friction welding, such as deformation of contact points and the material behind them. As the temperature increased to 200ºC -300ºC, dry friction obtains due to evaporation of lubricants and absorbed layers, and 'μ' increase, resulting in a further increase of temperature.

Oxide films can contribute to the frictional heat. Thin but hard oxide film decreases coefficient of friction while a thick soft oxide film increases the coefficient of friction (Bowden and Tabor, 1964). Rough surfaces give a greater 'μ' due to interlocking. Smooth surfaces according to Vill, should also give a high 'μ' due to interatomic forces, but it is very doubtful whether the smoothness or cleanliness of the surfaces is ever good enough for these forces to make an appreciable contribution before seizure has taken place (Vill, 1962).

## 3. Motivation of The Review

The works related to friction welding presented in various journals by eminent researchers have been studied with following objectives:

a) To review the work done by the researchers in the field of friction welding.
b) To explore the findings and the existing research issues.
c) To outline the various optimization methods applied for the enhancement of weld quality

## 4. Literature Surveyed

**Ahmet *et al.*** (1998) investigated the process of friction welding for Copper and Steel bars. They examined the heat transfer mechanism involved in initiation of friction welding and introduced a heat transfer model for joining of two different materials. They conducted experiments for different welding conditions to authenticate the theoretical predictions. The parameters that affect the mechanical properties of the welds formed, were analyzed and it was concluded that the significant parameters are the speed of rotation, the weld duration and the friction force. The mechanical properties included the tensile strength, the ultimate yield strength and the micro hardness of the weld cross-sections.

**Arivazhagan *et al*.** (2008) studied the joining of AISI 4140 and AISI 304 using friction welding under $Na_2So_4$+$V_2O_5$ environment and analyzed the weldment at raised temperatures and corrosion actions. The oxide scales in the weldment had been characterized systematically by using surface analytical techniques and found that weld area was more susceptible to degradation than in base metals.

**Cheng** (1963) considered the distribution of heat over the immobile component in friction welding. He asserted that the coefficient of friction is not a constant factor but is controlled by pressure, speed, pressure, surface temperature, hardness and surface conditions.

**Crawford and Tam** (1981) studied the friction welding characteristics of four thermoplastics: nylon 66, acetal, polymethylmethacrylate (PMMA) and polyvinyl chloride (PVC) by using specially constructed and instrumented friction welding setup and found that values of resisting torque increase as the axial pressure and rubbing velocity increase. The burn off rate increases as the axial pressure and rubbing velocity increases. The rate of heat generation was greatest in nylon 66 followed by actel, PMMA and PVC but burnoff rate was greatest in PVC followed by nylon 66, PMMA and actel in descending order.

**Dey *et al.*** (2009) Authors tried FW process to weld Titanium to SS used in nuclear industry. It was concluded from the studied that the welding of these dissimilar materials marked in a robust joint and during tensile test it has been observed that failure happened in the base metal (titanium). Further, the joints have shown significant resistance against ductility in bending. Ductility in bending has been improved by using heat treatment of the materials before welding and the reason stated is releasing of strain hardening and residual stresses at the weld edge. They investigated the joint by mechanical tests and microstructure analysis using optical and SEM.

**Fu, Duan and Du** (2003) developed a model using FEM to foresee heat development, stress, strain, and the shape of FW parts. Authors also investigated the effect of FW using numerical analysis and by experimentation.

**Gulyaev *et al.*** (1977) studied friction welding of Nickel alloy with steel Cryogenic structural steel and found that welded type of scalpel i.e., medical cutting instrument turnout a saving of the major cost when compared with a scalpel which is manufactured completely from nickel alloy.

**Hiizu Ochi *et al.*** (2008) FW of Cu alloys to SS and Carbon steel were accomplished. It has been observed that in view of tensile strength the efficiency of friction welded of different combinations were 73%, 61%, 78% and 77%.

**Hollander and Cheng** (1963) studied the friction welding of Low Alloy Steel to Austenitic SS and found that the hardness of both the SS and Alloy Steel at the weld interface had increased appreciably.

**Hussain, Noh and Ahmad** (2008) studied the friction welded of alumina rod to MS rod by using 99% pure Al sheet as an interlayer. Further, joint strength was evaluated via a four-point bending test and concluded that joint-strength of alumina rod to steel rod joint is mainly reliant on the wetability of the alumina surface by pure aluminum interlayer and the presence of mechanical meshing b/w the pure Al sheet and MS.

**Kimpura, Seo, and Fuji** (2005) they developed a continuous drive FW machine having electromagnetic clutch to avoid input of heat while braking and analyzed that the joint properties of friction welded joint of 780 MPa class high tensile steel is further improved than welded joint made by a conventional continuous drive FW machine.

**Kobayashi, Machida and Suzuki** (2003) studied the joining of composite materials, conventional steel and lighter Al alloy, by using friction welding and investigated various friction welding characteristics under various experimental conditions. The tensile strength of welded specimen has enough strength under friction welding conditions of 1000rpm, friction pressure of about 20MPa, friction time less than 1sec and forged pressure nearly plastic flow pressure of Al alloy. Authors also examined the macroscopic and microscopic interface structures in relation to FW conditions for different materials.

**Markovic, Savic and Ciric** (2008) studied rotation FW process with a continual drive of the high-speed steel with carbon steel. Characterization of the phenomena within the welded joint over friction phase was examined via straight measurement of heat cycles followed by investigation the structure and systematic procedure. Thorough studies enabled setting up of the model of the friction-welded joint of different types of steel with characteristic zones.

**Ozdemir and Orhan** (2005) Studied microstructure and mechanical properties of friction-welded joints of a Hypereutectoid Steel with 4% Al. In this study, joining characteristics of Hypereutectoid-steel with thermo-mechanical cycle was investigated using FW process and the effects of welding parameters on microstructure & mechanical properties of the FW joints also estimated. The microstructural properties of HAZ were studied by optical and SEM. The microhardness across and at interface were measured. Strength of joints was checked with tensile test. From the experiment it showed that individually all parameters have a small effect on the quality of the joint then combined effect of rotational velocity, friction pressure and time significant effect on the mechanical properties and metallurgical properties. Particularly, via choosing rotational velocity, frictional pressure and time properly, impossible to improve the quality of joint.

**Ozdemir, Sarsilmaz and Hascalik** (2007) studied the boundary properties in terms of rotational speed in FW AISI304L to 4340 steel. Authors conduct with 5 diverse rotational speeds using direct drive type FW machine. Friction pressure, Forge pressure, Friction time and Forging time were set aside constant. The veracity of the joints was examined by SEM and mechanical properties assessments included microhardness and tensile tests.

**Reddy, Satyanarayana and Mohandas** (2007) studied the effect of roughness on faying surfaces of austenitic stainless steel on FW dissimilar joints had been studied. It had been observed that improvement in strength and toughness was observed up to a roughness value of Ra of 5.0 μm in austenitic stainless steel. However, roughness value beyond this resulted in layered structure on the ferritic stainless steel leading to lower toughness.

**Reddy, Mohandas and Sobhana** (2003) studied the joining of AA8090 T6 Al-Li alloy by Friction Welding. The effect of joining parameters such as friction pressure, forge pressure and burn-off on microstructure, notch tensile strength, impact toughness and hardness of friction joint is analyzed further by ANOVA using Yate's algorithm to understand the interaction effects of parameters on properties.

**Ruge *et al.*** (1986) studied the joining of Copper to Titanium by FW. Metallurgy phenomenon during Friction welding of copper to Titanium was analyzed and optimum welding parameters were determined. A computer controlled, continuous drive friction welding machine was used for the welding trails.

**Sahin and Akata** (2003) did experimental work on FW of plastically deformed steel rods. It was concluded from the work that the rods having similar and unlike diameters deformed plastically, but identical metals were welded with different process parameters. The strengths of joints were also checked by the tension assessments. The hardness variation and microstructures in the FW zone were obtained and investigated.

**Sahin** (2007) experimentation was performed to examine the micro-structural properties and welding strengths of the stainless-steel parts welded by FW setup, constructed as continuous FW machine. Author conducted experiments under different process parameters i.e. time and pressure to obtain optimum combination of parameters using numerical approach. Strength of the joints was determined by tensile, fatigue and notch-impact tests and results were compared with strengths of materials.

**Sahin** (2008) studied the joining of dissimilar materials. Austenitic SS and aluminum metal were welded using FW method. optimum parameters for joints were obtained by using statistical approach and joints were further studied using EDX to check the phases which occurred during FW.

**Sahin** (2009) investigated experimentally the properties of plastically deformed Austenitic SS joined by FW under various controllable parameters. Tensile strength of the welded joint was further analyzed using statistical approach. Variation in hardness and microstructure were also studied by using SEM.

**Sathiya, Arvindan and Haq** (2007) studied the FW of ferritic SS of alike composition and shape and they analyzed the role of processing parameters on the strength. The joints were exposed to various mechanical testing methods. The microhardness variation across the joint was determined using hardness tester.

**Seop Shin *et al.*** (2006) Studied Friction Welding of Zr metallic Glass. Friction welding time span and pressure has been chosen as the process parameters. The effect of these process parameters on the upset shape and volume at the interface have been investigated. Authors have used the infrared thermal camera to measure the heat distribution around the joint. Further, notable welded joint of Zr metallic glasses was achieved via the precise control of friction time and pressure.

**Singh, J. and Singh, N.** (2005) Studied effect of spindle speed and forge load on the burst pressure strength of similar weld joining of Al and GI pipes and investigate the feasibilities of joining Al-to-Al pipe and GI-to-GI pipes. Mechanical integrity of the weld joint is also evaluated. For experimentation, a friction-welding machine had been developed and then weld joint was prepared. Forge load, spindle speed and heating pressure are taken as principal parameters for investigating their effects on weld quality.

**Vill** (1959) reported the results of research on low carbon steel bar 0.79 inch diameter. He investigated the torque-time and speed-time curves. He also found that power required was proportional to the axial pressure.

**Yeon *et al.*** (2003) studied the joining of pure Copper to Titanium by brake type friction welding machine. The effect of FW time and forge pressure on the mechanical properties and metallurgical properties has been analyzed. For constant upset pressure it has been observed that tensile strength ended with small change with an increase in friction welding time, whereas, at constant friction time, the tensile strength increased significantly with increasing upset pressure.

## 5. Conclusions

Literature identifies that the Friction Welding is a useful process for joining similar or dissimilar metals. Literature survey was done to identify and elaborate the gaps. The attempts will be made to bridge the same.

Based upon the literature surveyed the optimization of friction welding process parameters such as Rotational speed, Axial pressure and Forge pressure will be carried out using Taguchi's design of experiment.

In the present study, an attempt will be made to join dissimilar cylindrical metals having uniform diameter using a modified lathe machine Friction welding setup. For the Friction Welding process Rotational speed (N), Axial pressure ($P_a$) and Forge pressure ($P_f$) are the principal controlling variables which influence the mechanical properties of the of the Friction welded joints & it has been decided to take up the Breaking load and burn-off-length evaluation of ferrous and non ferrous metal joints to be made by Friction Welding. Three levels of friction welding parameters and L9 orthogonal array are taken. The effects of these parameters are checked on two output response variable factors such as breaking load strength and upset.

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