# Analysis of Response Parameter of Dissimilar Metals Harden by Induction Process

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***Abstract***

The objective of this study is to illustrate the effect of heat treatment on microstructure and mechanical properties of oxyacetylene gas welded copper and low carbon steel. The case in consideration is welding of copper to carbon steel of same diameters to be used in the aeronautic industry and in EDM tool. Carbon steel welded to copper can be used as the tool in EDM with copper end in contact with the dielectric medium. This will greatly reduce the cost of the material used in manufacturing EDM tool.

To perform experiments, the desired dimension of the specimen using turning and facing process are reduced from 25 mm × 30 mm size bar of copper and carbon steel to the desired (or required) 21 mm diameter and 27 mm length. 14 samples were prepared by using oxyacetylene welding. Mechanical testing of samples was carried out to determine the hardness and ultimate tensile strength. All the experimental work, mechanical testing and microstructural analysis were conducted at Lovely Professional University, Phagwara, Punjab.

Quenching were conducted to study the effect of cooling rate on material. Specimens were heated at 730°C and 850°C and were cooled by using three types of cooling medium; water quench, oil quench and sand quench. Hardness and Tensile strength of low carbon steel and copper are 55 HRC, 35 BHN, 370 MPa and 290 MPa was obtained for the as received specimen. It has been observed that cooling rate contributed to a higher strength due to local strain effect. Rapid cooling in quenched specimen had successfully increase the hardness by 57% for copper and for low carbon steel recorded the highest tensile strength of 548 MPa while slow cooling rate which experienced by an annealed specimen resulted in the lowest tensile strength of 251 MPa. Microstructure investigation shows annealed specimen produced coarse austenitic structure with larger grain size. Meanwhile, quenched specimen produced finer austenitic structure with smaller grain size.

***Keywords***: *Copper, Mild Steel, Dissimilar Welding, Induction Heating, Hardness and Tensile Strength*

## 1. Introduction

### 1.1 Surface treatment

The surface treatment is a method used to make the outer surface of the material more resistant to corrosion or wear. For example, zinc plating on steel towers, thermal spraying on a large structural object, chemical treatment is used to create resistance to corrosion and metal coloring. But despite this, there are lot of other surface treatment processes which, are mostly used to enhance the surface properties. Surface hardening is the procedure of metal surface modification, for example, carburizing, nitriding and induction hardening of steel. With advanced research in materials, the number of researchers suggested various surface treatment methods to enhance material properties like hot dipping, thermal spraying, chemical process (chemical coating), electroplating, surface hardening etc. A large volume of literature is available in journals and books explaining the phenomenon and various surface treatment techniques for ferrous and non-ferrous metals.

In the present work, the main focus is to study the effect of variation of induction hardening temperature on hardness and tensile strength of ferrous and non-ferrous metals.

### 1.2 Heat Treatment

Heat treatment is the process of metal heating and cooling using some heating media to transform their physical and mechanical properties, without letting it change its profile. Heat treatment is generally used for strengthening the metal but in some cases, we can also use this to alter some of the mechanical properties like improving fracture strength, machining, etc. There are five basic types of heat treatment processes which are hardening, tempering, annealing, normalizing and case hardening.

In some of the applications the metal needs to harden and the process used for this is known as hardness. In this, heat the metal to the required transformation temperature and then cooling the metal using a quenching medium, like oil, water, or brine. Furthermost, steels are generally cooled quickly to harden them. There is an increase in hardness and strength of metal but simultaneously the brittleness is also increased. To decrease the brittleness and to increase the ductility of ferrous alloys another heat treatment process is generally carried out which is known as tempering. In this metal is to be heat to a quantified temperature and then allow to cool in still air. Temperature castoff for tempering are usually considerably lower than the hardening temperature. As shown in Figure 1, the tempering is usually identified by color [1]. Tempering temperatures for tools and shafts along with temper colors. Depending upon temperature, tempering process are classified in three categories like low tempering temperature (150℃ - 250℃), medium tempering temperature (350℃ - 450℃), high tempering temperature (500℃ - 650℃).


**Figure 1:** Effect of Temperature and Tempering color [1]

### *1.2.1 Quenching*

Quenching is a rapidly cooling a metal back to room temperature subsequently heat which dissolved carbon that has not sufficient time to diffuse out of the austenite lattice. The various quenching medium is air, water, oil, and brine. Such rapid cooling is likewise known as quenching. At some point in quenching, the carbon forcibly dissolved within the forming the martensite which, may be seen as a needle-formed or plate-formed shape (martensite plates).

Air quenching is similar to fluid quenching in that a cooler supply is used to bring down the temperature of a piece-piece. Air quenching makes use of both airs of inert gases which might be then compelled over the piece to cool it down. Water quenching is accomplished by way of cooling warm steel in water, in addition by means of varying the medium of quenching we performed a special quenching system. The heating temperatures, cooling prices, and quenching medium are all factors that result in the final metallic homes like hardness, brittleness, grain length.

### 1.3 Induction Hardening

Induction heating is a form of heat treatment wherein steel elements are heated via electromagnetic induction and then quenched. The induction heating is also a form of case hardening and can be used for lots of metal and steel alloys to improve floor layer homes together with fatigue resistance and hardness. Hardening is ideal for metal additives that are a challenge to sliding touch with tough or abrasive substances, as the hardened metallic is more proof against surface wear. but, due to the fact hardened metallic is normally more brittle than softer metallic, thru-hardening (that is, hardening the metal uniformly in the course of the piece) isn't constantly an appropriate choice. In such instances, case-hardening can produce an element a good way to not fracture (due to the gentle middle which could absorb stresses without cracking), but also provides adequate put on the resistance at the hardened floor.

There are numerous advantages (or blessings) of induction hardening including: rapid process, no preserving time is required subsequently extra production rate, no scaling or decarburizing, greater case intensity up to 8 mm, selective hardening, high wear and fatigue resistance. commercial examples of induction hardening are various gears, spindles, crankshafts, camshafts, cylinder liners, piston pins, joints, crawler pins, machine device manual plates, worm and computer virus gears, valve tappets, diverse equipment, and so on.

## 2. Brief Introduction of Work

There's a lot of applications of joining multiple substances whose mechanical and chemical properties are distinctive. After combining the distinctive materials, we generally get the joint material with better properties.

because the improvement of metallurgy continues, the welding of multiple substances is increasingly on the demand as engineers are locating creative ways to optimize answers in the manufacturing area. areas where in the point of interest of this take a look at are located in the car and aerospace enterprise, energy generation packages, and pressure vessels.

The welding of distinct substances poses a project to manufacturers. each steel has extraordinary thermal residences, chemical houses, and mechanical properties. The more the distinction, the greater the difficulty concerned with welding of the 2 substances, however in distinct steel welding properties of 3 metals want to be considered, the 2 metallic being joint and the filler metal used to join them.

**Table 1** Physical Properties of Copper and Carbon Steel

| Materials | Density ($gm/cm^3$) | Melting Point (K) | Thermal Conductivity (W/cm-K) | Thermal expansion coefficient (293K) |
|---|---|---|---|---|
| Copper | 8.96 | 1353 | 401 | $16.5 \times 10^{-6}$ |
| Low Carbon Steel | 7.8 | 1700 | 43 | $12.5 \times 10^{-6}$ |

The aim of this work is to first explore the practicality of welding copper and mild steel with gas welding process using brass as a filler material and then study the effect of quenching after induction heating on microstructure and mechanical properties of gas welded low carbon steel with copper joint. The case in consideration is welding of copper to carbon steel of same diameters to be used in the aeronautic industry and in EDM tool. Carbon steel welded to copper can be used as the tool in EDM with copper end in contact with the dielectric medium. This will greatly reduce the cost of the material used in manufacturing EDM tool. As can be seen in Table 1, the low carbon steel has low thermal conductivity in comparison to copper and its alloy. Copper has very high thermal and electrical conductivity, but it is fairly soft and malleable. When these alloys are used at high temperature, heat dissipation to the environment because of their low thermal conductivity. Joining of copper to mild steel can increase the heat dissipation from these alloys during high temperature application.

Joining of dissimilar metals like copper and mild steel is indeed a challenge and limits the widespread application of these materials. They find various applications in automobile industries due to their complementary properties like high thermal and electrical conductivity of Cu and good mechanical properties of mild steel [3]. There are various benefits of joining dissimilar metals as we combine different properties in a single component which are popular in various industries like power generation, chemical, electronics and nuclear industries.

The objective of project work is to analysis of response parameter of dissimilar metal welding joint hardened by induction heating. As the dissimilar material joint are useful in automotive and aerospace and at so many places where two or more dissimilar material joint are needed, the knowledge of dissimilar material joint is must for a mechanical engineer that how dissimilar material joint is going to behave on various mechanical application.

## 3. Experimental set up and procedure

The experimental procedure for the capstone project work can be listed as:

a) Selection of material
b) Specimen preparation
c) Surface treatment (Induction heating)
d) Quenching
e) Mechanical Testing
f) Microstructure study

### 3.1 Selection of material

Selecting the appropriate material is the first and main step before starting the work. As shown in Figure 2, we have selected Carbon steel and copper because very less work has been done on induction hardening of Carbon steel and copper welded joint.

Material taken up for the study of friction welding is Copper and Carbon steel in the form of rod with following specifications:

| | |
|---|---|
| Diameter of Copper rod | = 21 mm |
| Length of Copper rod | = 27 mm |
| Diameter of Carbon steel rod | = 21 mm |

Length of Carbon steel rod = 27 mm

### 3.2 Specimen preparation

We have taken 14 pieces of each material that is of copper and Carbon steel. Rod of copper and Carbon steel are 25 mm in diameter and 30 mm length. By using lathe machine, the desired dimension of the specimen i.e. 21 mm diameter and 27 mm in length has been achieved using turning and facing process (Figure 3). To prepare specimen for welding, chamfering at one end of each specimen at 45 degree having V- shape has been done in order to join the carbon steel with copper.

After preparation the copper and carbon steel as desired dimensions, as shown in Figure 4, with V joint shape then carbide flame, oxygen pressurized Gas welding using brass as a filler material to weld. Specimen placed near oxyacetylene flame, heated them and used brass as a filler material during welding (Figure 5).

**Figure 2**: Copper and carbon steel samples

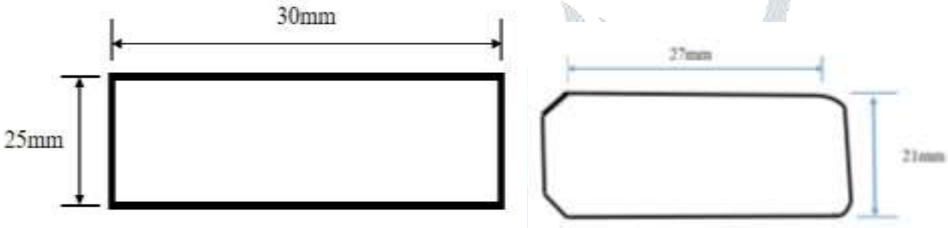


**Figure 3:** Line diagram of desired dimension of specimen for induction heating

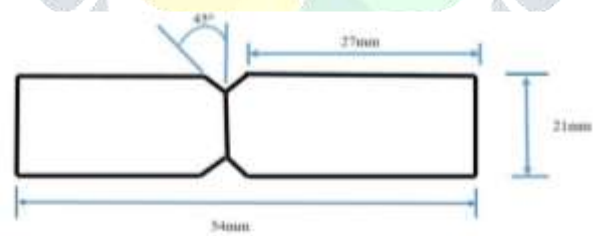

**Figure 4:** Line diagram of desired dimension of specimen for welding

**Figure 5:** Welded Specimen with brass as filler material

### 3.3 Induction heating

Copper and mild steel welded joint pieces are kept inside the coil of induction heating machine. Varied the required temperature of the joint by the setting the temperature of the induction furnace. Which allow short interaction times to reach the required temperature. To perform the surface treatment investigation of confined area, the specimens are divided into two groups i.e. for one group the heating time 15.30 sec (730°C) and for other group of specimens the heating time 18 second (850°C) has been set (Figure 6).

**Figure 6:** Induction Heating

### 3.4 Quenching

To analyze the surface hardness of welded samples for different quenching mediums we have taken three mediums water, oil (14 number mobile oil Servo company) and sand. We are having the set of 7-7 pieces of joint which is further used for quenching as 3 pieces for water quenching, 2 pieces for oil and remaining 2 pieces for sand quenching. Since we have heated the material for 15.30 second (730°C) and 18 second (850°C), so both the induction heated sample are taken and quenched with different media with different cooling time, as cooling time for water is 2 min (730°C) (Figure 7) and 3 min (850°C) (Figure 8), for oil 30 min (730°C) (Figure 9) and 35 min (850°C) (Figure 10) and for sand 3 hours (730°C) (Figure 11) and 3 and half hour (850°C) (Figure 12).

**Figure 7:** Water quenching (730°C)

**Figure 8:** Water quenching (850°C)

**Figure 9:** Oil quenching (730°C)

**Figure 10:** Oil quenching (850°C)

**Figure 11:** Sand quenching (730℃) **Figure 12:** Sand quenching (850℃)

**Figure 13:** Pieces placed inside the sand for quenching at both temperature

### 3.5 Mechanical Testing of Specimen

After quenching in different mediums, all the specimens are ready for testing so that the effect of variables on material's properties can be identified. Various tests can be done on the specimens to find its mechanical, physical and metrological properties. The following mechanical tests have been performed:

Hardness test
Tensile Test
Microscopic test

#### *3.5.1 Hardness Test*

The Rockwell hardness testing, as shown in Figure 14, is generally easier to perform, and more accurate than other types of hardness testing methods. The Rockwell test method is used on all metals. Rockwell hardness test is applied on the specimens. First, the specimens are properly machined. Then, it is placed on the cup of machine. The 150 kgf load is applied is applied on the specimen. Then, load is released after 10 to 15 second. The needle reflects and gets stable at a point. The reading on the scale is read on c-scale.

**Figure 14:** Rockwell hardness testing

#### *3.5.2 Tensile strength testing*

The quenched specimens were treated in UTS Machine for obtaining the Ultimate Tensile Strength and yield Strength.

#### *3.5.3 Microstructure analysis*

At some point of microstructure evaluation of metals, a microscopic examination is directed to investigate the microstructure of the material under magnification. the characteristics of a material decide the perform for a particular application, and those properties are dependent on the shape of the material.

First, the specimens are prepared for which the specimens are rubbed on the emery paper of grades 220, 500, 1000, 1500, 2000 and 2500 until we get glass type finish. Then etchant (98% Methanol and 2% Nitric acid) is applied on the finished surface of the specimen and the specimen is kept idle for one minute and then it is placed on an inverted optical microscope as shown in Figure 15. Then, the respective pictures of the specimens are taken.

**Figure 15:** Inverted Metallurgical Microscope

## 4. Result and Discussion

During the Rockwell hardness testing on Rockwell hardness machine we have got certain set of values of hardness on C-scale on the lateral surface area of the copper and mild steel metal joint as well as on the circular edge and at the core of cross section cut pieces from welded joint. Values of hardness on the lateral surface of mild steel, copper and filler specimen at various joint locations are shown in Table 2. We use Rockwell hardness machine with ball indenters for copper and take reading in HRB-Scale. Load applied on ball indenter is 100kgf. We use Rockwell hardness machine with ball indenters for copper and take reading in HRB- Scale. Load applied on ball indenter is 100 kgf.

**Table 2**: Hardness of Specimen at temperature - 730℃

| Quenching Medium | Mild steel (HRC-Scale) | Copper (HRB–Scale) | Filler Material (HRC – Scale) |
|---|---|---|---|
| Water | 69 | 34 | 36 |
| | 72 | 38 | 22 |
| | 74 | 42 | 53 |
| Oil | 47 | 30 | 23 |
| | 66 | 37 | 23 |
| | 62 | 34 | 28 |
| Sand | 67 | 24 | 19 |
| | 56 | 32 | 16 |
| | 50 | 32 | 23 |

**Table 3**: Hardness of Specimen at Temperature - 850℃

| Quenching Medium | Mild steel (HRC- Scale) | Copper (HRB- Scale) | Filler Material (HRC- Scale) |
|---|---|---|---|
| Water | 86 | 61 | 38 |
| | 84 | 51 | 48 |
| | 91 | 42 | 29 |
| Oil | 73 | 30 | 26 |
| | 86 | 36 | 20 |
| | 68 | 25 | 23 |
| Sand | 50 | 27 | 11 |
| | 68 | 25 | 14 |
| | 74 | 29 | 20 |

**Table 4:** Hardness on edge and core (after cutting from joint) at Temperature- 730℃

| Base Material | Quenching Medium | Hardness (HRC – Scale) | |
|---|---|---|---|
| | | Circular edge | Core |
| Copper | Water | 34 | 30 |
| | Oil | 29 | 28 |
| | Sand | 25 | 22 |

**Table 5:** Hardness on edge and core (after cutting from joint) at Temperature - 850℃

| Base Material | Quenching Medium | Hardness (HRC- Scale) | |
|---|---|---|---|
| | | Circular edge | Core |
| Copper | Water | 30 | 22 |
| | Oil | 25 | 18 |
| | Sand | 26 | 12 |

## 6. Conclusion

It has been observed that cooling rate contributed to a higher strength due to local strain effect. Rapid cooling in quenched specimen had successfully increase the hardness by 57% for copper and for low carbon steel recorded the highest tensile strength of 548 MPa while slow cooling rate which experienced by an annealed specimen resulted in the lowest tensile strength of 251 MPa (Figure 16 - 19). Microstructure investigation shows annealed specimen produced coarse austenitic structure with larger grain size. Meanwhile, quenched specimen produced finer austenitic structure with smaller grain size.

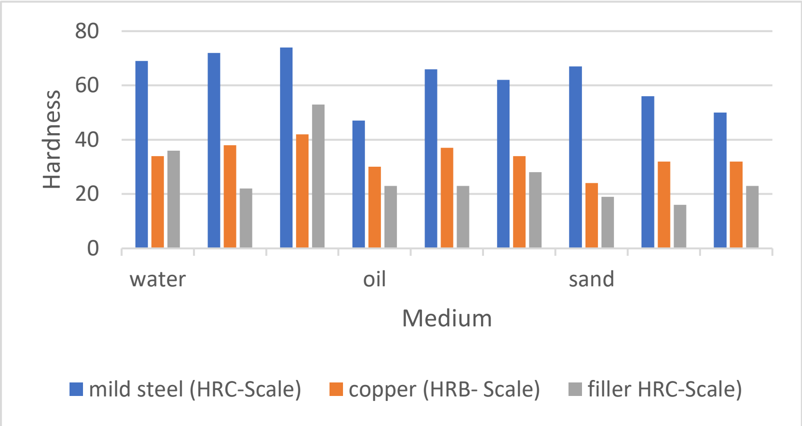


**Figure 16:** Variation in hardness versus various quenching media at temperature 730°C

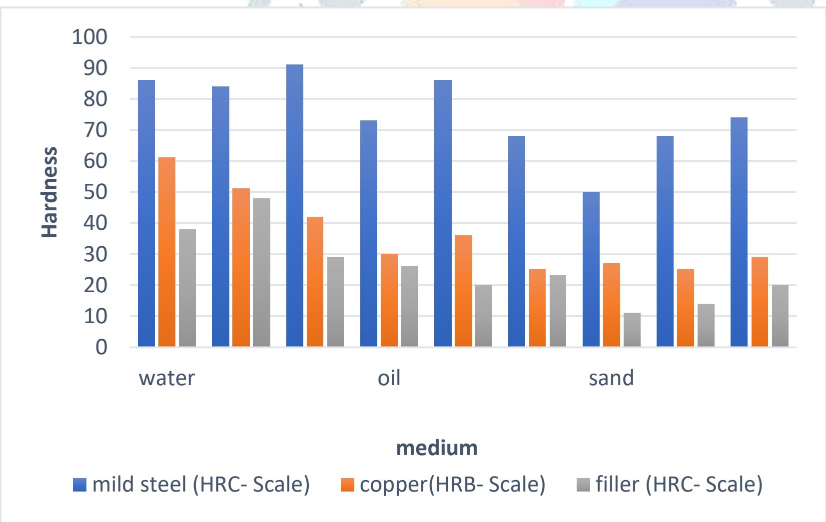


**Figure 17:** Variation in hardness versus various quenching media at temperature 850°C

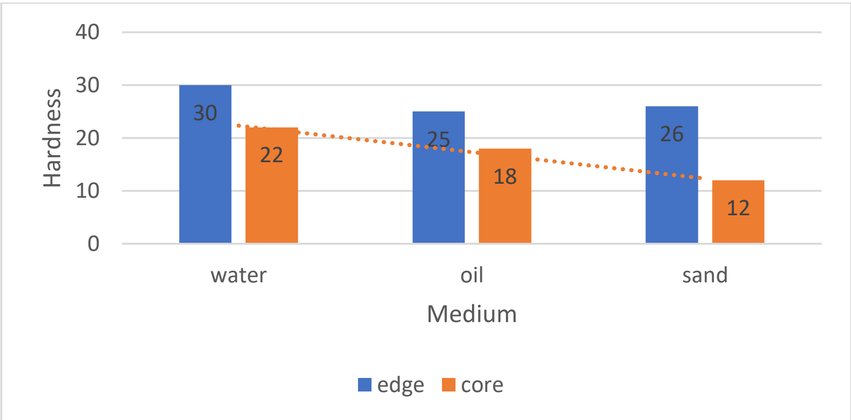

**Figure 18:** Variation in hardness on edge and core for different quenched media samples at temperature 850°C

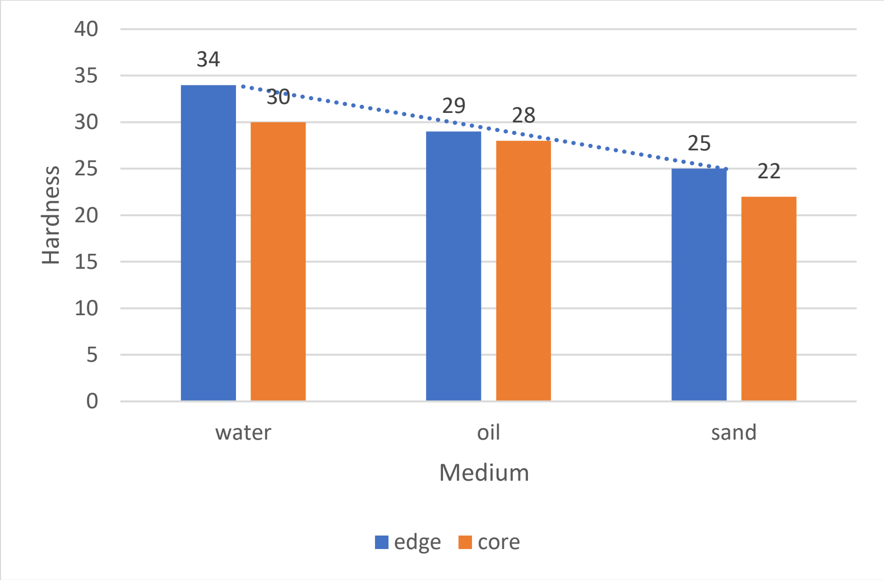


**Figure 19:** Variation in hardness on edge and core for different quenched media samples at temperature 730°C

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