KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

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Wear behaviour of coatings formed by submerged arc welding

Master's Degree Final Project

Supervisor
Assoc.prof. Dr. Regita Bendikiene

KAUNAS, 2016

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Mechanical Engineering and Design (621H30001)

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Wear behaviour of coatings formed by submerged arc welding

DECLARATION OF ACADEMIC INTEGRITY

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Kaunas

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING - 621H30001

Approved by the Dean's Order No.V25-11-7 of May 3rd , 2016 y

Assigned to the student **Raghupathi Veeraperumal**

1. Title of the Project

Wear behaviour of coatings formed by submerged arc welding

2. Aim of the project

The main aim of this research is to investigate the surface layer achieved using submerged arc welding technique overlay coating and to compare the results obtained.

3. Tasks of the project

The tasks of the project are:
- Specimens are prepared using waste materials by submerged arc welding technique
- Hardness of the specimen surfaced layer are calculated
- To research and study the microstructures of welded surface layer
- To test the wear of the surface layer

4. Specific Requirements

Conducting the final experimental project thesis according to KTU regulations and requirements.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2016 May 20th.

Task Assignment received _______________ (*Name, Surname of the Student*) _______________ (*Signature, date*)

Supervisor _______________ (*Position, Name, Surname*) _______________ (*Signature, date*)

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Studijų kryptis ir sritis: Mechanikos inžinerija, Technologijos mokslai.

Reikšminiai žodžiai: *suvirinimas po fliuso sluoksniu, silicio oksidas, silicio karbidas, grūdinimas, atelidimas, mikrostriktūra, dilimas.*

Kaunas, 2016. 47 p.

SANTRAUKA

Suvirinimas po fliuso sluoksniu buvo naudojamas šiame darbe siekiant sukurti kietas dangas naudojant volframo karbido ir grafito miltelius apvirinant anglinio plieno ruošinius; buvo tiriamas bandinių kietumas, dilumas ir mikrostruktūros pokyčiai. Buvo paruoštas ir naudojamas silicio karbido (SiC) ir silicio oksido (SiO) fliuso mišinys. Apvirinus, buvo matuojamas bandinių kietumas, paruošti ruošiniai atleidimui, mikrostruktūrinei analizei ir dilumo bandymui. Bandiniai buvo atleisti skirtingose temperatūrose ir išmatuotas jų kietumas po kiekvienos operacijos. Atleidimas atliktas siekianr sumažinti įtempius atsiradusius po suvirinimo. Bandiniai mikrsotruktūrinei analizei buvo poliruojami ir ėsdinami; mikrostruktūrinė analizė atlikta optiniu mikroskopu. Bandinių dilumas įvertintas masės pokyčiu, lyginant rezultatus su ankstesniais kitų autorių darbais. Gautos dangos pasižymi pakankamai dideliu atsparumu dilimui.

Veeraperumal, Raghupathi. Wear behaviour of coatings formed by submerged arc welding

Master's Final Project / supervisor Assoc. Prof. Dr. Regita Bendikiene; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study area and field: Mechanical Engineering, Technological Sciences

Keywords: *Submerged Arc Welding, cutting tools, Silicon-oxide, Silicon-carbide, Hardening, Tempering, Microstructure, and Wear.*

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SUMMARY

In this research work, the submerged arc welding technique is used to deposit the hard material of tungsten carbide and graphite on the base metal of plain carbon steel and examine the obtained hardness, resistance to surface abrasion, microstructural changes. The flux mixture for the submerged arc welding was prepared from silicon carbide (SiC) and silicon oxide (SiO). Once the weld is done their hardness is calculated using hardness machine and then it is split into three pieces and used for tempering, microstructural analysis and wear test. The specimens are tempered at various temperature and the hardness obtained are noted down. To increase its toughness, tempering process is handled. The microstructure specimens are prepared by flat, mirror polishing and lastly etching the surface. The etched surface of the specimen are observed under microscope with different magnification. Finally, wear test is conducted and the material loss is examined by comparing the results with previous research works. By observing all the work done and the results obtained the life of cutting tool can be drawn out, by minimizing its wear rate during machining processes.

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INTRODUCTION

Industrial machinery parts after a certain period of execution are subjected to severe wear condition. Using machinery parts or tools for quite a while in machining makes them wear and lose their strength and sharpness, but at that time rather than completely changing the part there is a chance to hardface the surface by coating with high alloyed powder mixture using submerged arc welding process. So, these process are very helpful in improving the strength of cutting tools in machining processes.

Machining processes, in general, particularly wood machining processes, are complex to explain and describe with many influencing factors. It is important to use high quality of tools during natural machining because of the properties of natural wood. Many research experiments have been conducted to coat the surface of wood machining tools using submerged arc welding process.

In this research the sample mixtures are prepared using various material powders and these powders are collected from waste. The primary aim of this research is to investigate the surface layer achieved using submerged arc welding technique overlay coating and to analyze the results obtained.

The objectives of this research are

- To accomplish a good weld of the samples prepared using waste powder materials by submerged arc weld overlay technique.
- To test the hardness of the samples prepared at various tempering temperatures and to examine the results.
- To research and study the surface microstructures of welded layer.
- To test the wear loss in surface layer.
- To compare wear results of coatings with tools with graphite additions in the flux for surfacing.

Despite the fact that the materials that are selected for this thesis are collected from waste, and the chosen materials have an advantage of good physical properties and they are of lower in cost so can be used as much as needed. The characteristics of the welded surface layer can be examined using the samples testing under different circumstances.

1. LITERATURE OVERVIEW

Wear is a progressive loss of material from the surface of the machine components and tools because of mechanical action with another solid body with or without rough particles or other medium. Such a protection against surface damages from wear is achieved through modifications of chemical composition and microstructure in the surfaces of machine parts and tools. Change of chemical composition can be accomplished by strategies using complex advancements of alloying or using welding forms for acquiring of wear resistant overlays on a substrate, such a hard surface can be achieved using overlay weld technique of high alloyed powders over the base metal substrate [1].

Generally, overlay welding methods are utilized in order to achieve higher wear resistance and hardness. The target of overlay welding is mostly to form wear resistant layer. Several welding techniques such as gas metal arc welding (GMAW), shielded metal arc welding (SMAW) and submerged arc welding (SAW) can be used for overlay welding.

Submerged arc weld overlay is one of the best procedures used to weld for the manufacturing of overlays because of its productivity and high deposition rate using continuous or powder wire, under flux or protective gas [2]. The wear properties of overlay welding depend on a couple of variables, for example, hardness, thickness of surfacing layers, the micro hardness and strength of lattice structure, working conditions and welding process [3].

The selection of the type of welding procedure depends on factors like the size of the clad area, welding position, alloy types, clad thickness and chemical composition limit.

The most of the common types in which overlay welding method can be implemented are below.

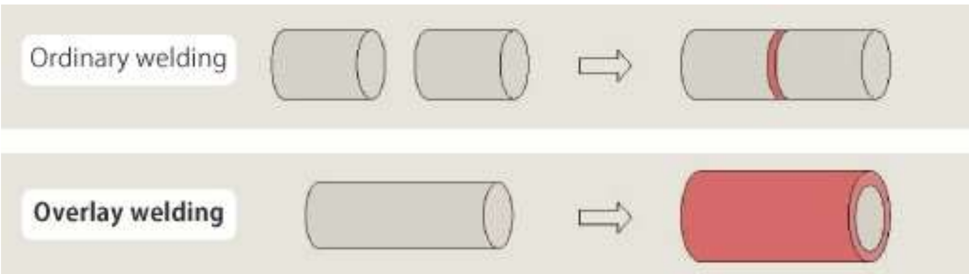

Fig. 1.1. Overlay welding [4]

1.1 Submerged-arc welding

Submerged arc welding is a top notch welding process with very high deposition rate and it can operate as fully automatic or semi-automatic. SAW includes developing an arc segment between an electrode and the workpiece. A cover powder flow, creating a shield gas defensive and a slag, ensures the weld area. No shielding gas is required. The arc segment is submerged below flux flow and is typically not noticeable during welding [5].

Submerged arc welding overlay coating is one of the normal procedure used for welding using constant wire or powder under a gas flow or defensive. Hard Coatings face can be delivered using submerged arc welding. [6] The type of powder in the mixture, as information powder welding and variables will influence the microstructure and type of framed combinations.

The arc heat melts the surface of the base metal and the electrode end. The molten metal out of the electrode is exchanged through the arc to the work piece, where it becomes the weld metal. The flow is melted and mixed with molten weld metal.

The flux acts as a slag as glass which is lighter in weight than the weld metal and floats on the surface as a defensive cover. The weld below this layer of flux and slag, hereinafter called submerged arc welding. Slag and flux regularly cover so that the arc is not visible. Drawing back through the suction channel cannot reuse the melt flow.

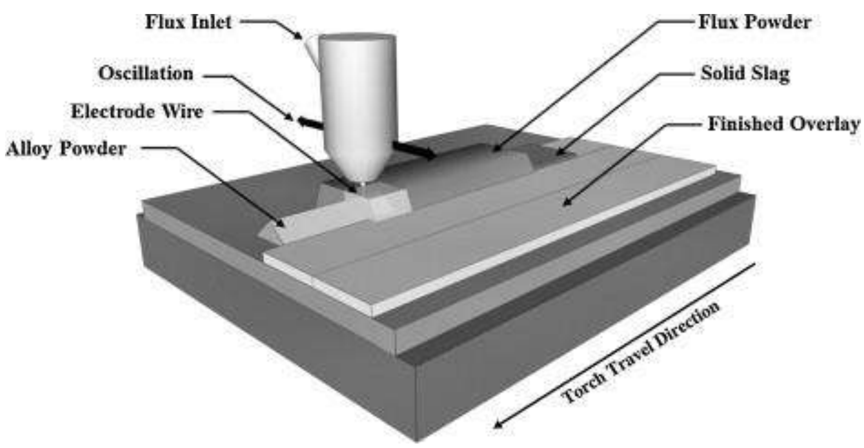

Fig. 1.2. Schematic diagram of automatically processed submerged arc welding [7]

1.2 Pros and cons in submerged arc welding

The major advantages are:

1) The weld quality is very high compared to other types [8] [9].

2) The electrode wire is significantly high use.

3) Productivity, speed and deposition rate is extremely high. The amount of smoke produced during the process will be low.

4) Different types of alloys are mixed with coated and welded to the metal surface in order to improve to increase the strength of metal cutting tools or flux.

5) Submerged arc welding is profitable and does not require any handling skill to use it.

6) Has Weld metal deposit uniformity, good ductility, corrosion resistance and good impact resistance.

The major disadvantages are:

1) It is limited only capable of welding materials such as steel, stainless steel and nickel.
2) High heat input and cooling cycle is slow one of the drawbacks of the processes.
3) It is able to weld only long, linear or rotated materials.
4) It is possible that the flux residue may be left behind that is harmful to the job.

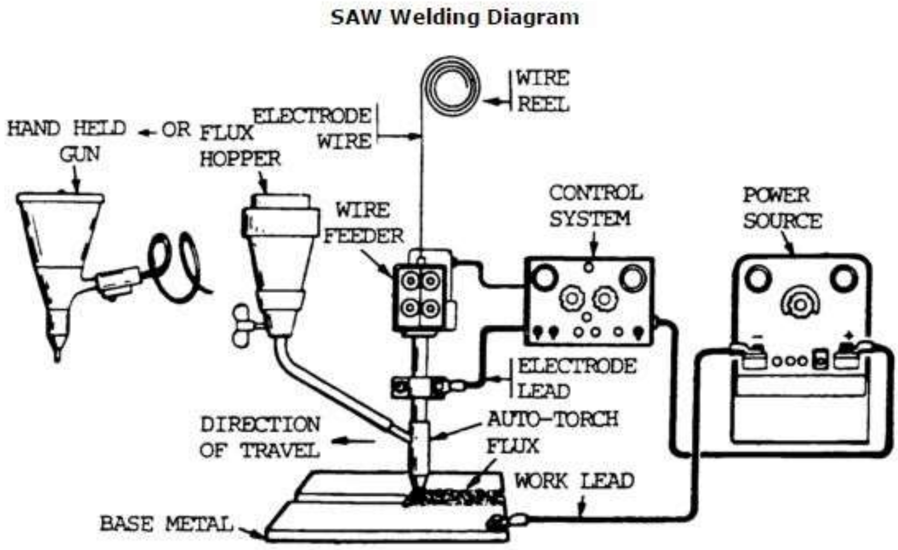

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Fig. 1.3. Diagram of submerged arc welding process [10]

Cladding is defined as the deposition of different materials on the substrate surface to obtain the desired properties, which the metal base that has no initially, using a source of special heat, such as arc, flame, induction heat and high energy beams.

Submerged arc welding coating has been used in modern industries, particularly for heavy section steel to a structure and the surfaces that need to be altered [11]. Due to the properties of the microstructure and mechanical welding weld zone will be different from the other unaffected areas. There are three areas to be classified during and after the welding process. They are:

a. Base metal

b. heat affected zone

c. Weld metal.

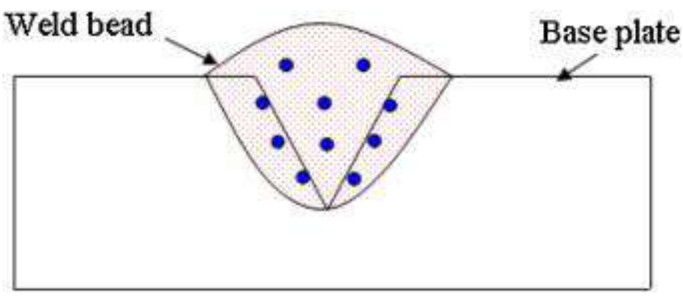

Fig. 1.4. Schematic diagram of welded plate [12]

The base metal is the part that cannot be adjustments in its structure and properties for unaltered piece of weld joint is maintained. In the heat affected, which is part of the base metal in their microstructures and properties they have changed due to the heat delivered by the welding, also when cooled after the process area.

The weld metal is the mixture of material, which melts and forms a layer on the base metal and its chemical composition will be transformed according to the base metal. When the surface layer is formed which makes the total change in the product having the ability to alter the hardness and wear dramatically [13].

In contrast to other welding processes coating submerged arc coating is capable of delivering very high deposition rate and ability of high surface layers with less sophisticated equipment.

The use of coating techniques, it is possible to improve the surface properties such as wear, corrosion and oxidation resistance, and to take advantage of a longer service life and total cost reduction.

A mixture of alloy (Fe, Mn, Cr, Mo, V), which is often used as a coating material to improve the properties of wear and corrosion resistance [14].

In submerged arc welding, coating technology is primarily used in many variations and are used to significantly improve weld quality in several ways, such as

a. Improved corrosion resistance

b. Improved productivity and efficiency

c. Improve wear property

Submerged arc strip cladding has been broadly-used for many years for coating large surfaces and is a flexible and economical way of depositing a layer resistant, corrosion protection in low alloy steel [15]. Experimental studies have found and investigated the use of metal that will increase the efficiency of deposition rate and powder arc welding, while reducing the consumption flow shielding.

Submerged arc welding coating with metal powder is an additive process that is capable of producing corrosion and wear resistance welding surfaces. This metal powder addition possibly used to weld alloy with optional chemical elements. These methods are variants submerged arc welding that can be used to significantly increase productivity and efficiency. Is possible to weld submerged arc and plating electrode multithreading and adding metal powder and which is capable of increasing the increased deposition rate, productivity and efficiency of arc Whereas consumption shielding flow reduced [16].

Coating can be used to improve the technique of increasing surface property: for example, wear and oxidation resistance. During the heat of the welding process because there are high chances of damage to structures affected if the heat zones. This can make a significant change in hardness and wear resistance property also begin to decline [17].

The relationship between the limits welding, coating microstructure and wear performance has an important role is achieving the highest quality of the surface layer. Surface wear is very influential and good as is needed for the mechanical parts of the machine to have a long life. Most parts of the machine are failed due to wear surface and for reducing it coatings of carbides, oxides and other harder materials are coated. Wear is dependent on the quality of the alloyed materials basically, the hardness and also the carbon content. The hardness of the surface layer has great potential to have a high wear resistance [18].

1.3 WEAR IN TOOLS

Cutting tools are normally used to perform a wide variety of cutting procedures such that there exist to be various sorts of them relying on engineering applications. Present day manufacturers require cutting tools having high quality, long life, low cost with less environmental dangers. It is understood that accomplishing these requirements simultaneously is very difficult. Every moving parts which occur in day to day activities are subjected to wear even the normal tools and industrial parts. Using tools for a long time in machining makes them wear and lose their strength and sharpness. Cutting tools must be harder than the materials, so it should have higher hardness, toughness and resistance to wear.

These type of wear problems can be eliminated by hard facing the surface of the tool using submerged arc welding technique. Many research papers have been totally focussed on using the submerged arc welding technique to manufacture cutting tools with hardened surface. Hardness and wear test results obtained from these research paper are compared with our thesis work.

In the previous research work, steel turning tools are surfaced using submerged arc welding technique in order to improve its wear resistance. For this WC-8 %Co powder on the surface of the base metal and inserting different amount of graphite into the flux are spread over plain carbon steel to prepare turning tool using submerged arc welding (SAW) technique. WC-8%Co powder was spread on the surface of each coating [19].

Plain carbon steel with dimensions of 135 × 15 × 15 mm are chosen with composition of (C 0.15-0.25 %; Si 0.12-0.3 %; Mn 0.4-0.75 %; S≤0.05 %; P≤0.05 %).

Once the samples are welded they are subjected to hardness measurement test. After the hardness of the samples are measured they are subjected to tempering treatment at 570 °C for one hour, it is a secondary heat surface treatment which will reduce the internal stresses and increase the toughness.

Table 1.1. Composition of materials mixture for surfacing [19]

S.No	Flux, wt. %		Hardness, HRC after	
	Graphite	AMS1	Surfacing	Tempering at 570 °C
1	-	100	47	63
2	5	95	53	63
3	9	66.7	56	63
4	13	87	60	62
4 mm WC-8%Co powder was spread on the surface of each coating				

Surfaced layer coatings are of higher hardness which makes it more difficult. Experimental turning tools were subjected for high temperature tempering at 570 °C on the purpose to minimise internal stresses and to reach maximum values of secondary hardness.

Table.1.2. Area of wear crates of experimental turning tools No.1 –No.4, and No.5 wear performance of commercial turning tool [19]

Specimen	No.1	No.2	No.3	No.4	No.5
Maximum	0.48	0.44	0.42	0.4	0.46
Minimum	0.44	0.42	0.39	0.37	0.44
Average	0.46	0.43	0.4	0.38	0.45

Wear crates results of these four specimens are obtained and compared with the commercial turning tool which is made of HSS tool steel. Surfaced experimental turning tools showed better wear resistance performance than standard tool. Wear crater area of experimental tool measured after wear test was 0.38 mm^2, while standard tool wear exceeded 0.45 mm^2. Presented results showed that the wear results obtained from experimental turning tool have ~ 15% higher wear resistance than the standard turning tool.

1.4. FLUX

In metallurgy, the word is derived from the Latin word meaning *fluxus* which means flow. Flux is a chemical cleaning agent that has more functions at once. It is mainly used in joining metals that is in the welding process.

Ensures welding bath and the solid metal air pollution and helps clean impurities from molten bath. After cool impurities floating on the surface of the pool and are easily removed. This contributes to the formation of a strong and durable welded joint [20].

Some of the specific advantages of flow include:

1) The metal surfaces are clean.

2) It joins filler metals to the base metal.

3) A defensive barrier against ignition is given.

4) It assists with heat exchange the heat source to the metal surface and can help in cleaning the surface of metal waste.

5) Similarly helps in the deposition of metal from the electrode.

1.5. WEAR IN THE SYSTEM

Wear is a deformation or removal of material from its surface when related to interactions as a result of the mechanical action of the opposite surface.

It is a common phenomenon that we face in everyday life. Every day the parts of each moving are subject to wear. It must be resistant to abrasion to increase the use of mechanical parts. The harder the metal less wear on the system.

Common types of wear in the systems are:

- Abrasive wear
- Adhesive wear
- Corrosive wear
- Surface fatigue
- Erosive wear

Wear can be controlled to various surface medications that build surface hardness. General surface coating improve wear resistance. Different surface coatings have a more prominent effect in the surface of the structure.

A portion of the wear tests evaluate periodically addresses the resistance of the materials used are grid using abrasive surfaces settled with the example of granulation or shredding papers or freewheels are rough that supported between the contact the sample and the counter face. Wear can be controlled by providing different surface treatments of materials that increase the surface hardness. Improve general surface coating to increase wear resistance. Multiple surface treatments have a greater impact in providing the desired surface in the system.

Some of the common wear conducted to evaluate the resistance of materials are using fixed abrasive i.e. grinding papers or loose abrasive are fed in which the contact between the sample and the counter face.

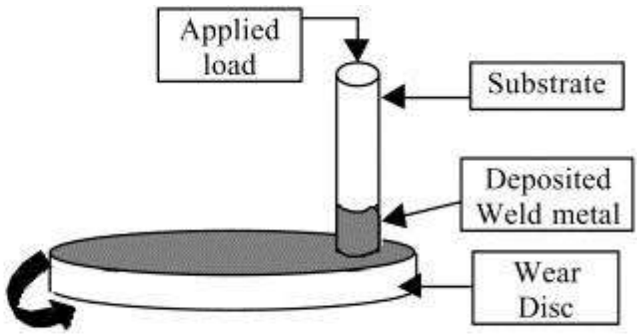

Fig. 1.5. Schematic diagram of pin on disk wear test [21]

Pin on disk wear test technique is another usually utilized strategy for computing the wear of the specimens. For this wear test, test are cut with a width of 6 mm and length of 40 mm.

Welded surfaces of the specimens were turned on a machine and the machined surfaces were cleaned acetone and alcohol. This device is furnished with a variable pace engine and the speed can be changed at whatever point inside the tests. Fig 1.5

Hard facing is the sort of surface treatment that is utilized to extend the surface property of base metal in which the materials to be welded at first glance must have brilliant wear resistance, strength and higher hardness. Normally these surface covering is used to improve the life and to ensure the metal base from high wear environment.

In microstructure examination the changes in the surface layer has been observed that can't be seen through naked eye. The mechanical and wear properties will be changed after addition of quick solidification of alloying.

2. METHODOLOGY

In this work, the powders of waste are collected for sample mixture preparation and combined in certain proportions. The material mixture to be mixed together should have high wear resistance, high hardness, high melting point and high corrosion resistance which are good in their properties for welding. Table 2.1 shows the powders and its properties for preparation of sample. These properties are the most important reason for selecting these material powders.

Table 2.1. Properties of material powders

Powder name	**Important Properties**
Silicon Carbide (SiC)	High temperature strength High hardness and wear resistance Low density Low oxidation resistance
Graphite	High melting point Low density than diamond Insoluble in water and organic solvents
Hard Materials i.e. [Tungsten Carbide (WC)]	High hardness and wear resistance High strength and rigidity High corrosion resistance
Silicon Oxide (SiO)	High melting point High chemical resistivity Low density Used as a shielding radiation in the welding

2.1. PREPARATION OF POWDER MIXTURE

The flux mixture for the submerged arc welding was prepared from silicon carbide (SiC) and silicon oxide (SiO).

Fig. 2.1. Grounded Silicon Carbide (SiC)

Table 2.2. Composition of powder mixture

Sample number	Mixture	Flux
01	100% HM	100%SiC
02	90%- HM, 10%- Graphite	100%SiC
03	80% HM, 20% Graphite	100%SiC
04	70% HM, 30% Graphite	100%SiC
05	60% HM, 40% Graphite	100%SiC
06	50% HM, 50% Graphite	100%SiC
11	100% HM	50%SiC+50%SiO
12	90%- HM, 10%- Graphite	50%SiC+50%SiO
13	80% HM, 20% Graphite	50%SiC+50%SiO
14	70% HM, 30% Graphite	50%SiC+50%SiO
15	60% HM, 40% Graphite	50%SiC+50%SiO
16	50% HM, 50% Graphite	50%SiC+50%SiO
21	100% HM	No Flux

Fig. 2.2. Grounded Silicon Oxide (SiO)

Fig. 2.3. Equal Mixture of Grounded Silicon Carbide (SiC) & Silicon Oxide (SiO)

The silicon carbide sample was prepared from the source of grinding wheel which has been crushed using hammer to a coarse powder. These powders are passed through the sieve to get the required size to be used in welding. The source for the silicon oxide is from the recycled ground glass which is rich in silicon oxide are crushed into powders using hammer and filtered through the sieve for the required size.

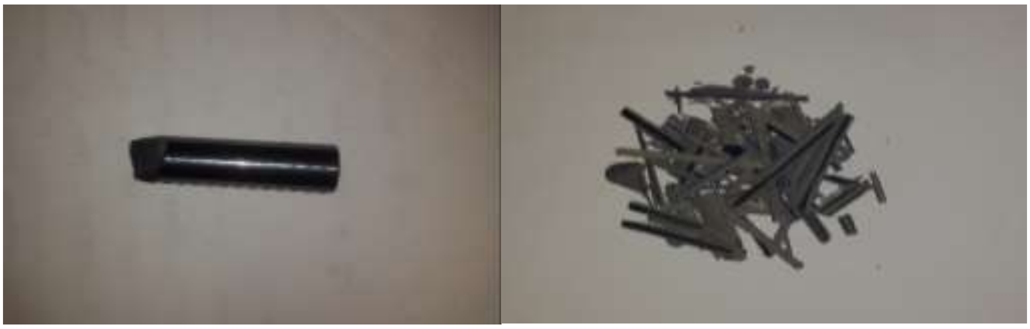

Fig. 2.4. Hard Material before and after annealing treatment

For the hard material source, we have used the tungsten carbide (WC). In this, the hard material is annealed for 5 hours in furnace. It is a heat treatment process that changes the properties of a material to increase its ductility and reduce its hardness.

After the annealed process, the material becomes soft and it’s crushed with the hammer to a coarse powder. These powders are passed through the sieve to get the required size to be used in welding.

2.2 WELDING PROCESS

Submerged arc welding is a high quality welding process with very high deposition rate. A single 1.2mm diameter electrode of low carbon wire was used in the submerged arc welding. Parameters for the welding process are welding current 180-200 A, voltage 22-24 V, travel speed – 14.4 m/h, and the wire feed rate – 25.2 m/h.

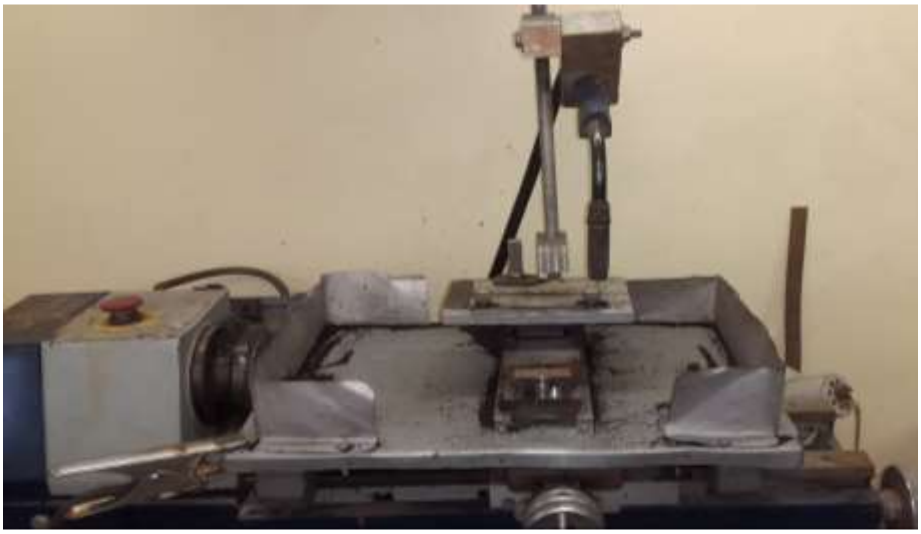

Fig. 2.5. Submerged arc welding

The submerged arc welding equipment which is used in this research is shown in figure 2.5. This equipment is used to weld the material powders over the surface of plain carbon steel. It consists of welding torch for automatic welding, an electrode wire feed, power source, flux hopper, stop button and work piece holder in this research work flux feed is manually done.

The base metal used in this research is 100mm in length and 15mm in breadth dimensions. The plain carbon steel is used as a base metal which is having a composition of carbon (0.12-1.12%), silicon (0.10-0.5%), Sulphur (>0.05%), manganese (0.4-0.75%), phosphorous (>0.05%). By using submerged arc welding process this base metal is surface layered with the sample mixture prepared.

In submerged arc welding, the different samples are prepared with addition of powder mixtures and flux for a depth of 3mm over the plain carbon steel with proportions in table 2.2 and when electric current is passed between the workpiece and weld wire, an arc is formed in this process.

Fig. 2.6. Plain carbon steel used as a base metal

The powder mixtures that has to be welded over the base metal is fed manually and the arc from the weld wire welds the powder mixtures on the base metal. Over this process, the welded area is secured by a flux layer which shields it from atmospheric contamination. All through the procedure the flux is incompletely dissolved shaping a fluid defensive layer called slag layer which gets hardened during the procedure creating a material of waste called slag.

At the point when the sample achieves the atmospheric temperature the slag layer gets removed, which makes the specimens prepared to be utilized for the further research. The surface layer of the sample is then grinded to get a smooth level surface which is much vital for hardness test to be taken after.

2.3 HEAT TREATMENT (TEMPERING) FOR THE SPECIMENS

Hardness in material is considered as the resistance to plastic deformation. Hardening involves the heating to such a temperature to produce a structure of austenitic, which has been kept at that temperature and quench in water or oil.

In hardening heat treatment process, the hardness of the materials gets increased however decreases their toughness. They turn out to be extremely brittle which are not suitable for use.

Consequently in order to avoid this, a process called tempering is introduced which is nothing but the secondary heat treatment. In this treatment, it increases the toughness on iron based alloys and eliminates excess hardness.

The main objective of heat treatment are

- To increase strength, hardness and wear resistance
- To increase toughness
- To increase ductility and softness
- To improve machinability
- To improve cutting properties of tool steels

Fig. 2.7. Electric Furnace

The microstructure of the retained austenite on hardened steel is unstable and varies in its dimensions. While tempering, these retained austenite changes over into non-balance yet more stable bainite, troostite, or sorbate.

Here in this work, the samples are initially cleaned and after that treated for tempering process. The temperature of the furnace is increased to require temperature by switching on and the samples are kept inside the furnace for one hour at maximum temperature of 3000°C and after the treatment it is allowed to cool in air. The various tempering temperatures are 500°C, 550°C, and 600°C and the hardness test and microstructural analysis test is conducted after this heat treatment process.

2.4 HARDNESS TEST

Once the samples are welded they are subjected to hardness measurement test. Hardness is defined as " resistance to plastic deformation of metals ' and can usually also explained that the scratch resistance, abrasion or cutting. The high resistance for deformation is seen in the material which has the high surface hardness and vice versa for low harden surface. Some of the most frequently used hardness test to measure the hardness of the material are

1. Rockwell hardness test
2. Brinell hardness test
3. Vickers hardness test

In this research work, Rockwell hardness test which is a common and widely used testing method to measure surface hardness. Rockwell hardness test method is a process of indenting the surface with diamond indenter or ball indenter depending upon the material to be tested. The indenter is forced into the material under primary load (minor load) of 10 Kgf. The units shown in the gauge represents the hardness of the material. The hardness numbers generally obtained have no unit. Here for hard surface materials C scale is used and generally it is combined with letter HR as HRC (Hardness Rockwell C scale). The scale C will be used for the following materials steel, cast iron and hardened steel.

Rockwell hardness test method

-Total test forces range from 15kgf to 150 kgf

Fig. 2.8. Rockwell Hardness Tester

The prepared samples are subjected to initial hardness testing and their hardness numbers are noted down and after tempering at various temperature the final hardness numbers are noted and best of the samples are picked for further process.

2.5 MICROSTRUCTURE ANALYSIS

The microstructure of all specimens are studied using metallographic test. There are some precautionary measures before observing the specimen surface that includes grinding and polishing process. In order to examine the microstructures clearly, the surface of the specimen are mirror finished properly. When all specimens are solidified with various tempering treatments then the investigation of the microstructure begins.

Fig. 2.9. Resin and Hardener Container

Fig. 2.10. Prepared Specimen for Microstructure Analysis

In the first place these specimens are put in a small round container. At that point the specimen is set to confront in the container, which is utilized for the investigation of the microstructure. One side of the holder was shut with tape so that the epoxy blend won't come up short on the container. At that point, the epoxy resin of 10 section and 1-section hardener is blended and filled the container of Fig - 2.9. At that point permitted it overnight to set. Next, all these examples are expelled from the compartment. These specimens are mirror completed for better precise microstructure. Distinctive phases of cleaning will be done which are as per the following in Table 2.3.

Table 2.3. Stages of polishing of microstructure specimen

STAGE	GRIT SIZE	SPEED (rpm)	TIME IN MIN
1^{st}	220	300	5 min
2^{nd}	1500	300	5 min
3^{rd}	2500	300	5 min
4^{th}	Polishing wheel	300	5 min
5^{th}	Polishing wheel	450	10 min

The specimens were initially set in a stand and hold immovably. At that point grating paper is settled on the wheel by means of adhesive spray and the backing is put on the abrasive wheel. The entire framework is set in the polishing machine LamPlan Fig. 2.11 and the machine is allowed to run for required time. Every time various abrasive paper is changed once it completes running for set time. At last, the polishing is done in buffing wheel changing from abrasive wheel. It is polished using diamond polishing agent for required time until a mirror polish complete on the face to be examined.

Fig. 2.11. Polishing Machine

Fig. 2.12. Buffing wheel and Diamond polishing

When polishing is done, these examples are set under a magnifying lens, before setting the specimen face are etched with alcohol in Fig. 2.10. After these are set under the magnifying lens Fig. 2.13. As etching procedure will uncover the microstructure, where we can see the distinctive hidden designs. The specimens are analyzed under various magnifications of 20X, 50X.

Microstructure of before and after tempering of specimens are noted and their difference in structure after tempering are studied and the results obtained can be either helpful or destructive.

Fig. 2.13. Microscope for Microstructural Analysis

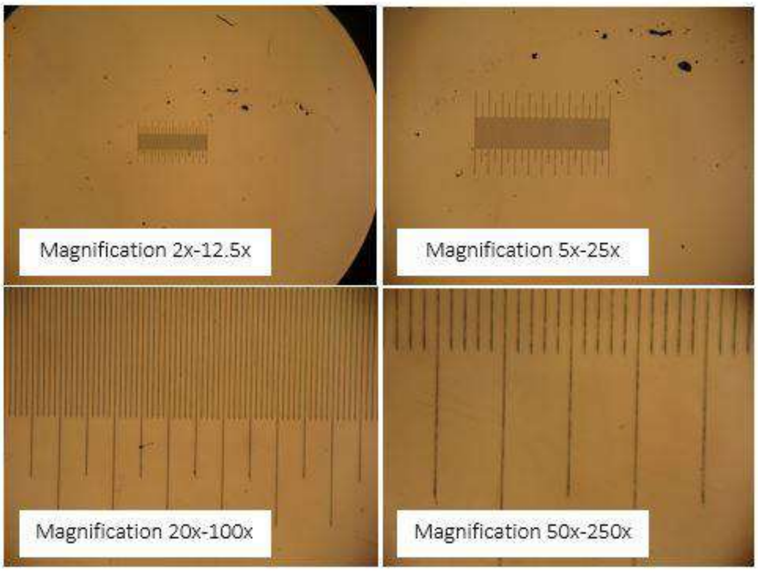

Fig. 2.14. Magnification range of microscope

Presently the microstructure assessed is taken by the camera connected to the magnifying lens. Here the diverse magnification is used. The magnification range of microscope is shown in Fig. 2.14.

2.6 WEAR RESISTANCE TEST

In this research work, the samples are performed to wear measurement test and the total amount of layer which was welded got evacuated or worn away are calculated and it is repeated after every test and the sample weights are checked and noted. The sample weights are measured utilizing the regular analytical balance machine with high exactness and zero error. Figure 2.15 demonstrates the machine which is utilized to test the wear resistance of samples.

For the specimens to be hold in the machine they are cut into 6mm pieces, so that they can fit inside firmly. The rotating metal rod which is 41mm diameter keeps running at certain rpm alongside the force given by the adjusting weight can build up a load of 320 N by which the force follows up on the samples.

Fig. 2.15. Wear Test Analysis

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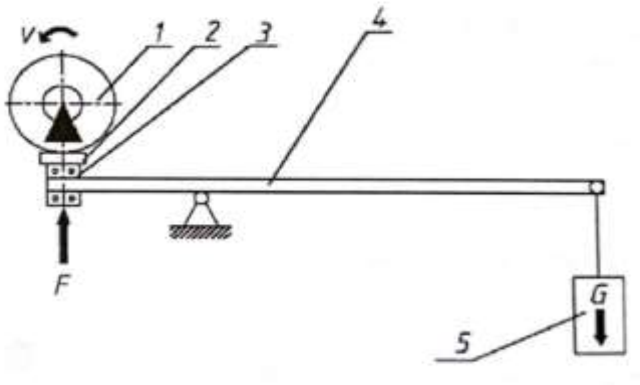

Fig. 2.16. Schematic representation of wear analysis setup [24]

1) Cylindrical hardened metal disc
2) The specimen to be analysed

3) Specimen holder
4) Connecting rod
5) Balancing weights

Calculation:

The velocity of rpm – 50rpm

Diameter- 41mm, radius- 21.5mm

$2\pi r = 2 \times 3.14 \times 21.5 = 128.8$mm

In order to find the wheel distance travelled, the velocity and the wheel circumference is multiplied.

128.8 ×50 = 6440mm= 6.44m distance travelled by the for one minute

Now to calculate the total time required for wheel to travel 40m

60sec- 6.44m

X (in seconds) = (60×40) / 6.44= 372. 7 seconds

We get Converting to minutes **6.13 minutes**

For every 40 meters sliding distance, the mass of the specimen were observed and this technique proceeds until the machine runs 200 meters in every specimen. The wear of the sample is calculated by decrease in its mass and if the loss in mass of sample is high then the wear resistance is less and vice versa.

Fig. 2.17. Specimen after wear test analysis

Fig. 2.18. Weighing Machine

In this work, the wear is calculated by taking difference between the mass of sample before the test and mass after each 40m sliding contact. It is calculated in grams using the weighing machine in Fig-2.18.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The samples are overlay welded using the submerged arc overlay welding process and it is shown in figure 3.1. Once they are overlay welded, the surface of the samples are grinded to make surface flat for hardness test which helps to determine the strength of the weld.

Fig. 3.1. Sample

The grinded samples are then cut into three parts and they are proceeded for further analysis. In these three parts, one is for hardness test measurement, second part is mirror finished and used it for microstructure analysis and the third part is for wear test analysis. These three parts results are analysed and results obtained are investigated.

3.1 INVESTIGATION OF HARDNESS TEST RESULTS

After welding the samples are tested using Rockwell hardness and the readings are noted. A set of readings are calculated in each sample and their average is noted down as the final hardness value.

The hardness value results obtained at different stages of tempering are shown in table 3.1. All the specimens are tempered at various temperature for one hour and after tempering, the hardness in the specimen may increase or decrease or hardness remain the same. This results will give a clear picture about the specimen toughness.

Fig. 3.2. Welding specimen's prepped and initial hardness tested

Table 3.1 Hardness values obtained after tempering

Sample number	Mixture	Flux	Hardness after welding	Tempering for 1hour		
				500 °C	550 °C	600 °C
01	100% HM	100%SiC	27.4	21.8	34.4	38.8
02	90%- HM, 10% Graphite	100%SiC	35.8	39.4	44	46.2
03	80% HM, 20% Graphite	100%SiC	36.8	39.4	40.2	41.4
04	70% HM, 30% Graphite	100%SiC	31.3	31.8	33	41
05	60% HM, 40% Graphite	100%SiC	61.7	48.3	52.2	50.6
06	50% HM, 50% Graphite	100%SiC	63.7	50.4	48	47.2
11	100% HM	50%SiC+50%SiO	16.4	3.2	2.7	8.4
12	90%- HM, 10% Graphite	50%SiC+50%SiO	25	26.2	29.8	32
13	80% HM, 20% Graphite	50%SiC+50%SiO	33	33.8	36.6	38.4
14	70% HM, 30% Graphite	50%SiC+50%SiO	31.8	37.2	42.4	42.8
15	60% HM, 40% Graphite	50%SiC+50%SiO	51.2	52.2	52.4	52.4
16	50% HM, 50% Graphite	50%SiC+50%SiO	61	50.4	50	47.6
21	100% HM	No Flux	13.4	55.4	36.8	35.8

Specimens 01-06 are prepared with the mixture of hard material tungsten carbide and graphite in different proportions with silicon carbide as a flux and **specimens 12-16** with equal percentage of silicon carbide and silicon oxide as a flux. At last, **specimens 21** with tungsten carbide mixture without any flux.

Specimens 01-06 , it is clear that from the specimens, silicon carbide as a flux and mixture of 50% of tungsten carbide and 50% of graphite (specimen no: 06) has the highest hardness of 63.7 HRC after weld compared to other samples. This shows that the hard material tungsten carbide and graphite influences in increase of hardness. The second hardness is seen in the specimen 05 HRC 61.7 with the mixture of 60% tungsten carbide and 40% graphite. Here, silicon carbide present in the flux mixture has helped in retaining hardness in the weld.

Although there is a decrease in hardness compared to specimen06 this is due to the mixture proportions of graphite and tungsten carbide. Graphite, which is rich source of carbon plays a significant role in increasing hardness. Specimen 01 has 27.4 HRC which is one of the least reading we recorded. By this we can see tungsten carbide doesn’t help or contribute in gaining hardness in the specimen. All the specimens used silicon carbide as a flux but still specimen01 didn’t gain significant hardness compared to specimen 05 and 06. By this we can clearly see that graphite has influenced in gaining hardness.

Now coming to **specimen 11-16** with 50%silicon carbide and 50%silicon oxide as a flux, it is clear that the specimen16 has the highest hardness of 61 HRC after weld compared to other samples. This shows that the hard material tungsten carbide and graphite influences in increase of hardness. The second hardness is seen in the specimen 15 HRC 51.2 with the mixture of 60% tungsten carbide and 40% graphite. Here, silicon carbide and silicon oxide present in the flux mixture has helped in retaining hardness in the weld. Although there is a decrease in hardness compared to specimen16 this is due to the mixture proportions of graphite and tungsten carbide. Graphite, which is rich source of carbon plays a significant role in increasing hardness. Specimen 11 has 16.4 HRC which is one of the least reading we recorded. By this we can see tungsten carbide doesn’t help or contribute in gaining hardness in the specimen. All the specimens used silicon carbide and silicon oxide as a flux but still specimen11 didn’t gain significant hardness compared to specimen 15 and 16. By this we can clearly see that graphite has influenced in gaining hardness.

Specimen 21 with tungsten carbide mixture and no flux has a hardness value of 13.4 HRC which is lowest of all specimens, it shows that due to the lack of flux there is a huge decrease in hardness value.

Once the primary hardness values are noticed, these specimen are set up for treating procedure called tempering to decrease the hardness and improve the toughness in the samples. Be that as it may, essentially, the hardness may increment or diminish or the hardness may stay same. The samples are tempered at three unique temperatures i.e. 500°C, 550°C to 600°C for 60 minutes in this examination work.

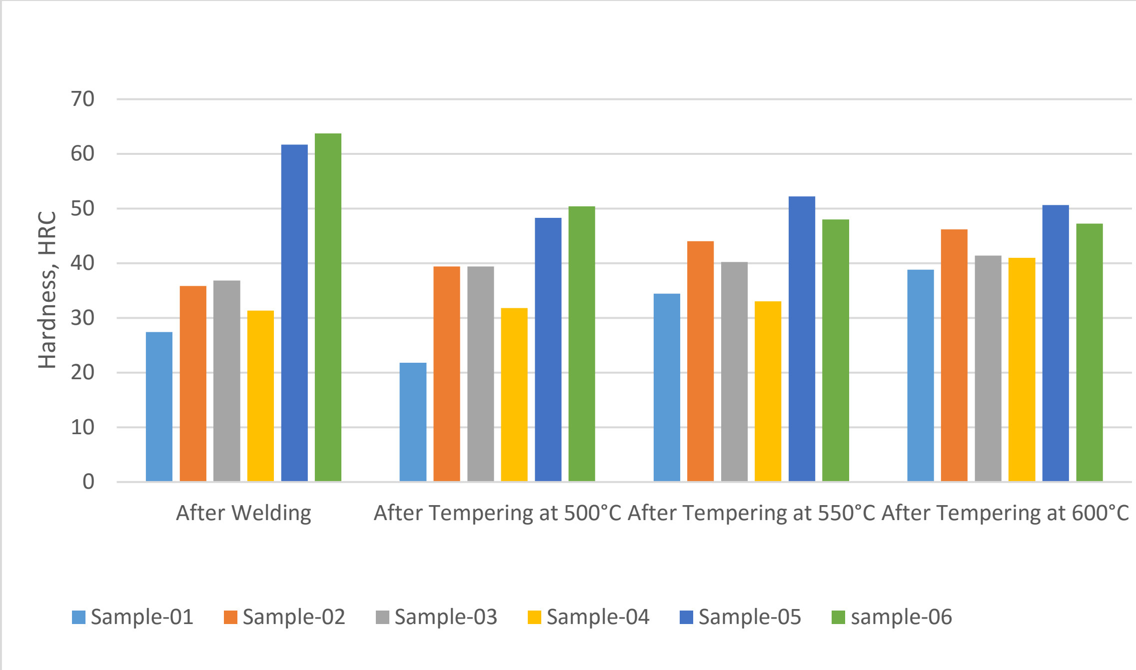

Fig. 3.3. Distribution of the specimen's 01 – 06 hardness

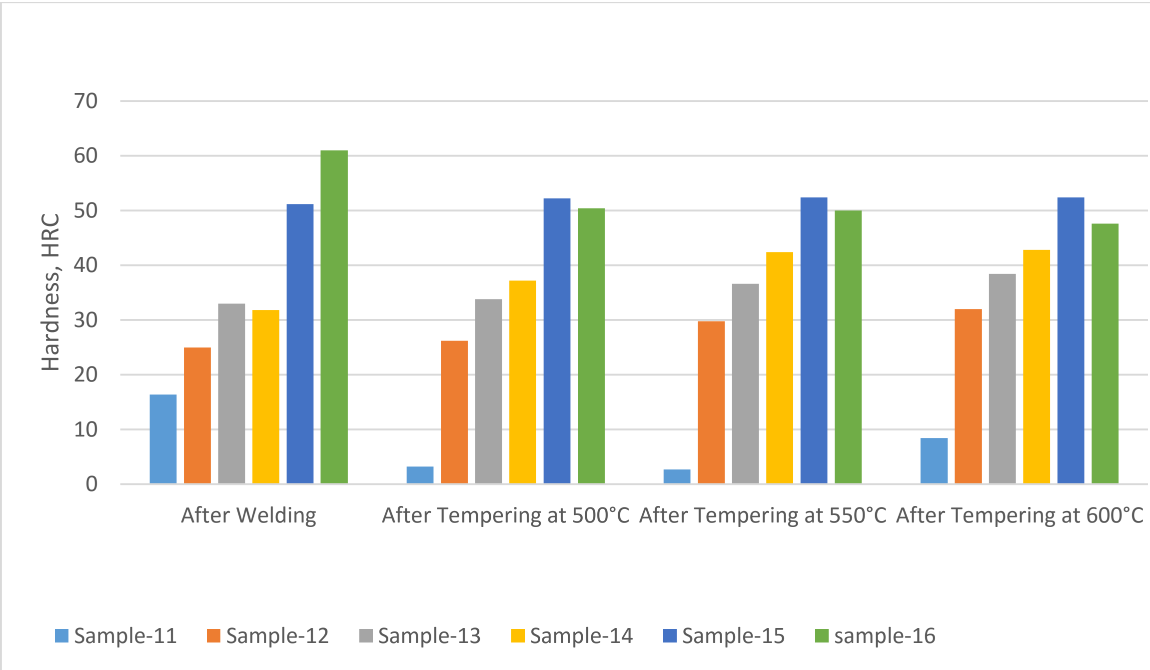

Fig. 3.4. Distribution of the specimen's 11 – 16 hardness

Figure 3.3 and 3.4 demonstrates the hardness readings of all the samples under all conditions and it is then clearly shown the variations in hardness at various temperatures of tempering.

Figure 3.5 shows the hardness value comparison of all the samples before and after tempering. While being compared, the hardness of sample01 is 21.8 HRC which less than the hardness it has when it is welded. But the difference is very less so there maybe not more change in its strength. Similarly for sample 06 the hardness is reduced by 13 HRC, which means it was 63.7 HRC when it is welded and now after tempering at 500°C the hardness reduces to 50.4 HRC. Appears like tempering doesn't work for the sample01, 05 and 06. But for all the other three samples hardness value is significantly improved at a sensible number. For sample 02 the hardness is 35.8 HRC after tempering at 500°C which is actually 4 HRC higher than previous condition. Likewise the hardness of sample 03 increased by 3 HRC and it is now 39.4 HRC which seems to be a considerable increase. So it is assumed that the hardness will be even much better after the next tempering at 550°C.

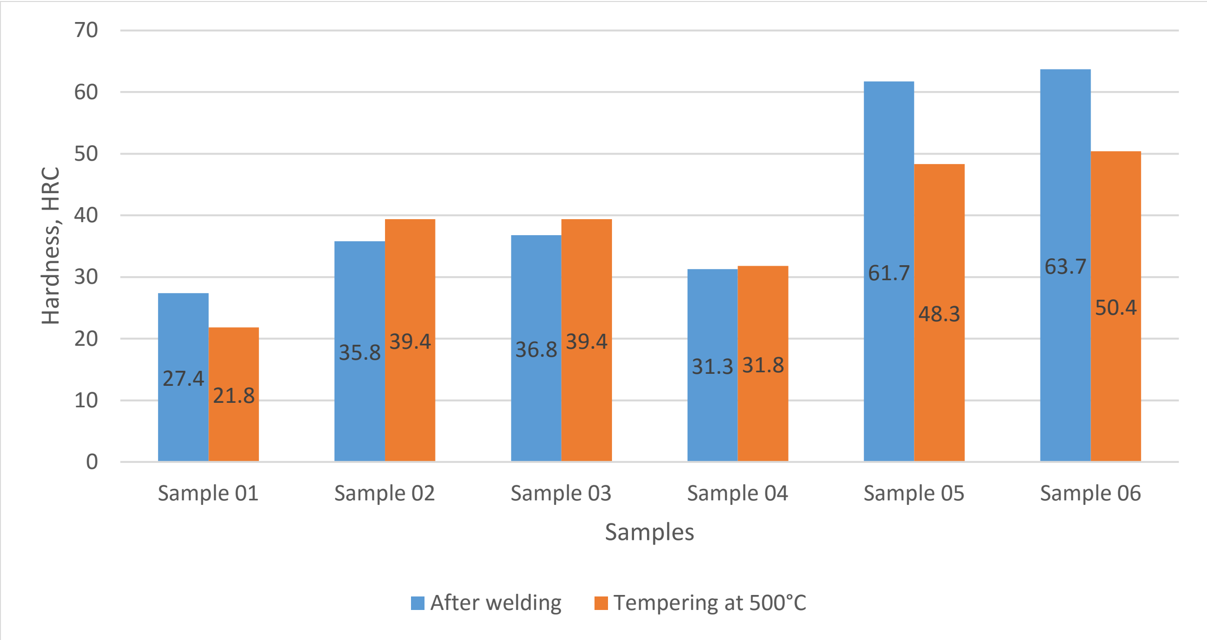

Fig. 3.5. Hardness comparison of samples 01-06 (after welding Vs tempering at 500°C)

Figure 3.6 shows the hardness value comparison of all the samples before and after tempering. While being compared, the hardness of sample11 is 3.2 HRC which less than the hardness it has when it is welded. Similarly for sample 16 the hardness is reduced by 11 HRC, which means it was 61.7 HRC when it is welded and now after tempering at 500°C the hardness reduces to 50.4 HRC. Appears like tempering doesn't work for the sample11 and 16. But for all the other four samples hardness value is significantly improved at a sensible number. For sample 14 the hardness is 37.2 HRC after tempering at 500°C which is actually 5 HRC higher than previous condition. Likewise the hardness of sample15 increased by 1 HRC and it is no 52.2 HRC which seems to be a considerable increase. So it is assumed that the hardness will be even much better after the next tempering at 550°C.

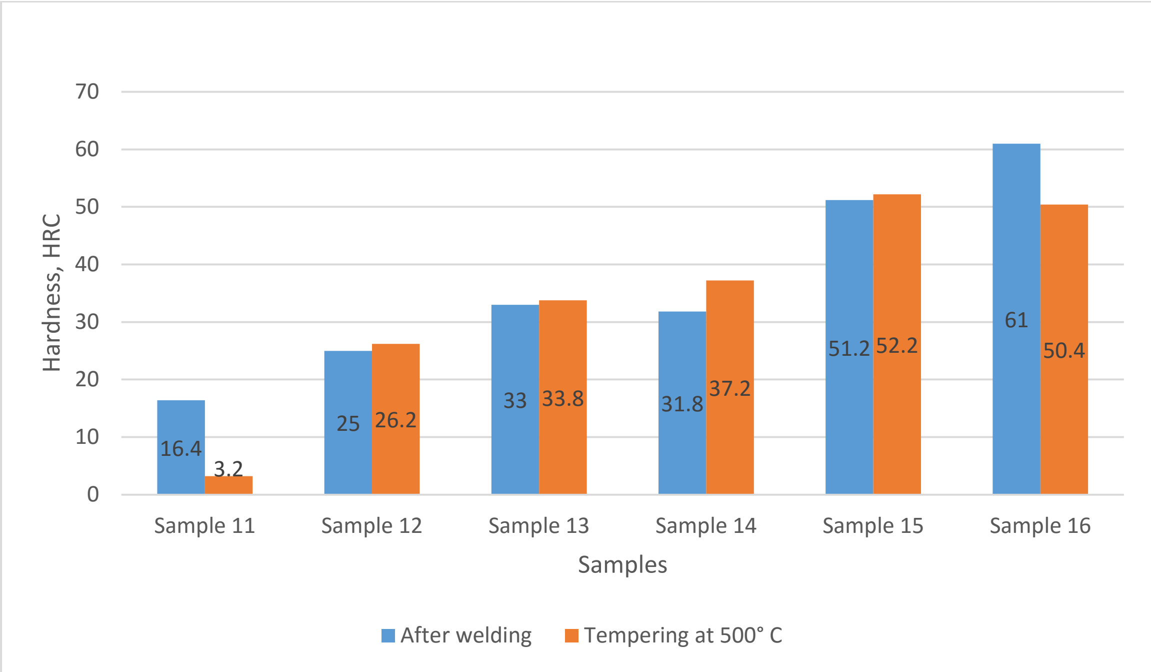

Fig. 3.6. Hardness comparison of samples 11-16 (after welding Vs tempering at 500°C)

From Fig. 3.7 comparison of hardness HRC with different tempered temperature i.e. 500°C Vs tempered at 550°C for the specimen 01-06 can be seen. Here we can clearly observe each and every specimen has increase in hardness significantly. With the highest hardness obtained from specimen 05 with 52.2HRC that to after tempering at 550°C. The highest hardness difference is from specimen 01 with 34.4 HRC but in this significant rise in hardness was found.

From Fig. 3.8 comparison of hardness HRC with different tempered temperature i.e. 500°C Vs tempered at 550°C for the specimen 11-16 can be seen. Here we can clearly observe each and every specimen has increase in hardness significantly. With the highest hardness obtained from specimen 15 with 52.4HRC that to after tempering at 550°C. The highest hardness difference is from specimen 14 with 42.4 HRC but in this significant rise in hardness was found.

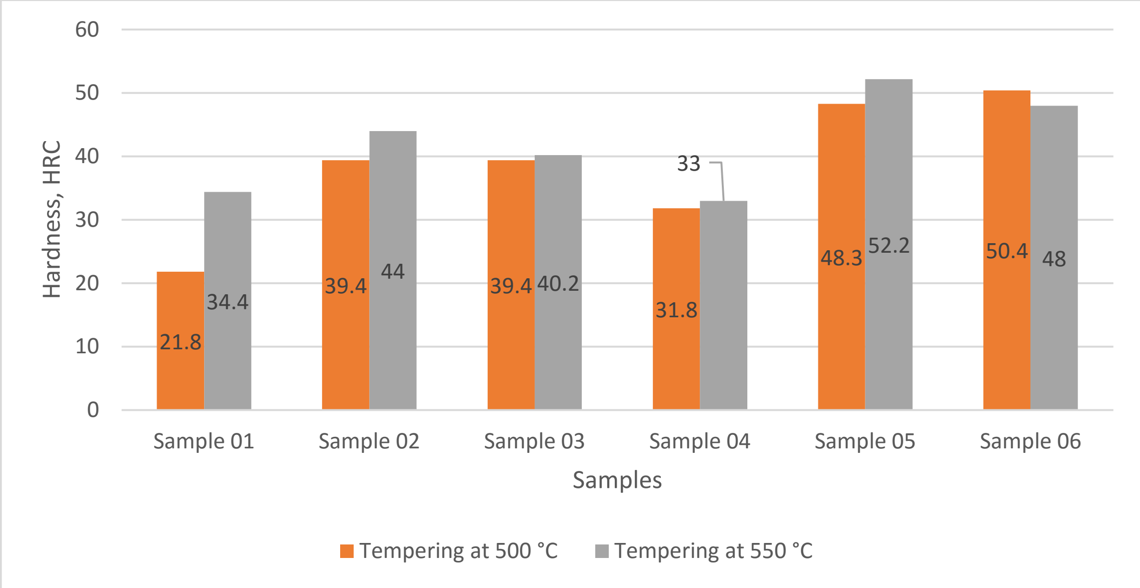

Fig. 3.7. Hardness comparison of samples from 01-06 after tempering (500°C Vs 550°C)

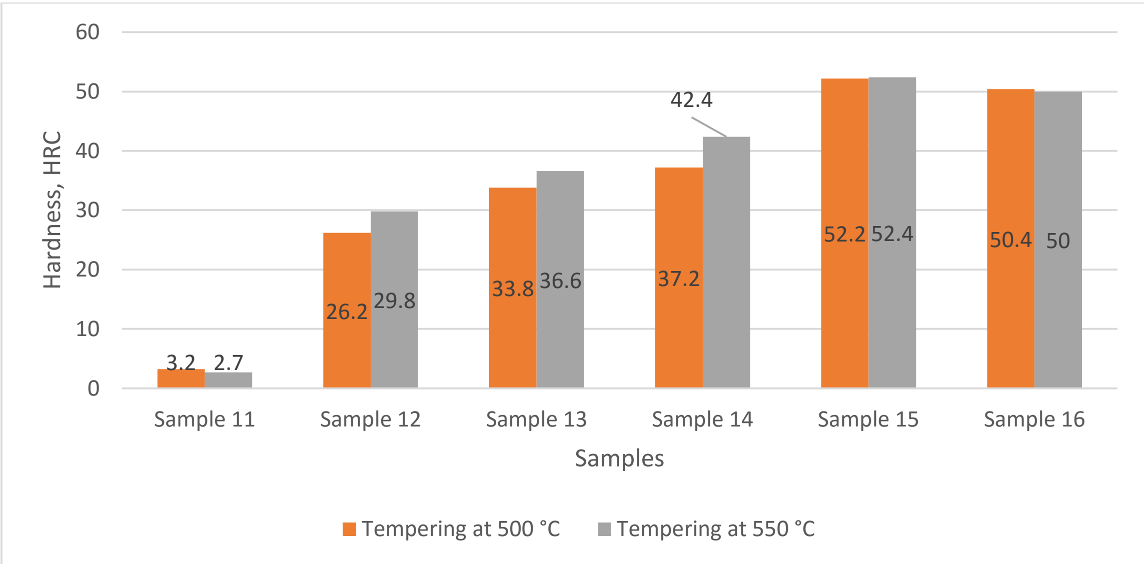

Fig. 3.8. Hardness comparison of samples from 11-16 after tempering (500°C Vs 550°C)

From Fig. 3.9 where the comparison of hardness is between the tempered specimens with tempering at 550°C Vs tempering at 600°C. Here we can see that at 600°C not so difference has been seen in the hardness number. At the same time even with the other specimen the Hardness number remained the same with very slight or negligible changes.

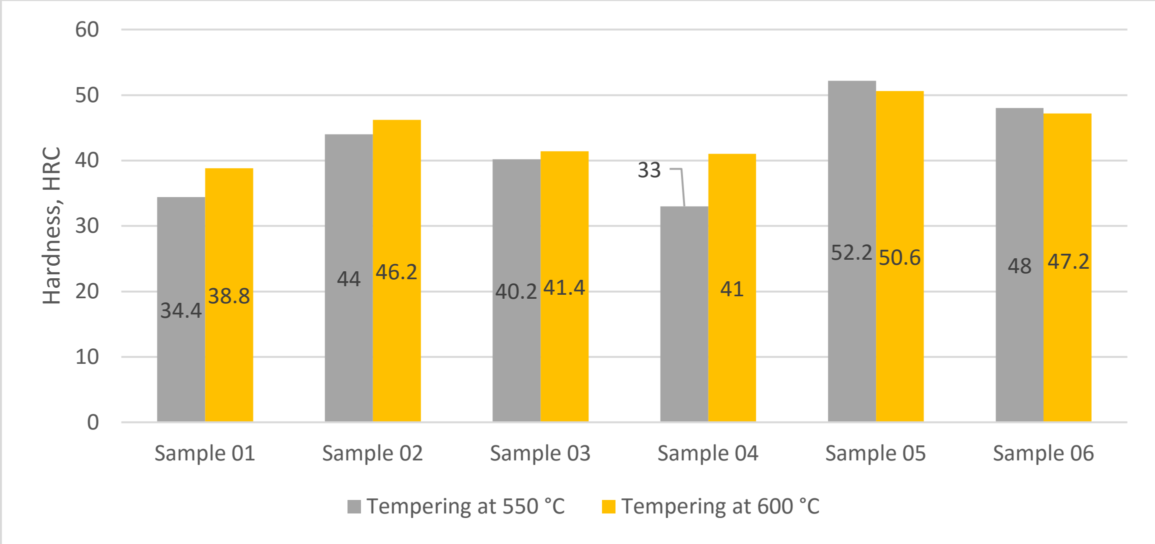

Fig. 3.9. Hardness comparison of samples from 01 – 06 after tempering (550°C Vs 600°C)

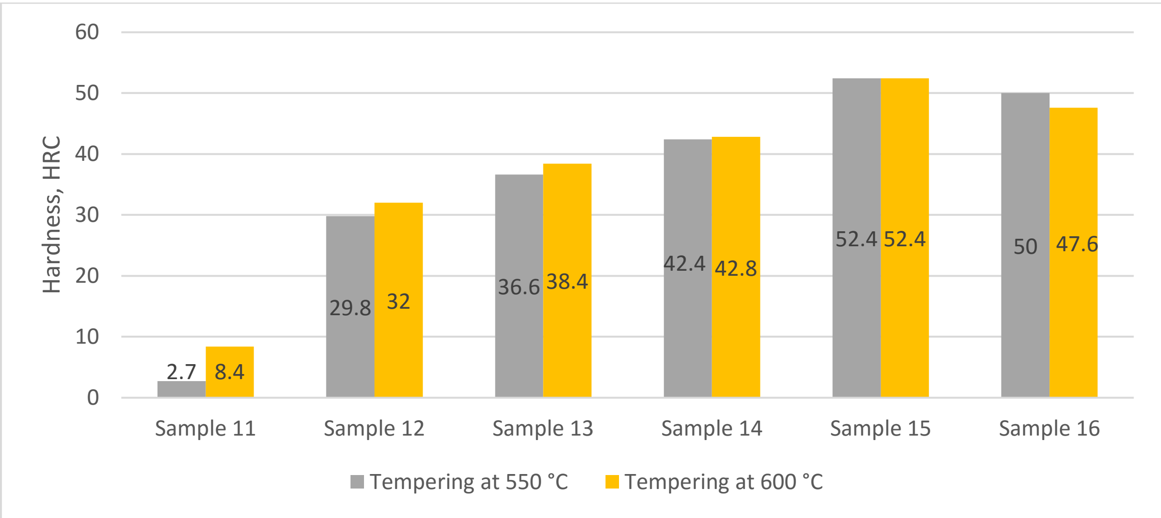

Fig. 3.10. Hardness comparison of samples from 11 – 16 after tempering (550°C Vs 600°C)

From Fig. 3.10 here we can see during tempering at 600°C there is drop in hardness in the specimen. This makes clear with the graphs that the ideal tempering temperature for the specimens is 550ºC. This graph shows how the value of hardness has been increased for all the samples after tempering at 550°C and this heat treatment gave the highest hardness. It is decided that for the microstructure examination and wear resistance test the samples are subjected to tempering at 550°C because of the more positive result of hardness at this temperature. These data's are then compared and analyzed with the results obtained after welding.

3.2 Microstructure investigation

3.2.1 Microstructures of samples after welding

The specimens that are after weld and tempered at different temperature are prepped for microstructure analysis and this specimens are initially grounded flat and then the surfaces are smoothened using various grit sand paper that would be 200, 600, 1500 and 2000. Finally the surface is polished to a mirror finish for examination of structure under microscope.

From the microscopic observation, the initial weld layer before tempering shows the formation of martensitic crystalline structure and retained austenite under magnification of 200X.

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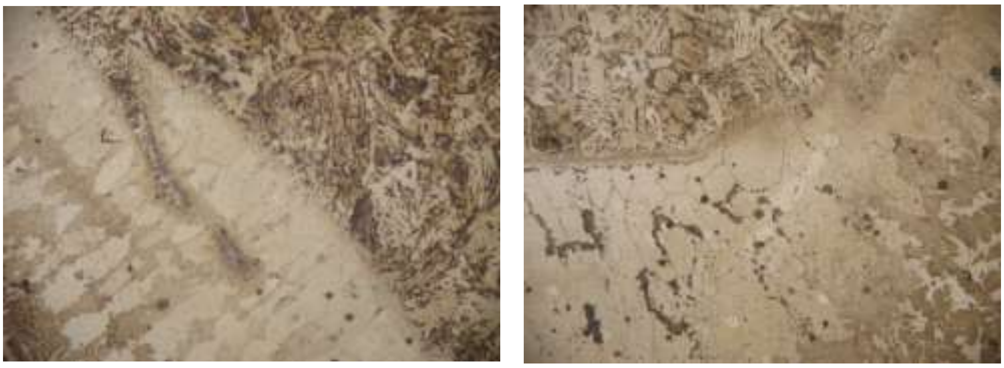

Fig. 3.11. Microstructure of Sample 01 after welding under Magnification 200x

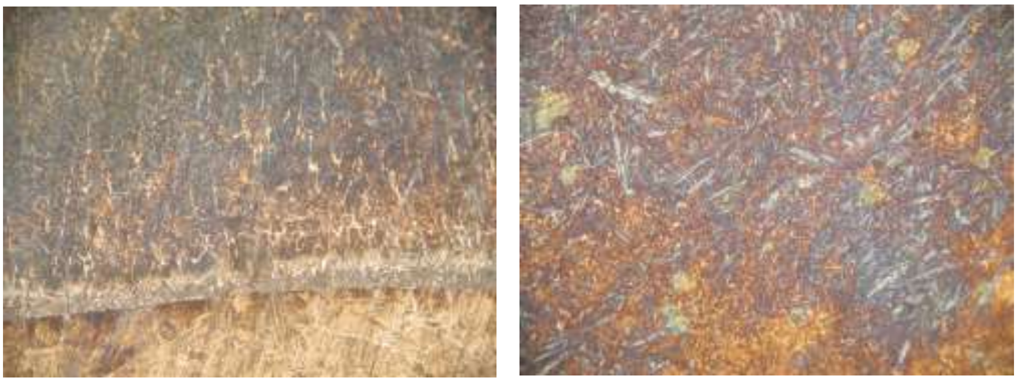

Fig. 3.12. Microstructure of Sample 05 after welding under Magnification 200x

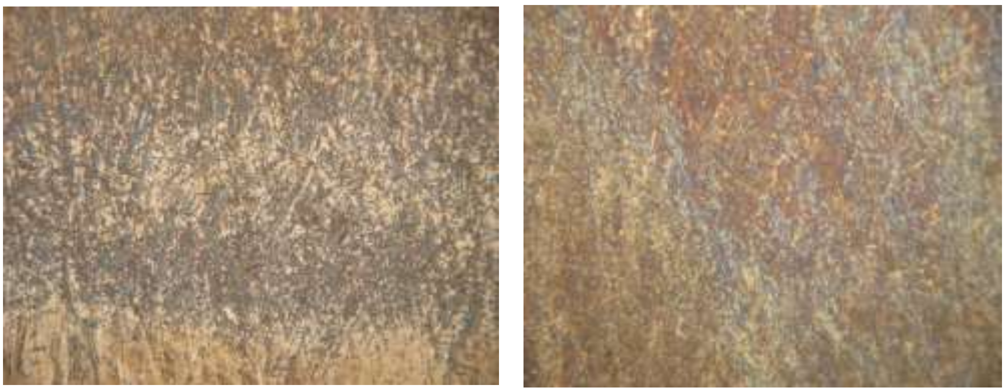

Fig. 3.13. Microstructure of Sample 15 after welding under Magnification 200x

Figure 3.11 (sample 01), Figure 3.12 (sample 05) and Figure 3.13 (sample 15) demonstrates the microstructure test taken directly after the initial welding of surface layer has done. It is perceived from the photos that it is like the cast iron material taking into account iron and carbon, carbon substance is high contrasted with steel. From Sample 05, the martensitic structure is framed and the martensitic structure resembles the needles. Apart from needles at some spots little measure of carbides shapes can be seen. Also, the limit layer between the weld material and substrate is observed. In Sample 15, lamellar type of graphite is recognized with cementite of bright coloured surface with regions of ledeburite. Once the specimen is tempered at the temperature 550°C. The change occurs from structure of martensitic to sorbate i.e. nothing but the next stage to martensite. In this stage the specimen toughness increases and the hardness gets diminished.

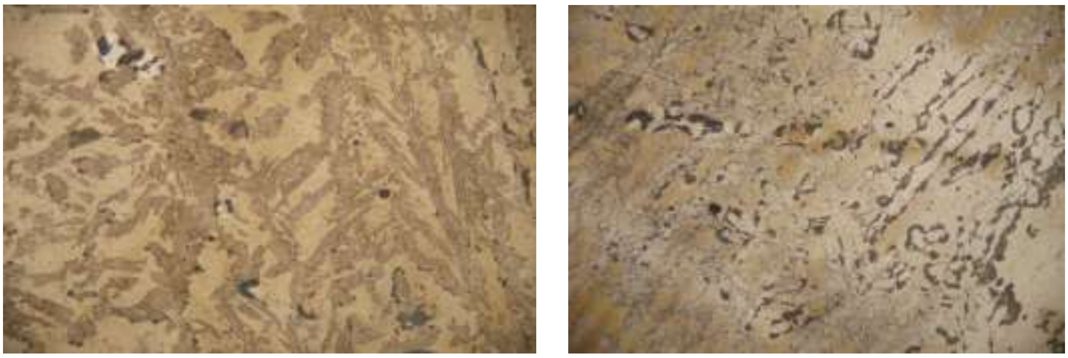

Fig. 3.14. Microstructure of Sample 01 after tempering. Magnification 200x

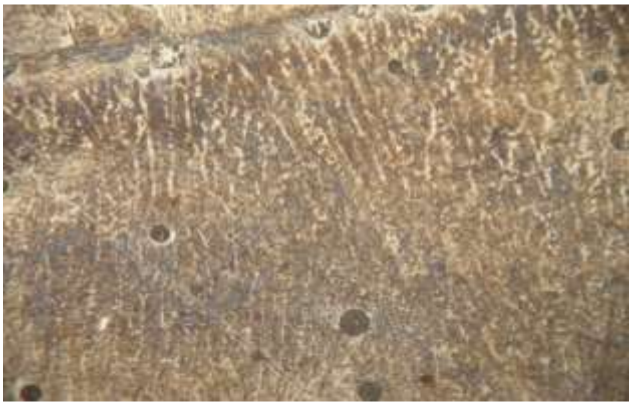

Fig. 3.15. Microstructure of Sample 05 after tempering. Magnification 200x

Figure 3.14 to Figure 3.15 demonstrates the microstructure pictures of tests taken at 550°C after tempering. During the hardness testing of the surface layer, the hardness appears to be higher for the specimens and so the tempering temperature of 550°C is chosen. The microstructure after tempering appears to have prominent structure changes.

In Sample 01, the Ledeburite structure is recognized since it has high carbon substance in it which can be upto 4.3%. It is eutectic blend of austenite and cementite structure and there are conceivable outcomes that it can even structures independently in high carbon steels and substance can shift from 2-7%. Cementite is an iron and carbon compound which can be establish in ledeburite structure. It has similar properties as martensite however not the structure.

In sample 05, as distinguished prior before heat treating the structures haven't changed and they are still present. In the microstructure after tempering, graphite is available in lesser amount. However the regions of pearlite is available with ledeburite and cementite.

3.3 WEAR TEST VALUES AFTER WELDING

After welding the samples are subjected to wear test, for each 40m sliding contact the values of wear test are noted in table 3.2. The loss of material is calculated for 40m each till it reaches 200m sliding contact.

For the specimen 02, 03 the flux used are silicon carbide and for specimen 12 and 13 the flux used are 50%silicon carbide and 50%silicon oxide are chosen for the wear resistance test.

Table 3.2. Wear specimens tempered at 550°C material loss measured.

Specimen number	Wear (weight loss in g)					
	0 meter	40 meter	80 meter	120 meter	160 meter	200 meter
Specimen 02	20.77410	20.77120	20.76920	20.76570	20.76330	20.76040
Specimen 03	24.67540	24.67010	24.66745	24.66410	24.66050	24.65780
Specimen 12	19.11160	19.10950	19.10830	19.10730	19.10415	19.10100
Specimen 13	23.44100	23.43740	23.43630	23.43265	23.42930	23.42810

Table 3.3. Wear specimens tempered at 550°C measured with actual material loss in grams

Specimen number	Wear (weight loss in g)					
	0 meter	40 meter	80 meter	120 meter	160 meter	200 meter
Specimen 02	0	0.0029	0.002	0.0035	0.0024	0.0029
Specimen 03	0	0.0053	0.00265	0.00335	0.0036	0.0027
Specimen 12	0	0.0021	0.0012	0.001	0.00315	0.00315
Specimen 13	0	0.0036	0.0011	0.00365	0.00335	0.0012

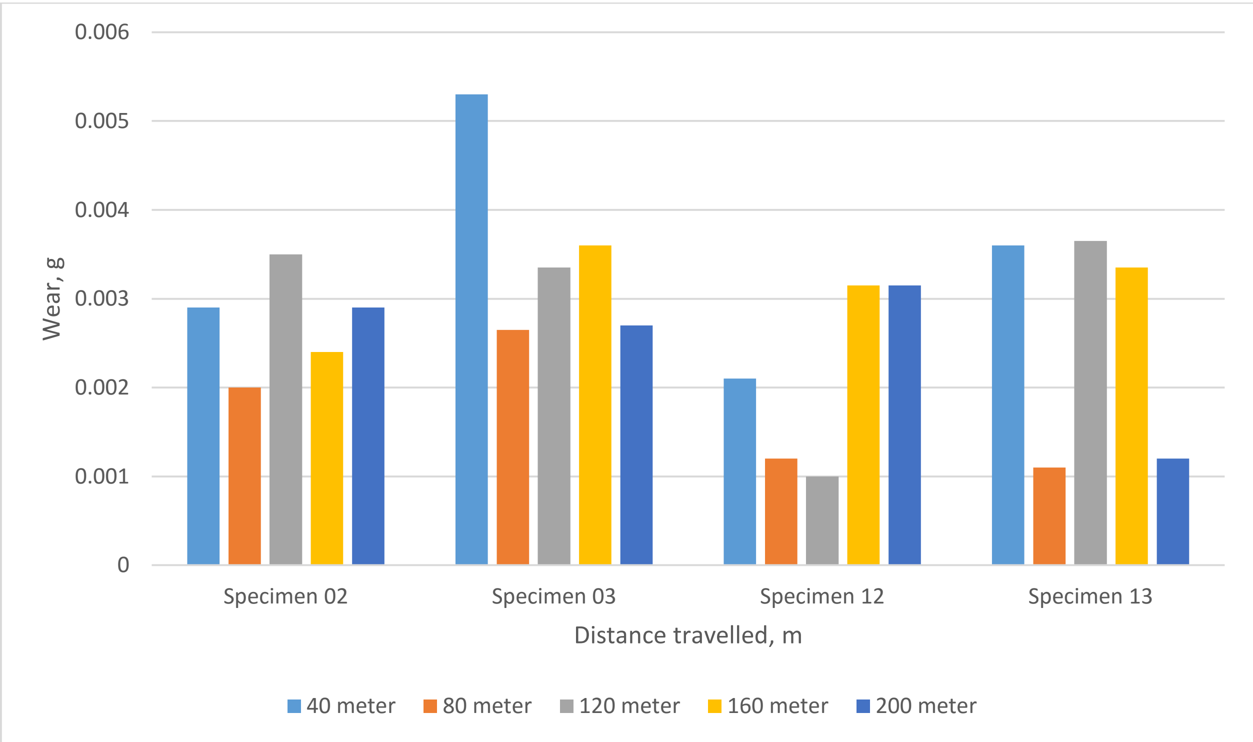

Fig. 3.16 Comparison of wear of the different specimens tempered at 550°C

Now looking at the Fig-3.17 and Fig 3.18 the highest wear resistance is obtained in the mixture added to the specimen 12 and 13. The lower the graph higher the wear resistant. From fig 3.17, there is a steady increase in wear loss of material from its surface. Alloying element of mixture significantly improves the strength i.e. addition of carbon adds extra strength to the weld. Similarly to improve wear resistance the alloying element that to be added should have more resistance to abrasion.

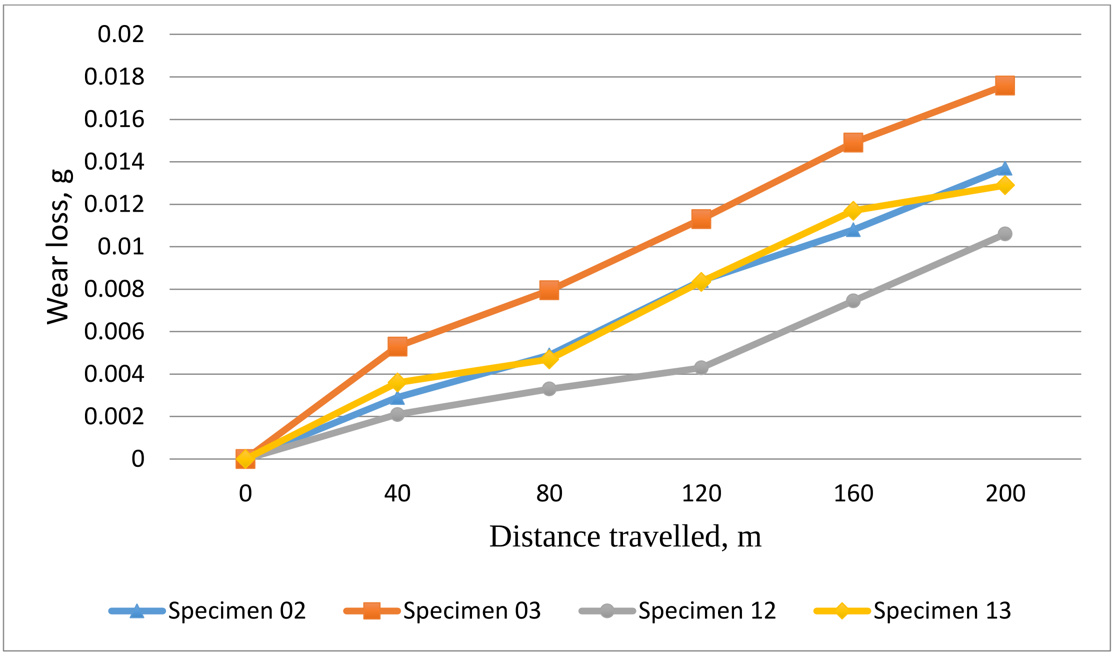

Fig. 3.17. Comparison of wear loss in grams at different distance

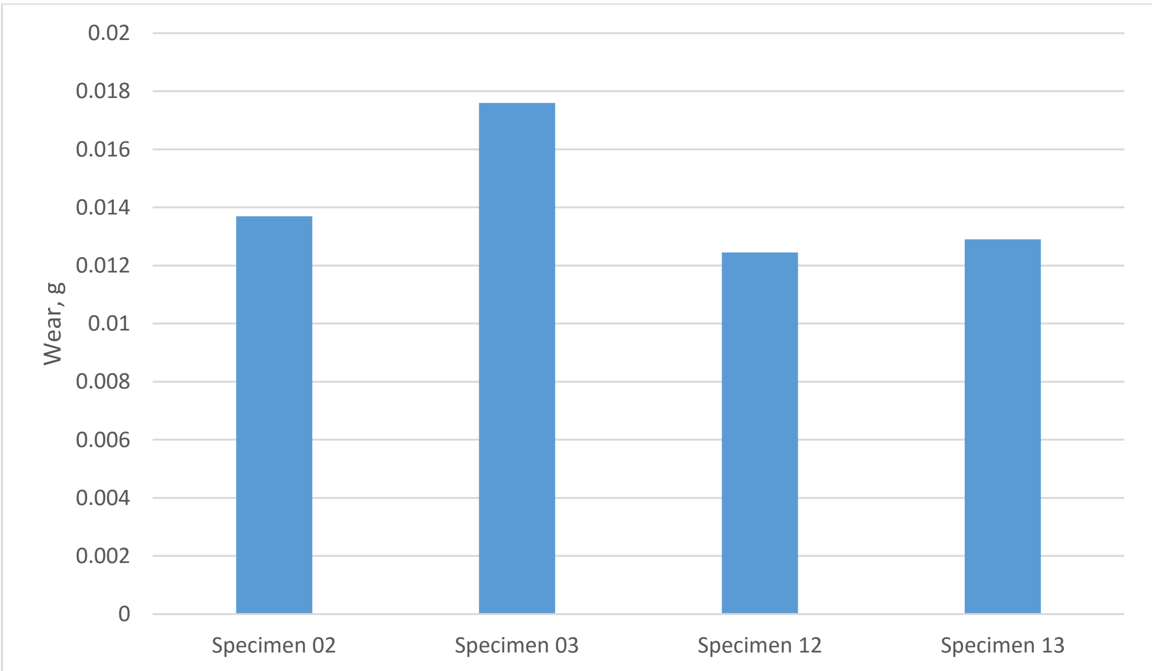

Fig. 3.18. Comparison of wear after 200 m

Here and now observing the above graphs it is clear that wear is increased in all specimens, the values are noted down after each 40m sliding contact. After certain distance, the wear of the specimen gets reduced and this may be due to the plastic deformation on that specimen. The least wear resistance is found in the specimen 02 with the flux blend of silicon carbide and followed by the second least wear resistance was in the specimen 03 with the same flux mixture of silicon carbide. The material should not be harder, if so it's brittle in nature. It should have more toughness that makes the material more wear resistance.

The specimen i.e.12 and 13 has the higher wear resistance in which the flux blend is silicon oxide and silicon carbide. In this we can see that infer that the blend included will unquestionably help in picking up resistance against wear. In the example 13 there was steady decline in the wear on the specimen surface. However, in the example 12 there was reduction in the wear after 40 meter till 120 meter yet toward the end, nearing to 200 meter there was growth in the surface wear.

Tempering at different temperature has increase the hardness in certain specimen's. Simultaneously there is a drop in hardness in some specimens. Wear resistance of the specimens depends on the hardness obtained on the surface at the same time microstructure play an important role.

CONCLUSION

Submerged arc welding is a type of welding technique which is a cost effective process to deposit the hardened layer on the not so strong substrate layer (which is plain carbon steel used in our research). After the deposition of the hardened materials over the substrate they are subjected to various tests such as finding out the surface hardness using Rockwell hardness tester, analysis of microstructural obtained and finally checking resistance against the surface wear. The specimen 01-06 have various proportions of tungsten carbide and graphite material powders and flux mixture of silicon carbide and specimen 11-16 with additional flux mixture of silicon carbide and silicon oxide.

By observing the microstructure, the specimens after the initial hardening process i.e. welding there is a dominance in martensitic structure. After tempering at 550°C, there is a change in microstructure which is from martensitic structure to retained austenite.

Sample hardness begin to raise when tempered at 550°C and above, by observing the results, it is clear that hardness is at its high for all samples after tempering at 550°C.

1. Specimen 05 with 60% HM-40% Graphite of powder mixture and silicon carbide as a flux resulted in increase of hardness after tempering at 550°C compare to other samples;
2. Specimen 15 with 60% HM-40% Graphite of powder mixture and 50% SiC- 50%SiO as a flux also showed an increase in hardness after tempering at 550°C and then decreased on further tempering at 600°C.
3. Specimen 12 with 90% HM-10% graphite and 13 with 80% HM -20% graphite has highest wear resistance. But other thing we need to conclude is that only the flux will not influence in increase the hardness of the specimen. The mixture of hard metal like the tungsten carbide and graphite mixture plays an important role as an alloying element which adds extra carbon to the weldment. This supports in increasing wear resistance.
4. From the experimental results the suitable tempering temperature that helps out in all the aspect is 550°C. Where the wear resistance with good hardness are seen.

By comparing the results obtained with the previous research paper, it can be concluded that hard facing the surface using submerged arc welding improves wear resistance and hardness of the cutting tools. Addition of graphite, as a rich source of carbon increases the surface hardness of the tools. So these tools are suitable for wood machining process which requires high feed rate and strength.

Hard facing method can be very useful and efficient if implemented in conventional welding methods. It then increases the overall strength, wear resistance, prevention from corrosion and rusting of the welded materials (cutting tools). So, using suggested technology it is possible to reduce expenses of machining of wood-based products, and to recycle industrial metal waste for the preparation of cutting tools.

Similar to this research work, paper has been presented in Pramonės inžinerija conference 2016 which have been included at the end of this thesis report.

LIST OF REFERENCES

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