KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Kiran Kumar Arumugham

INVESTIGATION OF SURFACE LAYER IN SUBMERGED ARC WELD OVERLAY CLADDING TECHNIQUE

Final project for Master degree

Supervisor
Assoc. Prof. Dr. Antanas Čiuplys

KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN
INDUSTRIAL ENGINEERING AND MANAGEMENT

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Final project for Master degree
M5106L21 Industrial Engineering and Management (621H77003)

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DECLARATION OF ACADEMIC HONESTY

29 MAY 2015

Kaunas

I confirm that a final project by me, **Kiran Kumar Arumugham**, on the subject "**Investigation of surface layer in submerged arc weld overlay cladding technique**" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Investigation of surface layer in submerged arc weld overlay cladding technique

Approved by the Dean 2015 May 11 Order No. **ST17-F-11-2**

2. Aim of the project

To investigate the surface layer achieved by submerged arc weld overlay cladding technique and compare the results obtained.

3. Structure of the project

Summary, Introduction, 1. Literature Overview, 2. Methodology, 3. Experimental results and discussions, Conclusions, References.

4. Requirements and conditions

To prepare final project according to KTU regulations and requirements.

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

6. Project submission deadline: 2015 June 1st.

Given to the student Kiran Kumar Arumugham

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

Supervisor ________________________ ________________________
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Kaunas, 2015. 48 pages.

SUMMARY

In this research work the welded surface suing submerged arc weld overlay cladding technique is investigated to determine which sample mixture has higher hardness, higher wear resistance at various conditions. The materials used for surface layering of base metal is of different waste material powders collected for the research purpose and these powders are mixed in various proportions to prepare five samples. Samples are tested for hardness after welding using Rockwell hardness test and then the samples are cut into three different parts for further examination. Microstructure examination is done is this research using microscope that has maximum magnification range of 250x. Wear test is performed using the wear testing machine for which the samples are cut into 6mm length small piece These three parts are used as each for analyzing the hardness, inspecting the microstructure and calculating the wear resistance. Tempering of the samples are done to investigate whether at which tempering temperature the efficiency of the samples are increasing and also to evaluate the value it is increasing. The results obtained from these tests are studied, analyzed and investigated in this work and the usefulness of the waste material powder are assessed.

Keywords: Weld overlay cladding, Surface layer, Microstructure, Tempering, Hardness, Wear resistance.

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Kaunas, 2015. 48 psl.

SANTRAUKA

Šio baigiamojo darbo tikslas yra ištirti ir nustatyti apvirintų sluoksnių kietumą ir atsparumą dilimui. Naudojamos medžiagos iš metalo apdirbimo atliekų miltelių, kurie yra sumaišomi įvairiomis proporcijomis ir įvedami į fliuso sluoksnį. Paruošti penki skirtingi bandiniai. Bandiniai yra apvirinami, bei tiriamas jų kietumas. Vėliau bandiniai supjaustomi į tris dalis. Šios trys dalys yra naudojamos kiekviena atskirai analizuojant kietumą, mikrostruktūrą ir atsparumą dilimui. Mikrostruktūros tyrimas yra atliekamas naudojant metalografinį optinį mikroskopą, kurio objektyvo maksimalus didinimas yra 250×. Dilimo bandymai atlikti naudojant specialių dilimo bandymo įrenginį. Bandiniai dilimo bandymams buvo specialiai ruošiami supjaustant į 6mm pločio juosteles. Po apvirinimo bandiniai buvo atleidžiami, tada matuojamas kietumas ir atliekami dilimo bandymai. Atleidimas atliekamas norint ištirti, kurioje temperatūroje bandinių kietumas gaunamas didžiausias. Gauti rezultatai yra tiriami, analizuojami bei atliekamas jų vertinamas.

Raktiniai žodžiai: Apvirinimas, Paviršinis sluoksnis, Mikrostruktūra, Atleidimas, Kietumas, Atsparumas dilimui.

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INTRODUCTION

Industrial machinery parts are subjected to severe wear condition after a certain period of run. It may even take years for the machine parts to get worn out, but at that stage instead of changing the part completely there are possibilities to hardface those parts. Hardfacing is essentially the most inexpensive method to improve the wear resistance of the machinery parts that have poor wear resistance. Industries give out material waste obviously and are used in several ways as a process of recycling, but those material waste can also be used to overweld the worn out parts so that it can increase the life of the part temporarily and also saves more money.

In this research the several material powders are used to prepare sample mixtures and as said earlier those powders are collected from waste Wear take place for every material even the hardest such as diamond, but it is important that which is more wear resistant when compared. The **main aim of this research** is to investigate the surface layer achieved by submerged arc overlay weld cladding technique and to compare the results obtained. The surface layer is obtained by welding the sample material powders collected from waste.

The **objectives of this research** are

- To achieve a quality weld from the samples prepared using waste powder materials by submerged arc weld overlay cladding technique.
- To determine hardness of the samples prepared, before and after tempering and analyze the results.
- To investigate and study the microstructures of welded surface layer, before and after tempering.
- To calculate the wear of the surface layer, before and after tempering and examine the results obtained.

However to achieve a surface layer with higher hardness and good wear resistance, the mixture that is going to be hardfaced on the base layer must have an extraordinary physical properties. Even though all the materials that are chosen for this research are collected from waste, it has certain kind of advantages such as all the chosen materials have good physical properties and they are of lower cost so can be used as much as necessary. These samples are tested under various situations and conditions to analyze the characteristics of the welded surface layer by which a precise conclusion can be drawn from it.

1. LITERATURE OVERVIEW

Generally overlay welding techniques are used in order to achieve higher wear resistance and hardness. The objective of overlay welding is mostly to form wear resistant layer. Submerged arc weld overlay cladding is one of the common technique used to weld using continuous or powder wire, under flux or protective gas. [1]. Hardfacing coatings can be produced using Submerged arc welding. The type of powder in the mixture, amount of powder input and welding variables will affect the microstructure and type of formed alloys [2].

The wear properties of hardfacing welding depend upon several factors such as hardness, thickness of surfacing layers, the microhardness and toughness of matrix structure, volume fraction and distribution of the hardness phases, operating conditions and welding process [3]. There are four main ways in which many objects lose their usefulness they are obsolescence, breakage, corrosion and wear. For complex objects, the wear is almost always the most significant mechanism [4].

Submerged arc welding is a high quality welding process with a very high deposition rate. It is usually operated as fully mechanized or automatically processed or semi-automatically processed. But to obtain a quality weld the parameters are decided according to the engineering facts. In submerged arc welding, there are more than a few ways of increasing welding efficiency. They are multiple-wire welding, multiple electrode welding, hot wire welding, cold wire welding, and metal powder addition welding [5] [6].

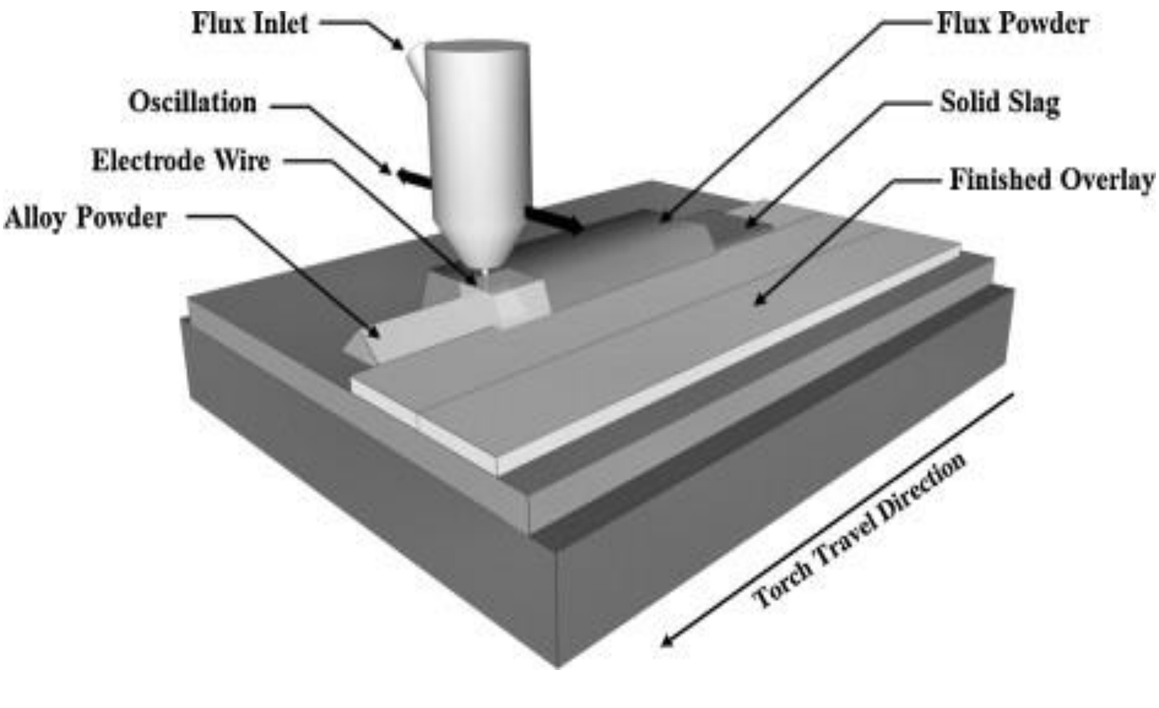

Figure 1.1 Schematic diagram of automatically processed submerged arc welding [7]

Based on the thickness of the metal, type of the joint and component size, the bead shape can be improved and also the deposition rate can be increased. The advantages of using two are more electrodes refer to high welding speed, high productivity, defect free welds and possibility of welding plates of large thickness [8][9].

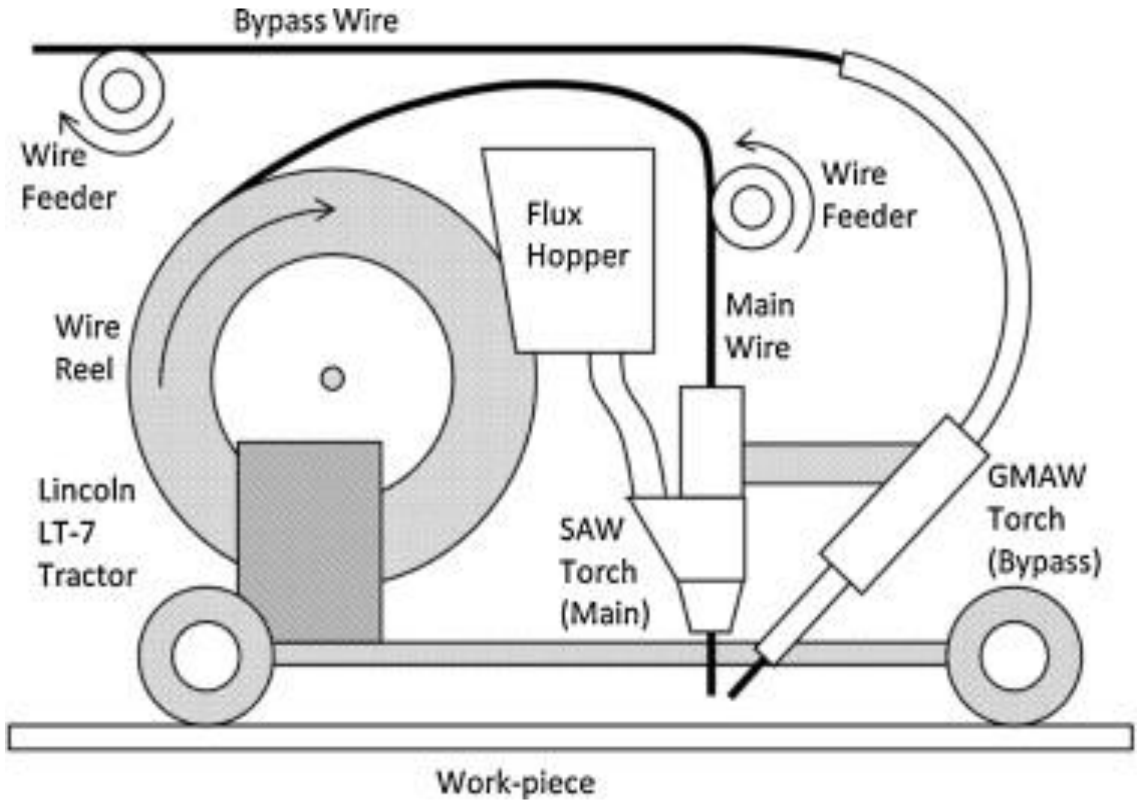

Figure 1.2 Schematic diagram of two electrode arc welding process [10]

In light of hypothetical investigation and encounters gained from examinations, numerous new diverse blends of double electrode have been endeavored as of late. As shown in Figure 1.2, this procedure is one of the new uses of Double-Electrode innovation. This is built up on a routine SAW transform by adding another gas metal arc welding next to the SAW light of Lincoln LT-7 tractor to give a second/sidestep circle for the welding current. The fundamental wire feeder is consolidated with the tractor itself the detour wire needs an extra wire feeder [10].

Due to its advantages, such as high productivity and increased welding speed, the process is successfully applied in various manufacturing. These variants can be extensively useful in improving the productivity by increasing weld metal deposition rate and also the travel speed will increase accordingly [7] [8].

1.1 Advantages and disadvantages of submerged arc welding

The major advantages of submerged arc welding process are

a. The quality of weld will be very high when compared with other types [11] [12].

b. The utilization electrode wire will be significantly high.

c. The productivity, deposition rate and speed is extremely high.

d. The amount of smoke produced during the process will be low.

e. The flux prevents high levels of radiation from spreading.

f. The protective clothing is not needed much because there will be no arc flash.

The major disadvantages of arc welding process are

a. It is capable of welding only limited materials like steel, stainless steel and nickel.

b. It is capable of welding only long, straight or rotated materials.

c. It is possible that the residue from the flux can be left behind which is harmful to the worker.

d. High heat input and slow cooling cycle is also one of the drawbacks of this process.

1.2 Characteristics of submerged arc welding

The characteristics of submerged arc welding gives the clear understanding of the process

a. Flux and molten slag shield the overall weld bead.

b. The fabricated flux wall shields the flux cavity.

During the SAW process, a small portion of the flux is melted and consumed. Chandel (1998) found that the flux consumption relies upon three sources

a. Conduction from the molten metal

b. Radiation from arc and

c. Resistance heating of the slag.

However, their individual contributions to flux consumption are still unclear. In any case, the total flux consumption can be calculated by measuring the mass of the flux used. Renwick and Patchett (1976) analyzed the relations between welding parameters and the flux consumption and found that flux consumption initially increased with increasing current, reached a maximum, and then decreased [13].

Fluxes are coarse mineral compounds which are assorted according to various patented interpretations. Singh.R (2011) said that they may be fused, bonded and sometimes more than one type is mixed for highly critical or proprietary applications. Materials has its stand alone ability and different physical property in which manganese is known for its strength, molybdenum is much appreciated for its high-temperature strength and nickel provides toughness.

The addition of molybdenum will result in a decrease of fracture appearance transition temperature and also escalation of impact toughness. When nickel is added alone then the weld metal will show a lesser toughness however the combined presence of nickel and molybdenum in the weld metal leads to a high volume fraction [14]. Recently there are some explanations involving submerged arc welding of carbon and carbon–manganese steels have generated data for both commercial and experimental fluxes from which composition of weld metal can be projected for a given flux, wire and base plate. Such data have been used to inspect the extent to which levels of elements such as manganese, silicon, etc., can be predicted [15].

1.3 Cladding using submerged arc welding

Cladding is defined as the deposition of dissimilar material on the surface of substrate to get the desired properties, which the base metal initially does not possess, using special heat source such as arc, flame, induction heat and high energy beams.

Submerged arc weld cladding has been used in modern industries, particularly for the heavy section steels and for a large structure surfaces needing to be altered. Due to welding the microstructure and mechanical properties of welded zone will be different from the other unaffected zones. There are three zones to be classified during and after the welding process. They are

a. Base metal

b. Heat affected zone

c. Weld metal

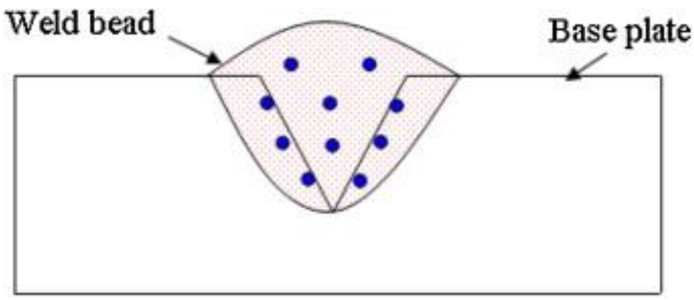

Figure 1.3 Schematic diagram of welded plate [16]

Base metal is the part where there might be no changes in its structure and property so it remains unchanged part of weld joint. In heat affected zone, it is the part of the base metal where its microstructures and properties have transformed due to the heat produced by the welding and also when it gets cooled after the process. Weld metal is the material mixture which is melted and forms a layer on the base metal and its chemical composition will gets transformed according to the base metal. When the surface layer is formed it makes the total change in the product which has the capability to alter the hardness and wear drastically [17].

Comparing to other weld cladding processes submerged arc cladding is capable of delivering very high deposition rate and high surface layering capacity with less-sophisticated equipment. Surface condition of structural components has been an insistent problem in modern engineering application. Some components stop working due to minor damage on the surface. Using cladding techniques, it is possible to improve surface properties, such as the wear, the corrosion and oxidation resistances, and to take advantage of a longer service life and the consequent reduction of total cost. An alloy mixture (Fe,Mn,Cr,Mo,V) which is often used as a cladding material on rollers, idlers, mine car wheels and similar equipment has been used to investigate the effect of welding parameters on the microstructure and wear behavior of the cladding [18].

Boron is one of the alloying elements than can be added to the system or replaced with carbon to form chromium and iron borides instead of carbides. Previous studies on alloys of various boron and carbon compositions showed that different microstructures containing chromium carbides and borides are developed. Among those alloys, those having carbides and borides showed the lowest abrasion resistance based on a pin-on-disc abrasion test. Enhanced wear resistance was observed in microstructures containing mixed types of hard phases. Nickel and manganese are also added to hard facing alloys to improve toughness as these elements remain in the matrix to stabilize the austenite and prevent the formation of secondary carbides [2].

In submerged arc welding, cladding technology is mostly used in many variances and they are significantly used to improve the weld quality in several manners such as

a. Improving corrosion resistance

b. Improving productivity and efficiency

c. Improving wear property

The composition change resulting from phase transformation, precipitation and difference in the electrochemical activity between any two adjacent phases are the main factors controlling the corrosion performance of the weld [19].

Stainless steel or nickel-base alloys are required in many applications to provide shield from corrosion. Though, in many cases the relatively high price of these materials makes the deposition of a protective layer on a less expensive load-bearing mild or low alloy steel the most realistic economic substitute. Besides, weld surfacing gives the freedom to choose a wide variety of parent materials and consumables. Cladding by surface welding also permits flexibility in the production of objects of various shapes and sizes.

Commonly to get higher productivity in weld surfacing, the deposition rate should be high and dilution with parent material should be as low as possible. Submerged arc strip cladding has been widely used for many years for surfacing large areas and it is a flexible and economical way of depositing a corrosion resistant, protective layer on the low alloy steel [20].

Experimental studies and researched found that the use of metal powder will increase the deposition rate and welding-arc efficiency, at the same time it will reduce the shielding-flux consumption. The deposition rate is defined as the weight of filler material deposited in unit time. In the process concerned this involves melting of the filler material and the metal powder. The source of metal powder to the welding area will toughly increase the deposition rate.

Submerged arc weld cladding with metal powder addition is a process that is capable of production of weld surfaces with corrosion and wear resistance. This metal powder addition is used possibly to alloy a weld with optional chemical elements These methods are actually the variants of submerged arc welding which can be significantly used to increase the productivity and efficiency. It is possible to submerged-arc weld and clad with a multiple-wire electrode and metal-powder addition and it is capable of increasing the deposition rate, productivity and arc efficiency whereas consumption of shielding flux is reduced [6].

Cladding technique can be used to improve the surface property such as wear and oxidation resistance. During welding because of the heat process there are high chances for damage in the structures if heat affected zones. This can make a significant change in hardness and also the wear resistant property will begin to drop [21].

The relation between welding limits, cladding microstructure and wear performance has a significant role is attaining the higher quality of surface layer. Surface wear is very influential and as it needs to good to make the mechanical machine parts to have an extended life. Most of the machine parts are failed due to its surface wear and for reducing it coatings of carbides, oxides and other harder materials are coated. Wear is basically depended on the quality of alloyed materials, their hardness and also the carbon content. The hardness of the surface layer has great potential to have a great wear resistance [22].

Surface engineering is a commercial method for producing materials, machine tools, machine parts with the needed surface property based on the area it is used. The surface property is mainly the wear resistance and corrosion resistance [23].

Wear takes place when two surface comes in contact to each other and that makes the industries to focus on the wearable surface and other will be as abrasive surface. So surface coating is used to increase the wear and corrosive property of the base part that provides improvement in overall operation and protects it from breaking. But it is apparent that single surface treatment will not have greater impact on the properties and so the base must be done with material mixtures that has greater and proved physical properties. Abrasive wear rate can be frequently reduced by hard materials, choosing of materials is important in increasing surface property.

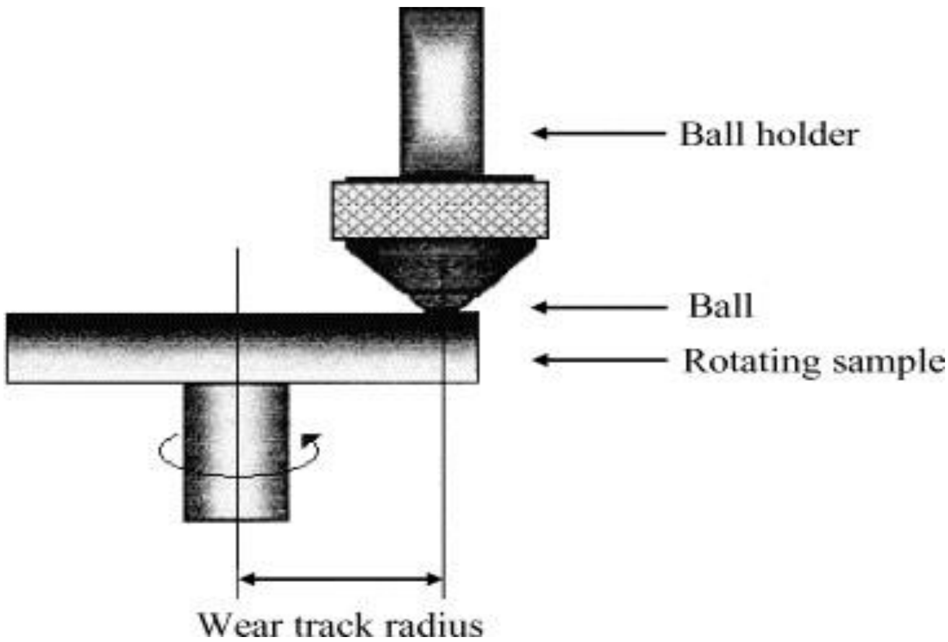

Figure 1.4 Schematic diagram of ball on disk wear test [18]

Wear test was are done with many methods and this is one of the commonly used method as shown if Figure 1.4 with a ball-on-circle wear test machine at room temperature without lubrication. The test examples were sliced to, the cladding surface of which was ground to a surface completion of Ra=0.2 μm. Wear tests were led under four distinctive weights (5, 8, 12 and 16 N), four diverse tangential sliding speed (8, 15, 25 and 35 cm/s) and four sliding distance (500, 1000, 1500 and 2000 m). Previously, then after the fact the wear tests the plate examples were ultrasonically cleaned and their weight was resolved on an accuracy offset with exactness of ±0.0001 g, and afterward the weight reduction was ascertained [18].

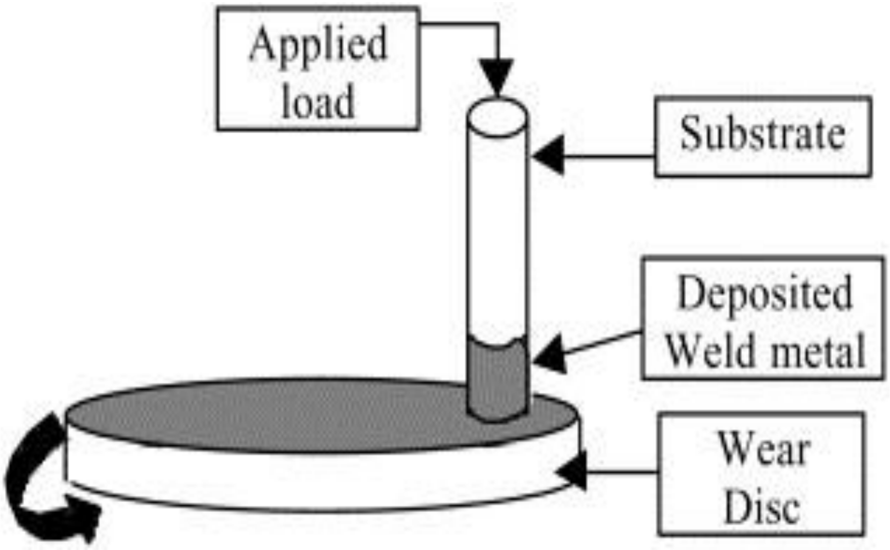

Figure 1.5 Schematic diagram of pin on disk wear test [23]

Pin on disk wear test method is another commonly used method for calculating the wear of the samples. For this wear test, sample are cut with a width of 6 mm and length of 40 mm. Welded surfaces of the samples were turned on a machine and the machined surfaces were cleaned in alcohol and acetone. The samples were then subjected to wear tests on a pin-on-disk test mechanical assembly, which is indicated schematically in Figure 1.5. This gadget is equipped with a variable speed motor and the velocity can be changed whenever within the tests.

Hardfacing is the kind of surface treatment that is used to expand the surface property of base metal in which the materials to be welded on the surface must have excellent wear resistance, higher hardness and strength. Commonly these surface coating is used to extend the life and protect the base metal that will be subjected to high wear environment during its operational process.

Moreover microscopic examination is used to check the surface layer that has several changes internally that cannot be viewed by direct observation. The microstructure of weld always has noticeable changes upon alloying addition and rapid solidification. These changes subsequently affect the mechanical and wear properties of all the alloys. [23].

2. METHODOLOGY

2.1 Sample preparation

In the present work the sample mixtures used are waste powder materials that are collected and mixed in certain proportions. Each powder has some common property that are necessary to obtain a quality weld. For a weld to be very high in its properties the material powders mixed together should have high hardness, high wear resistance, high melting point, low density and finally high corrosion resistance. Each sample has been made in order to analyze which mixture gives higher wear resistance and hardness. Table 2.1 shows the properties of powders that are used in this research work to prepare the sample. These properties are the most important and the reason for which the materials are used in various purposes.

Table 2.1 Important properties of material powders

Powder name	Important Properties
Silicon Carbide	High temperature strength High hardness and wear resistance Low density and oxidation resistance
Graphite	High melting point Insoluble in water and organic solvents Low density than diamond
Boron Carbide	Good chemical resistance Extreme hardness Low density
Chromium	High melting point High hardness and wear resistance High corrosion resistance
Ferro Manganese	It increases ductility and strength Helps to increase shrinkage
Tungsten Carbide	High strength and rigidity High hardness and wear resistance High corrosion resistance

Table 2.2 shows the sample powder material details along with the amount and percentage of each powder in every sample mixture.

Table 2.2 Sample details

Sample name	**Powder name**	**Weight of powder (gms)**	**Percentage of powder (%)**
1	Silicon Carbide (SiC)	30	50
	Graphite	6	10
	Boron carbide (B_4C)	6	10
	Chromium	18	30
2	Ground Recycled Glass	22	43
	P6M5	25	49
	Ferro Manganese (FeMn)	4	8
3	Ground Recycled Glass	30	68
	P6M5	10	23
	Graphite	2	4.5
	Ferro Manganese	2	4.5
4	Ground Recycled Glass	30	60
	Tungsten Carbide (88% WC 12% Co)	15	30
	Graphite	2.5	5
	Ferro Manganese	2.5	5
5	Silicon Carbide	42	70
	Calcium Carbonate ($CaCO_3$)	18	30

It is known that material powders which has carbide in it will certainly have very high hardness and lower density. Here in this research silicon carbide has been used along with boron carbide, chromium and graphite in sample 1.

At the same time it is also used in sample 5 along with calcium carbonate. So that not all samples are not prepared to be extremely hard but also to be little doubtful because calcium carbonate is not a material that has higher hardness and wear resistance.

Sample 2 has ferro manganese in that, which has high strength and decreases shrinkage. It is been mixed with P6M5 steel cutting tool's powder and glass powder. In the same manner the material powders used in 2 are added with graphite which in reality makes the sample 3. This is done to monitor whether which sample is more resistant and whether addition of graphite can provide extra properties that are necessary to give a quality surface layer. Once again the material powders of 2 is mixed with tungsten carbide to make sample 4 which can give another possibility to check whether addition of carbide can provide the strength, hardness and wear resistance as necessary.

2.2 Welding process

The dimensions of the base metal used in this research is 70mm in length and 15mm in breadth. The base metal is plain carbon steel of Russian grade Cт3. The plain carbon steel used in this research is having a composition of carbon (0.14-1.22%), silicon (0.15-0.5%), manganese (0.4-0.65%), Sulphur (>0.05%), phosphorous (>0.04%). This base metal is surface layered with the sample mixture prepared by using submerged arc welding process.

Submerged arc welding process is used in this research. Figure 2.1 shows the submerged arc welding equipment used in this research. The purpose of this equipment is to weld the sample material powders on the surface of the base metal strip made of steel which is the initial step of the research. The equipment consists of an electrode wire feed with power supply, the welding torch for automatic welding or the welding gun, power source, work piece holder, emergency stop button, flux hopper (in this present work flux feed is done manually) and earth lead connection.

In submerged arc welding, the process consists of an arc that is formed when electric current passes in-between the weld wire and the work piece. The sample material powder mixtures that has to be over welded on the base metal is either fed manually or through flux hopper. The weld wire with the power of electric arc welds the powder mixture on the base metal strip.

During this process the welded area is covered by a layer of flux which protects the whole operation from the atmospheric contamination. Throughout the process the flux is partially melted forming a liquid protective layer called slag layer which gets solidified during the process generating a waste material called slag [24].

When the sample attains the atmospheric temperature the slag layer comes off from it, which makes the samples ready to be used for the further research. The surface layer is then grinded to get a flat surface which is much necessary for hardness test to be followed.

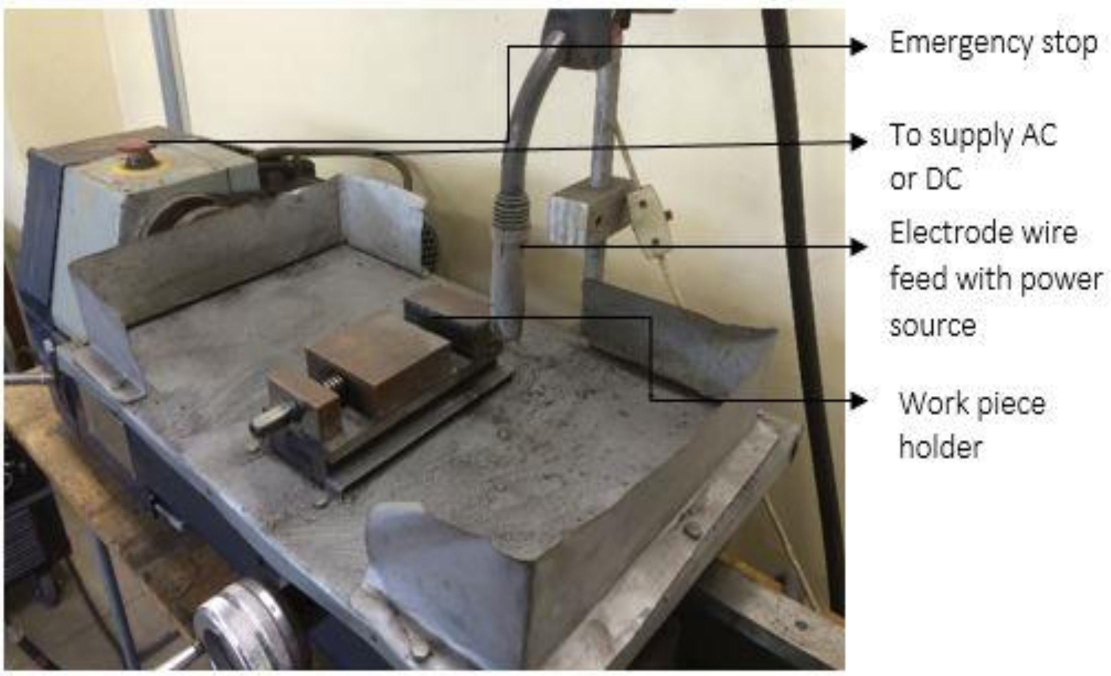

Figure 2.1 Real time submerged arc welding equipment

Figure 2.2 shows the schematic diagram of the submerged arc welding equipment during the process.

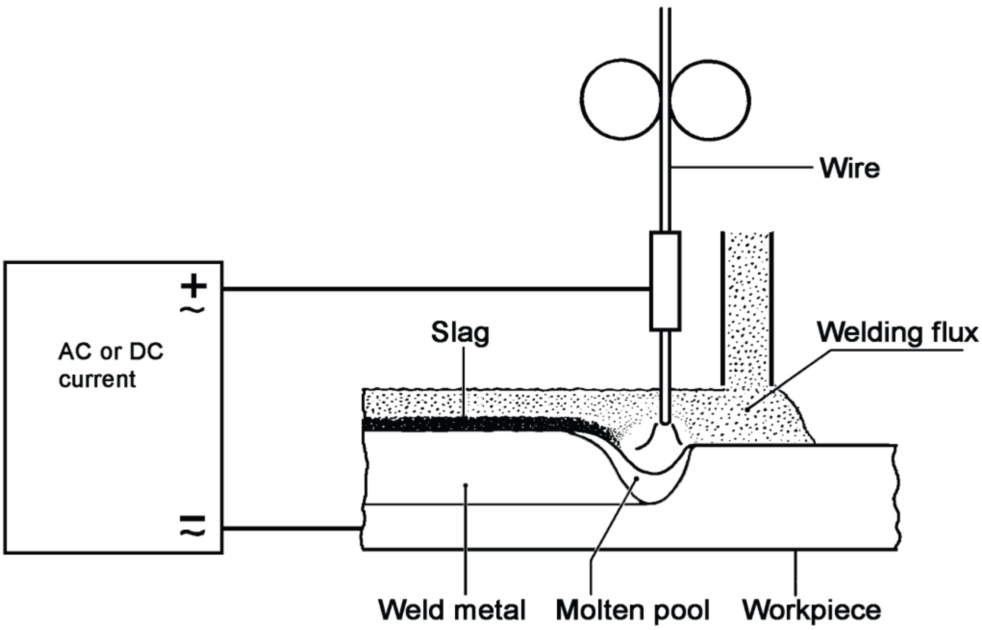

Figure 2.2 Manually operated submerged arc welding schematic diagram (Weman, K., 2011)

2.3 Hardness test

Right after the welding of samples they are subjected to hardness measurement test. Hardness is defines as 'Resistance of metal to plastic deformation' and also can be generally explained as to resistance to scratching, abrasion or even cutting. It is the property of the metal, which gives the capability to resist being permanently deformed. If the hardness of the metal is high, then it has the higher resistance against deformation. There are three methods that are most commonly used to measure the hardness of the metal. They are

1. Rockwell hardness test

2. Brinell hardness test

3. Vickers hardness test

In this research Rockwell hardness test has been used to measure the hardness of the samples prepared. Rockwell hardness measurement test is based on the net increase in depth of impression when the load is applied. The number read in the dial gauge/display screen of the equipment gives the hardness of the metal. Hardness numbers have no units and they are denoted by the letters HR (Hardness Rockwell) followed by another letter according to the Rockwell scale. For example as used in this research the hardness values are mentioned followed by HRC, which means the materials used in this research comes under the scale C. The scale C has steel, hardened steel, cast iron and other materials that are harder than aluminum, copper and malleable iron.

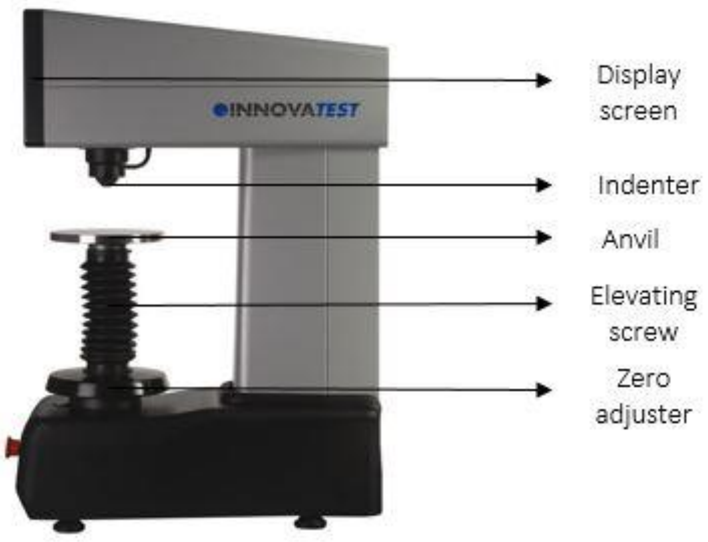

Figure 2.3 Rockwell Hardness testing equipment

Figure 2.3 shows the equipment used for hardness measurement. The Rockwell letters scale are listed in Table 2.3 along with the material types.

Hardness is measured in this present work in another situation too where the samples are cut into several parts where each parts will undergo different test to determine the best among it. One among the part of every sample has been tempered under certain degrees such as 500°C, 550°C, 600°C, 650°C. After each tempering it has been checked for hardness so that the variance in hardness of the samples are noted for analysis purpose.

Table 2.3 Rockwell hardness letter scale [25]

Letter	Type of Materials
A	Cemented carbides, thin steel and shallow case hardened steel
B	Copper alloys, soft steels, aluminum alloys, malleable iron
C	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel and other materials harder than B
D	Thin steel and medium case hardened steel and pearlitic malleable iron
E	Cast iron, aluminum and magnesium alloys, bearing metals
F	Annealed copper alloys, thin soft sheet metals
G	Phosphor bronze, beryllium copper, malleable irons
H	Aluminum, zinc, lead
K,L,M,P,R,S,V	Bearing metals and other very soft or thin materials, including plastics.

2.4 Microstructure analysis

Metallographic examination is further done to study the microstructure of all the samples prepared. Before examining the surface of all samples it should be done with some serious steps that involves coarse grinding, fine grinding and polishing. The samples are mirror finished in order to examine the accurate microstructures. Initially abrasive sheets are used to grind the surface carefully and then it should get mirror finished, so aluminum oxide is used in powder form. With the help of vibrator fixed with cotton sheet, aluminum oxide is spread all over the sheet and water is mixed with it.

When the vibrator is switched on the sample to be mirror finished is slid on the cotton sheet with aluminum oxide paste. This method is done for more than 20 minutes on each sample to get the mirror finish on the surface to be examined with the microscope. Figure 2.4 shows the microscope used for the structure examination in this present work. This is the laboratory microscope used to study the materials at a closer look to analyze the change in the microstructures and so the impact of this change can be physically expected in the product while doing the wear test.

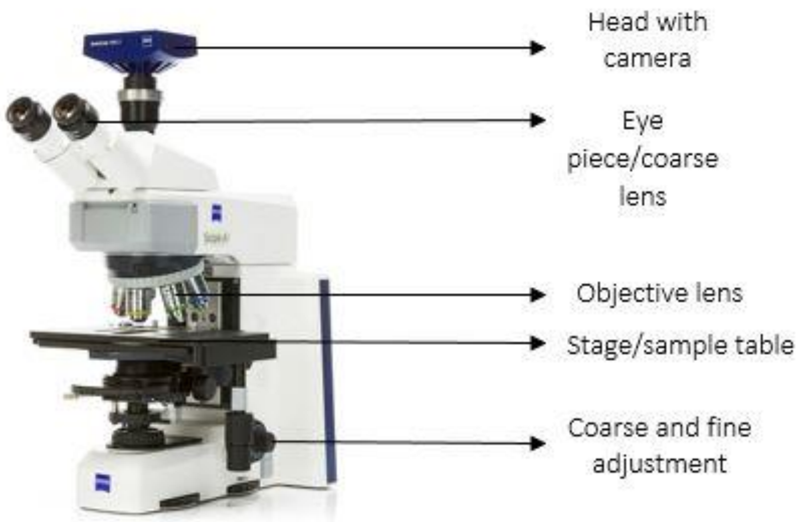

Figure 2.4 Microscope for micro structure analysis

After the sample surfaces are mirror finished, it is kept in microscope stage to examine under magnification from 2x to 250x (see Figure 2.5) where the structures are prone to get analyzed using photographs.

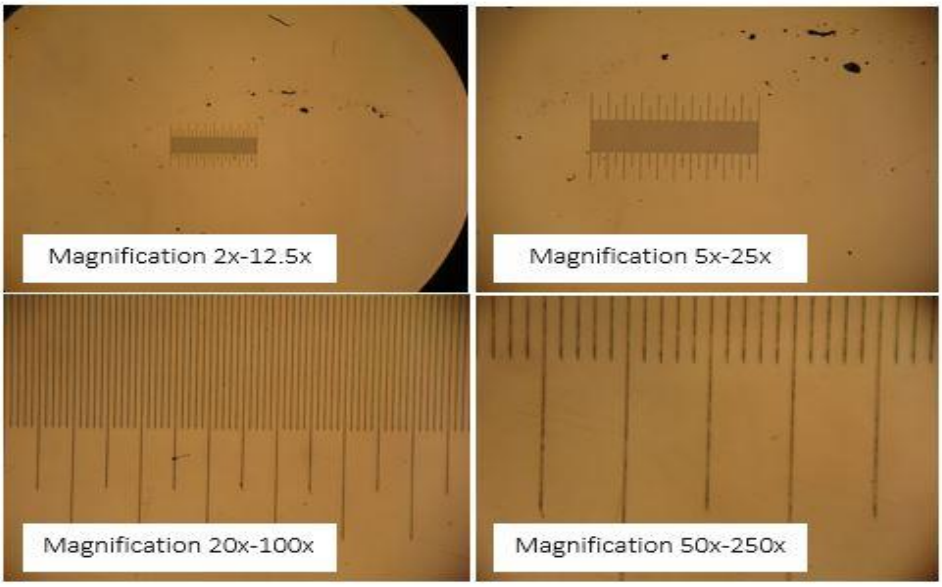

Figure 2.5 Magnification range of microscope

The same samples which are analyzed initially is then tempered at a certain temperature and then again the microstructure photographs are taken using microscope to analyze the changes that take place. This gives a clear understanding of structural changes due to tempering which in turn can be either be a positive effect or maybe negative too.

2.5 Wear resistance test

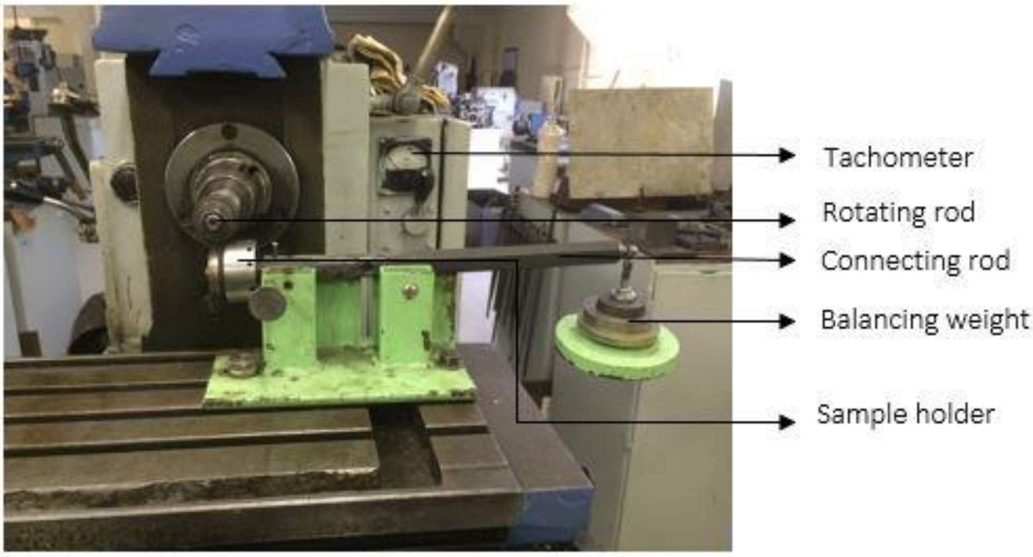

Figure 2.6 Wear resistance test machine

Wear test is performed on materials to acquire the wear property which in turn will be useful to determine the specific wear application. In this present work wear measurement test is performed on samples to determine the total amount of welded layer got removed or worn away after each test and the weight or mass of the sample must be checked and noted. The mass of the samples are measured using the common analytical balance with very high accuracy and zero error. Figure 2.6 shows the machine which is used to test the wear resistance of samples.

The samples are cut into a 6mm small piece so that the sample holder of the machine can hold it. The rotating hard metal rod of 41mm diameter which runs at certain rpm along with the force given by the balancing weight can develop a load of 320 N by which the force acts on the samples. For every 40 meter (~4 minutes 22 seconds) sliding distance, the weight of the samples are noted and this procedure is followed till the machine runs 200 meter on each sample. The decrease in weight of the samples gives the wear of the samples. It is believed that if the decrease in weight of the sample is less, then the wear resistance is more and vice versa. In this research wear is calculated by taking the mass of the sample after every 40m sliding contact and then subtracting it with the mass of the sample before the test. It will denoted in grams and will be easy to identify which has the best wear based on the results obtained.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 3.1 to Figure 3.5 shows the actual pictures of the samples taken after the submerged arc overlay welding process. After the overlay welding the samples are subjected to grinding of the welded layer to make the surface layer flat for proper hardness test which determines the strength of the layer.

Figure 3.1 Sample 1

Figure 3.2 Sample 2

Figure 3.3 Sample 3

Figure 3.4 Sample 4

Figure 3.5 Sample 5

These 5 samples are then cut into three parts each and each are subjected for three kinds of analysis. One part of each sample is for hardness measurement test, one part is surface smoothened with mirror finished and used for microstructure investigation and analysis, one part is cut into 6mm length small piece for the wear test and analysis. These three investigation and analysis of results are discussed in the coming section where the changes in the surface layer at different conditions are deeply studied.

3.1 Hardness test results and investigation

Rockwell hardness test is done on the samples after welding and the readings the noted. The final hardness values are obtained after taking a series of readings and the average is calculated from it. Table 3.1 shows the hardness values of samples taken right away after welding. It is clear that the sample 4 with tungsten carbide, graphite, P6M5 tool steel powder and glass powder has the highest hardness of 57 HRC compared to other samples.

Next comes the sample 2 with 46 HRC which has the sample materials similar to sample 4 except the tungsten carbide. Sample 1 and 5 has almost similar hardness of 34HRC and 32HRC. It is notable that sample 1 has silicon carbide, boron carbide, graphite and chromium but the 5 has just silicon carbide along with calcium carbonate. So perhaps the silicon carbide plays a significant role in sample 1 but the other material addition doesn't show much more impact as expected. Sample 3 has the lowest hardness among the five of just 25 HRC.

Table 3.1 Hardness of samples measured at various conditions

Sample name	**Hardness after welding (HRC)**	**Hardness after tempering for 1hr**			
		500ºC (HRC)	**550ºC (HRC)**	**600ºC (HRC)**	**650ºC (HRC)**
1	34	33	55	43	40
2	46	49	49	47	43
3	25	34	35	35	35
4	57	54	52	46	43
5	32	46	48	41	41

Tempering is a method of heat treating that give toughness for alloys and so these samples are subjected to tempering to check whether this makes the samples to come under one of the three conclusions (Hardness can increase, hardness may decrease or it may even remain the same). So the samples are heat treated under four temperatures 500ºC, 550ºC, 600ºC, 650ºC.

Table 3.1 displays the results of hardness values obtained after tempering at every stage of all the samples. All the samples are heat treated for 1 hour at each temperature as mentioned before to obtain and analyze that how much the material get hardened or loses it hardness at certain point. These results are clearly explained using graphical figures to draw the conclusions more precisely.

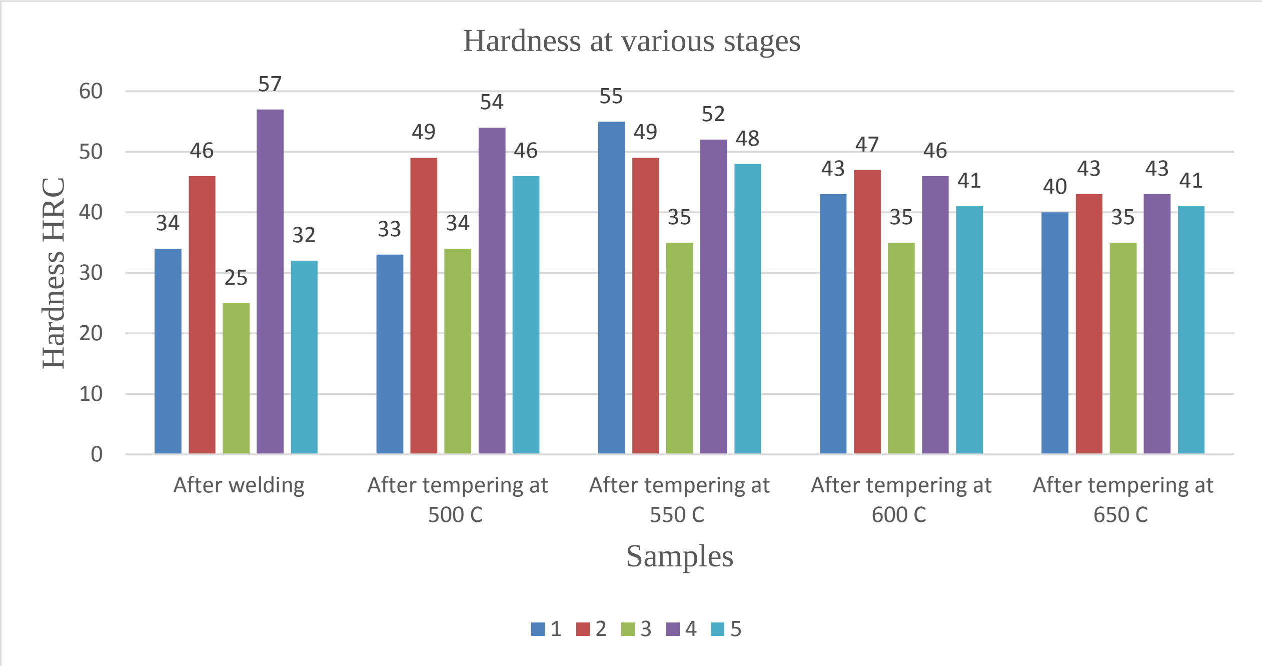

Figure 3.6 Hardness comparison of samples at various stages

Figure 3.6 shows the hardness values of all the samples under all circumstances and it is then clearly explained stage by stage to get a clear understanding how hardness change at every stage of heat treating.

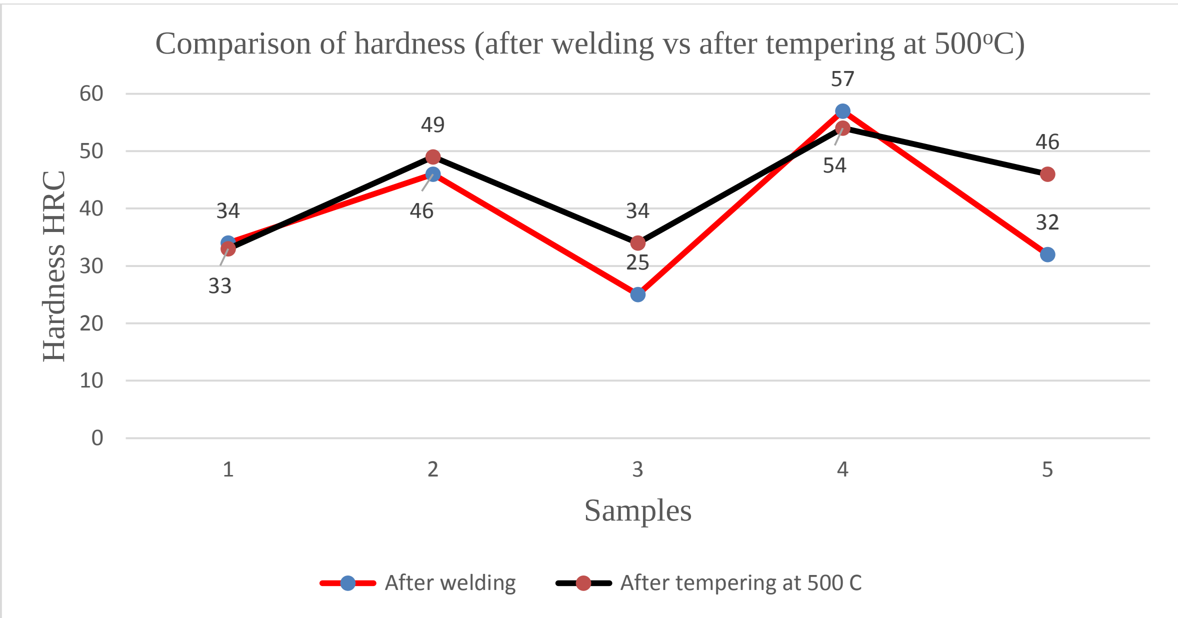

Figure 3.7 Hardness comparison of samples (after welding vs after tempering at 500ºC)

Figure 3.7 shows the hardness value comparison of all the samples before and after tempering. While being compared, the hardness of sample 1 is 33 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 4 the hardness is reduced by 3 HRC, which means it was 57 HRC when it is welded and now after tempering at 500°C the hardness reduces to 54 HRC. Appears like tempering doesn't work for the sample 2. But for all the other three samples hardness value is significantly improved at a sensible number. For sample 5 the hardness is 46 HRC after tempering at 500°C which is actually 12 HRC higher than previous condition. Likewise the hardness of sample 3 increased by 9 HRC and it is now 34 HRC which seems to be a considerable increase. Sample 2's hardness is actually increased to 49 HRC which is 3 more than the previous hardness of it. So it is assumed that the hardness will be even much better after the next tempering at 550°C.

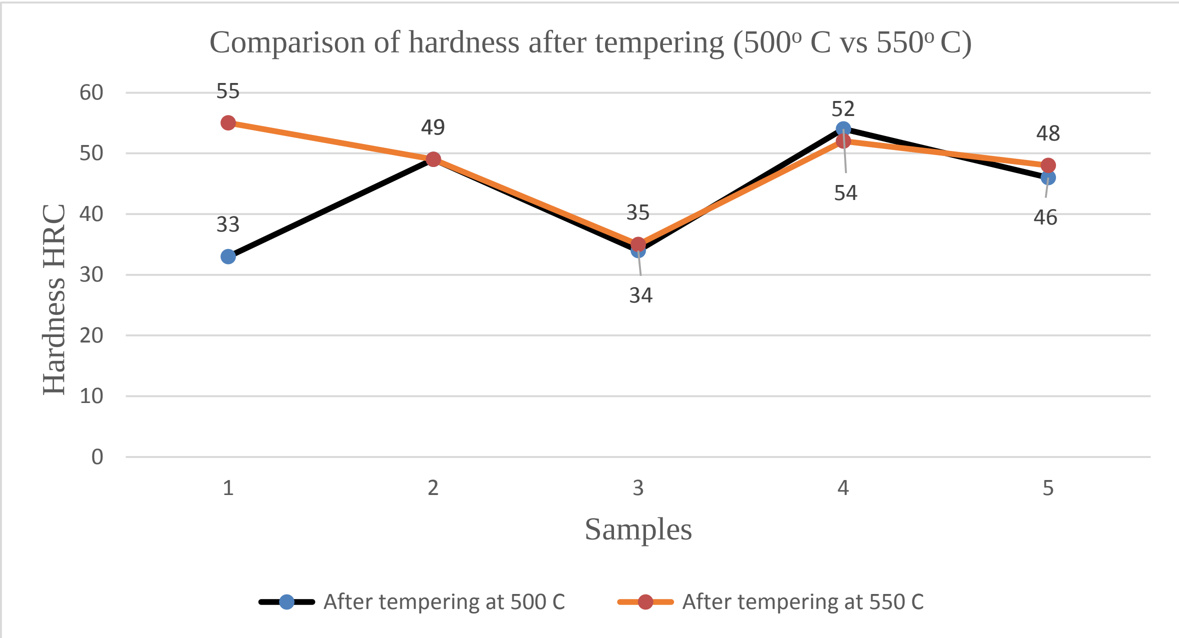

Figure 3.8 Hardness comparison of samples after tempering (500°C vs 550°C)

The comparison of hardness values of samples after it has been tempered at 550°C along with the hardness it had after tempering at 500°C is shown in the Figure 3.8. This heat treatment has given an enormous amount of increase in hardness to the sample 1 which is now 55 HRC that is much more than the hardness after welding and also after tempering at 500°C. For sample 3 the hardness is increased by 1 which is now 35 HRC and for sample 5 it's increased by 2 which is now 48 HRC. Sample 2 started to halt the heat treatment which remains at the same hardness of 49 HRC. But sample 4 is on track to reduce the hardness, it reaches 52 HRC which is now lower than previous tempered hardness.

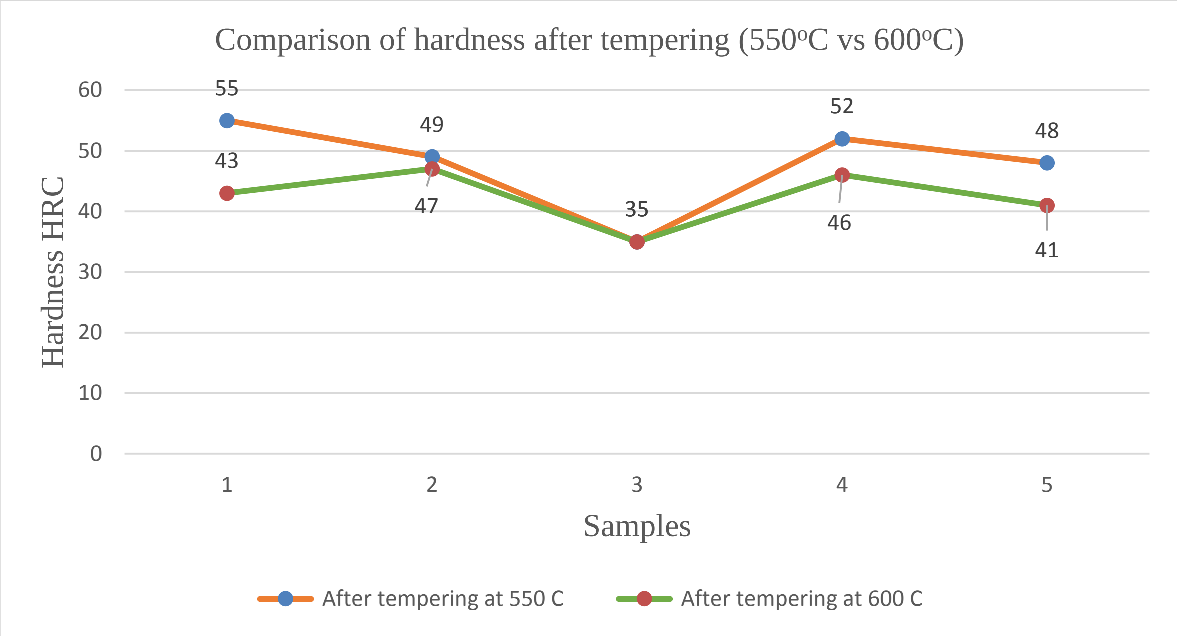

Figure 3.9 Hardness comparison of samples after tempering (550°C vs 600°C)

Figure 3.9 and Figure 3.10 explains the hardness values of samples after it has been heat treated at 500°C, 600°C and 650°C. When comparing these values it is clear that the hardness remains same for the sample 3 but for all the other samples hardness started to reduce which makes it clear that these sample with the welded surface layer cannot be tempered more. Among all stages of heat treatment, tempering at 550°C makes the samples more hardened except for sample 3.

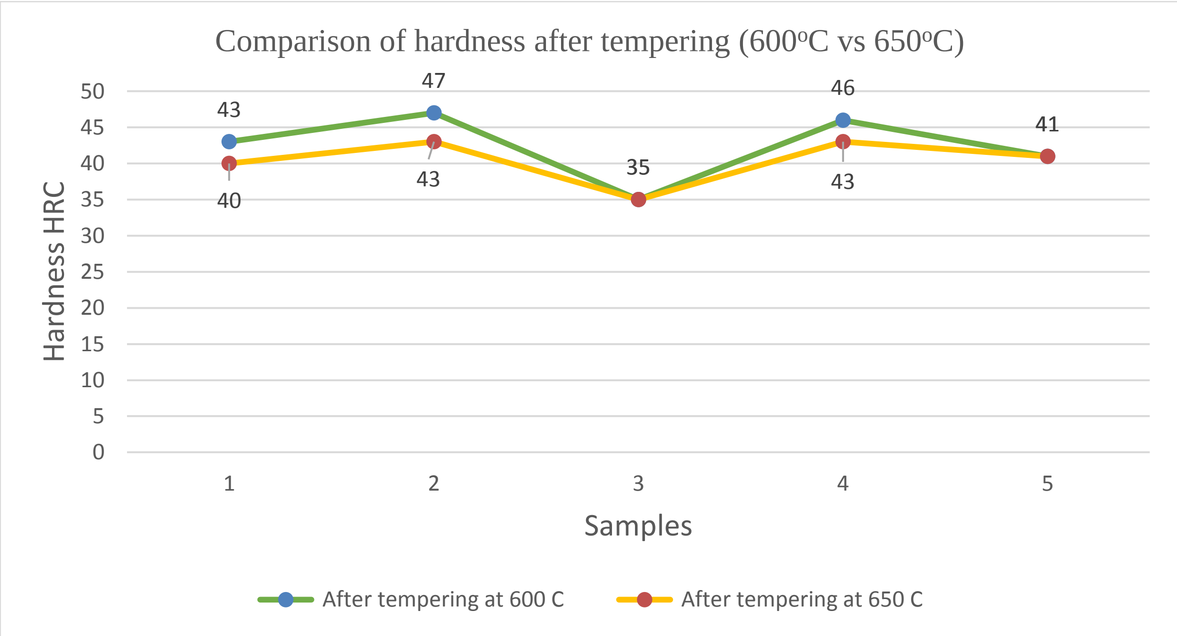

Figure 3.10 Hardness comparison of samples after tempering (600°C vs 650°C)

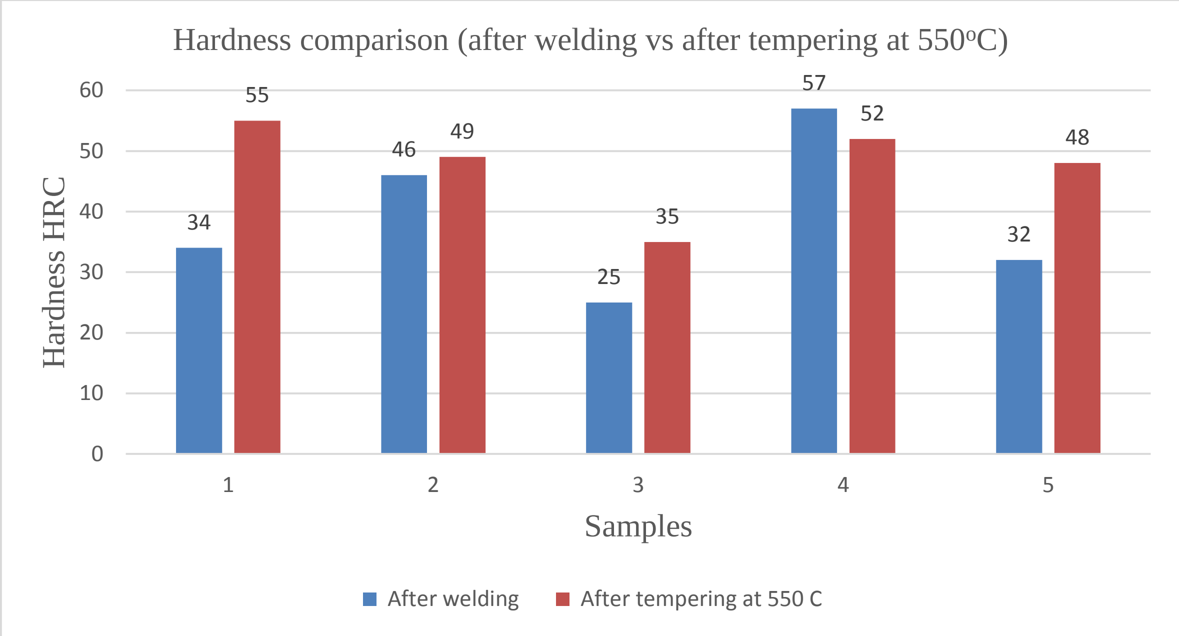

Figure 3.11 Hardness comparison of samples (after welding vs after tempering at 550°C)

Figure 3.11 shows the hardness comparison of samples after welding and after tempering at 550°C. This bar 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 samples are welded and cooled rapidly under water in room temperature, then its cut, surface smoothened manually and mirror finished for microstructure examination. Samples are examined under microscope to study the structures formed after welding. Figure 3.12 to Figure 3.16 shows the microstructure picture of samples taken right after welding.

It is seen from the pictures that welded layer under magnification of 2.5x-50x shows the formation of microstructures clearly for all the samples. It is known from the structures that after welding and rapid cooling under water made it to form the retained austenite and martensite mostly. Retained austenite is the crystalline structure of iron and steel which is light in color and it is soft and tough in its property. It is so called retained austenite because it won't transform into martensite crystalline structure after quenching.

Retained austenite at certain temperature has the ability to transform into austenite or martensite and it has high density compared to martensite. Depending on the specific heat treatment temperature the level of retained austenite in the structure can vary from 0-50%.

Martensite is another crystalline structure formed by carbon steel. It can be identified as dark colored needle type structure and it has lower density than austenite. It is hard, strong and brittle and can change to tempered martensite from brittle martensite after being tempered.

Figure 3.12 shows the microstructures of sample 1 which as carbides and retained austenite in it. The light colored crystalline structures are the formation of retained austenite with carbides combined. The other color changes are due to the heat affected during the welding process.

It is already known that sample 1 has carbides in the powder mixture that is used for surface layering and so the presence if carbide is very high with retained austenite which is the crystalline form of iron and steel. The amount and size of carbides can increase depending on the temperature of the tempering process and this is being expected as the samples are tempered and analyzed again.

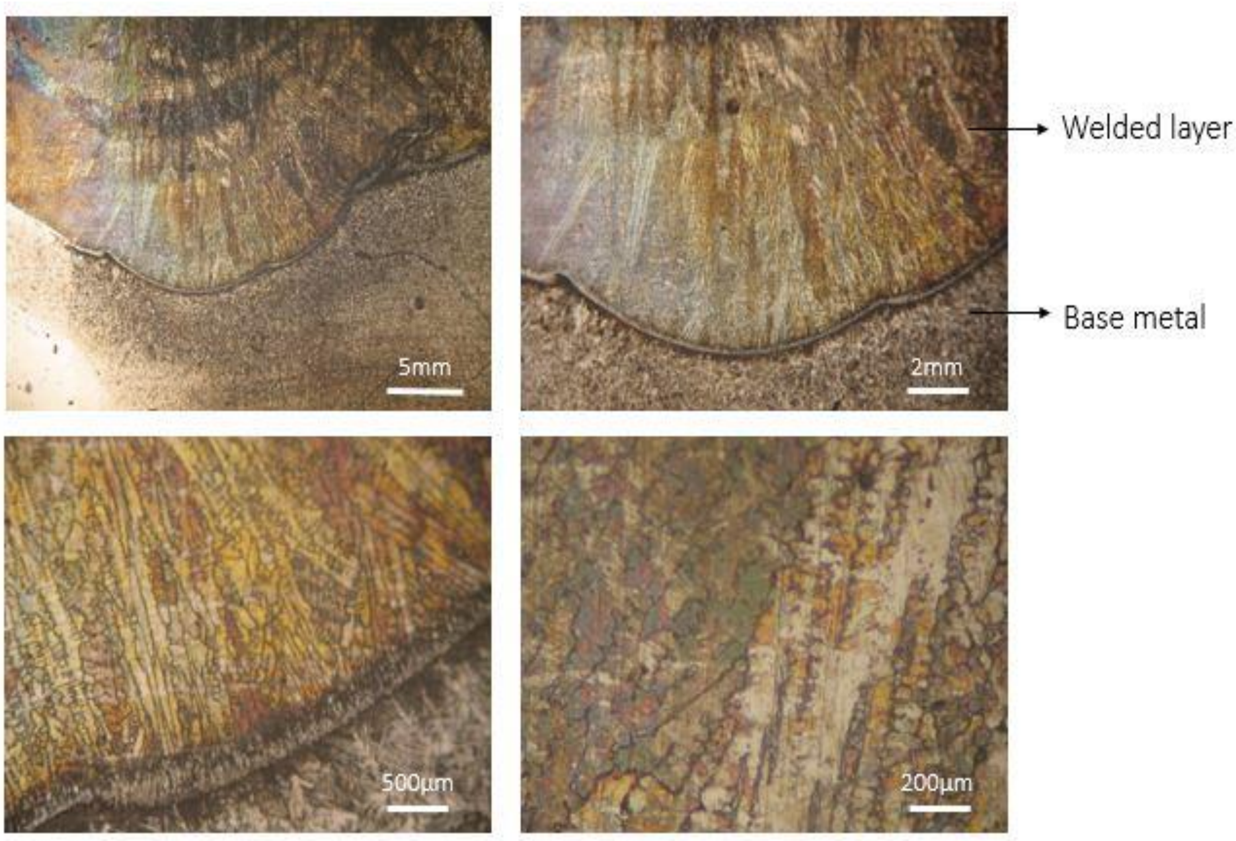

Figure 3.12 Microstructure of Sample 1 after welding

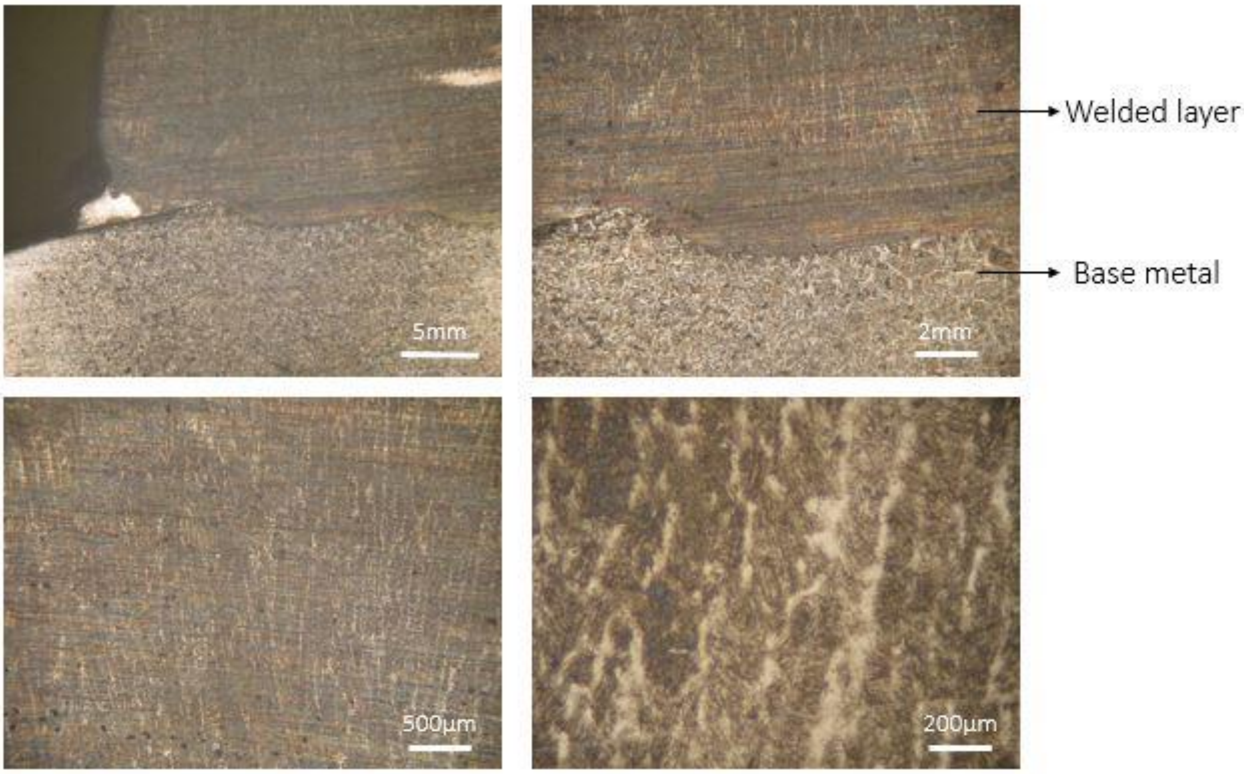

Figure 3.13 Microstructure of Sample 2 after welding

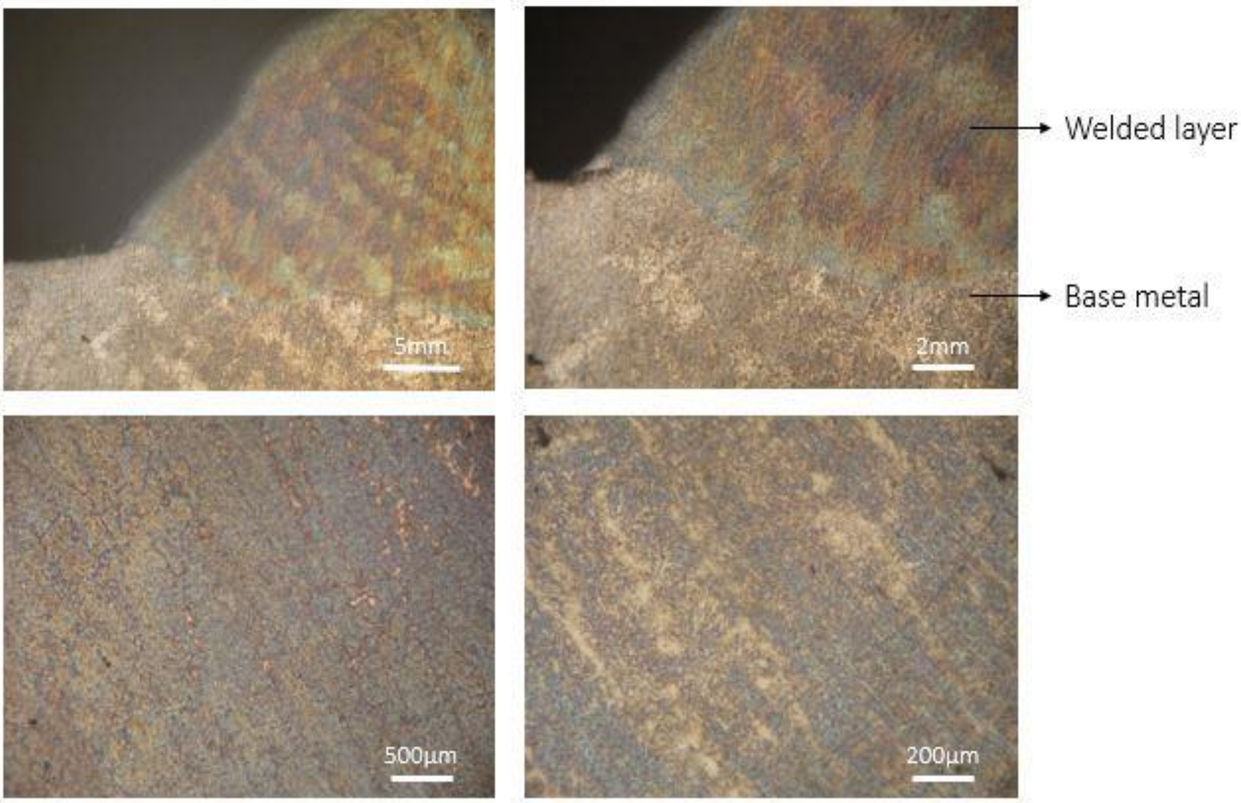

Figure 3.14 Microstructure of Sample 3 after welding

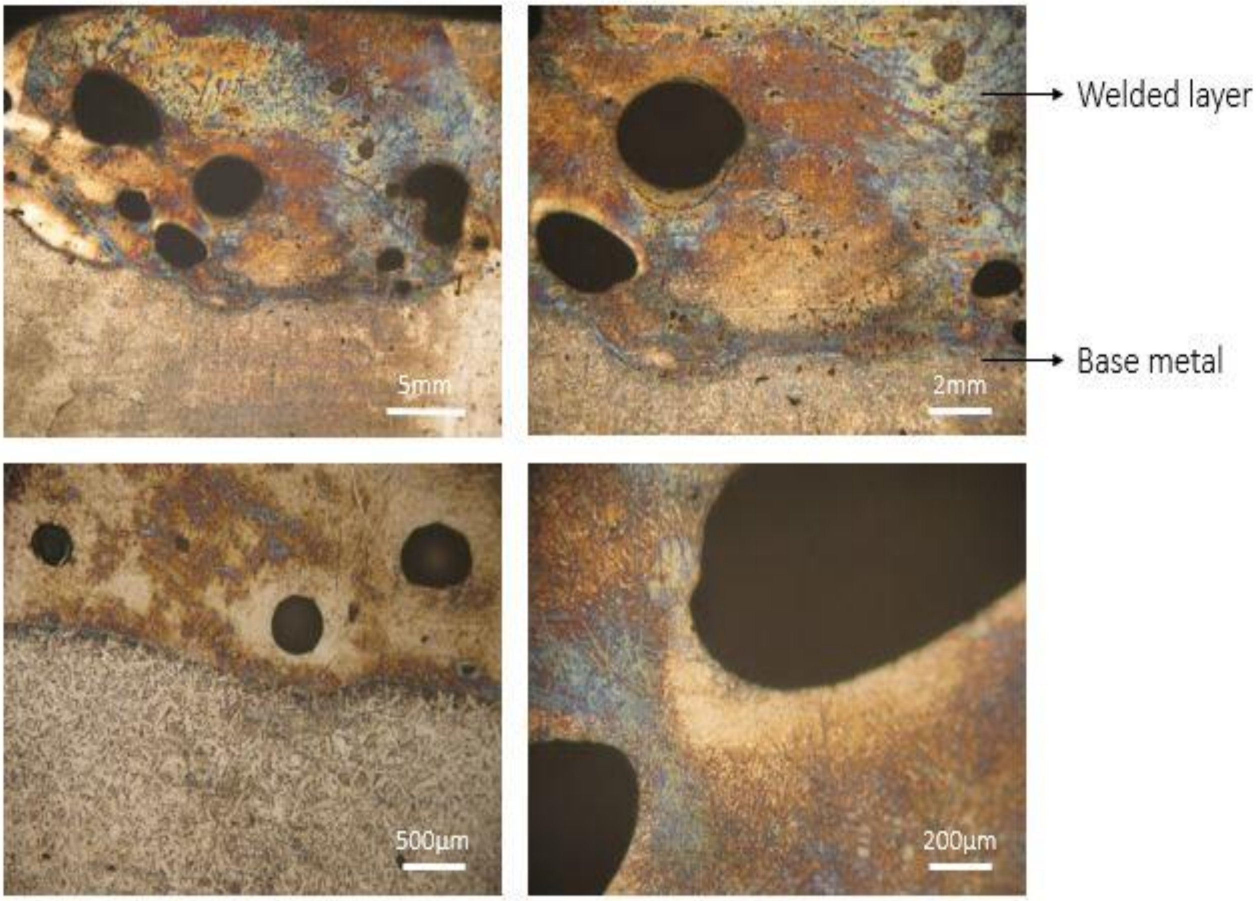

Figure 3.15 Microstructure of Sample 4 after welding

Figure 3.13 (sample 2), Figure 3.14 (sample 3) and Figure 3.15 (sample 4) shows the microstructure of samples taken right after the welding of surface layer has done. It is recognized from the pictures taken that all the three sample structure has dark crystalline structure of martensite and light colored retained austenite in it. Retained austenite will transform into martensite when the sample is tempered totally and can even impact the change if dimensions and it can even affect the strength of the surface layers and initiate crack. On the other side martensite will remain but the brittle martensite can fully transform into the tempered martensite.

In sample 4 the structure shows large porous formed in-between the welded layer and so the for the wear resistance test the sample is cut excluding the porous which may affect the resistance and cannot be compared with other samples.

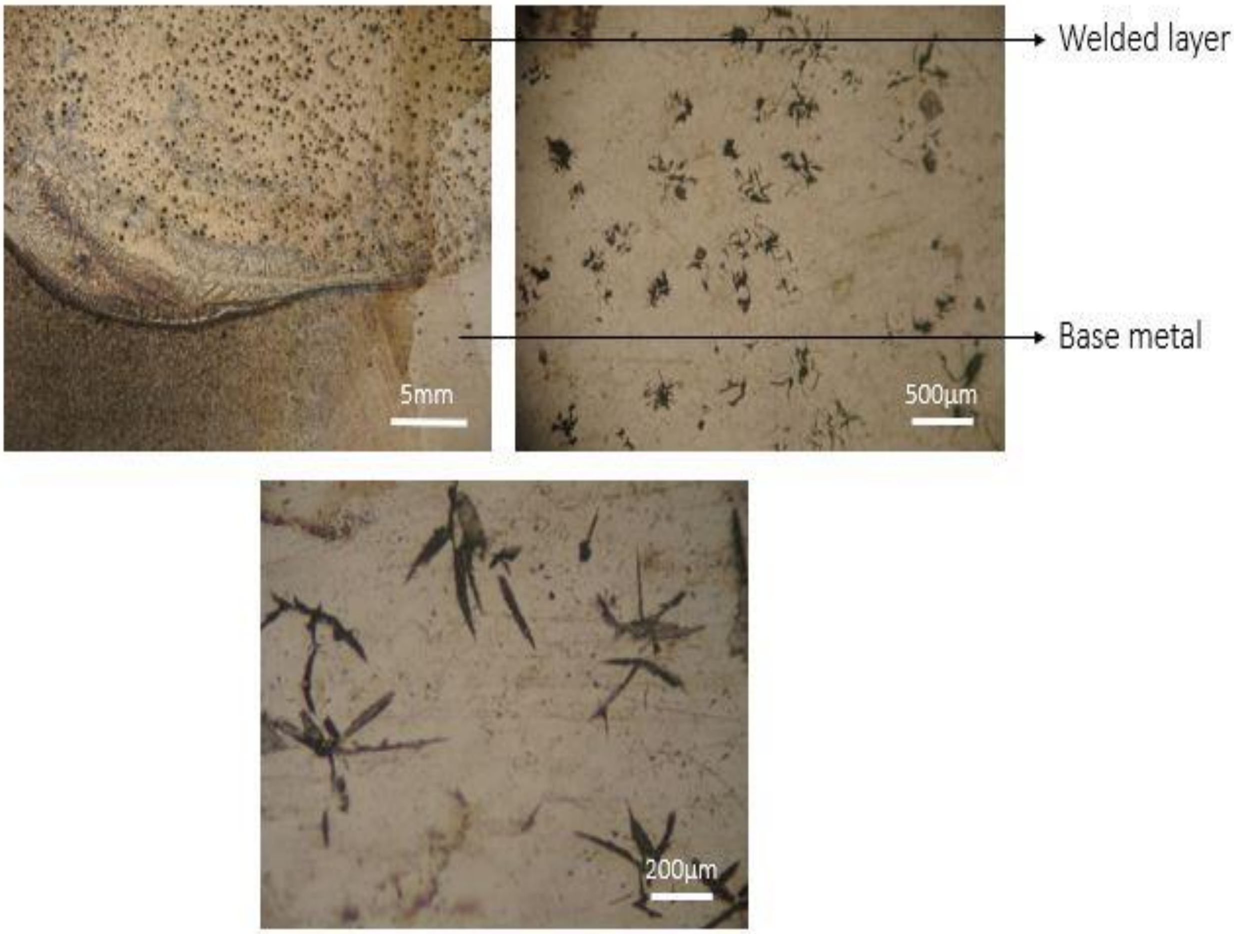

Figure 3.16 Microstructure of Sample 5 after welding

Figure 3.16 shows the microtructure of sample 5 after welding. In this strucuture there are graphite fromed which can be identified as flower shaped strucuture in the picture. Along with it the light colored surface are cementite with areas of ledeburite. Graphite identified here is the lamellar type graphite which is actually a cast iron type material based on iron and carbon.

Ledeburite identified here in this strucuture is not a steel type because it has more carbon content in it which can be upto 4.3% and it is eutectic mixture of austenite and cementite. There are possibilities that it can even forms separately in high cabron steels and content can vary from 2-7%.

Cementite is the chemical compund of iron and carbon which is found in this strucuture with ledeburite. It is a hard and brittle material which has same properties as found in martensite but not the strucutre. It is commonly called as ceramic.

3.2.2 Microstructure of samples after tempering

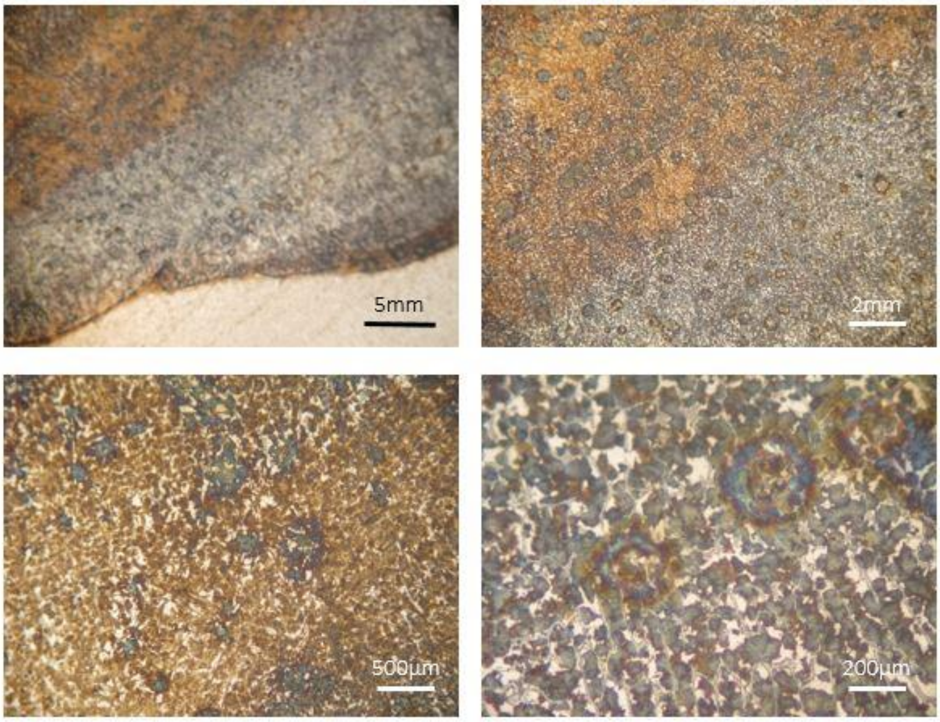

Figure 3.17 Microstructure of sample 1 after tempering

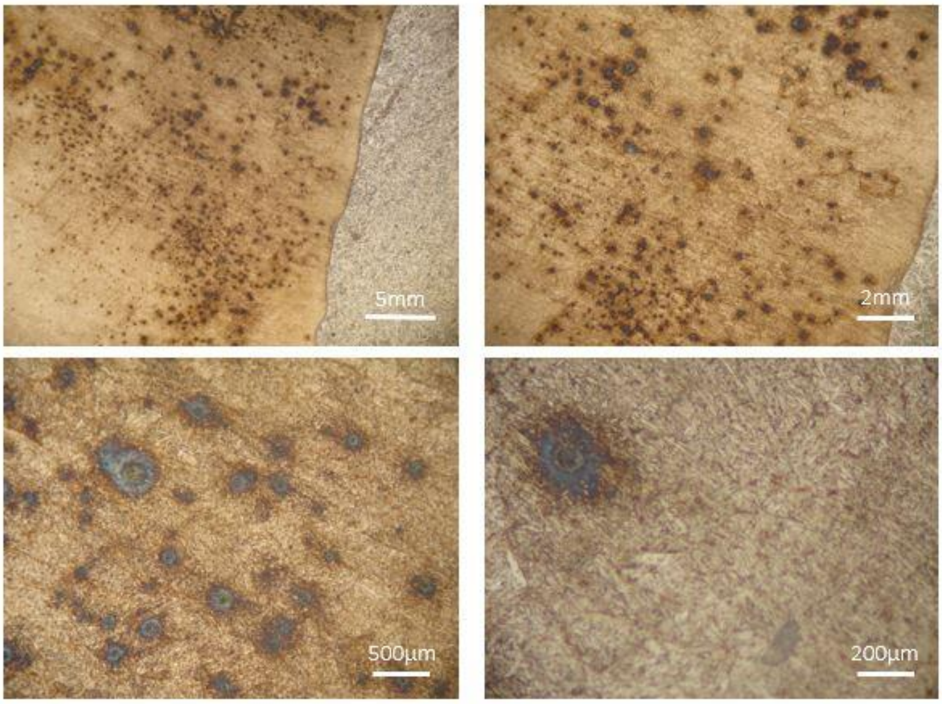

Figure 3.18 Microstructure of sample 2 after tempering

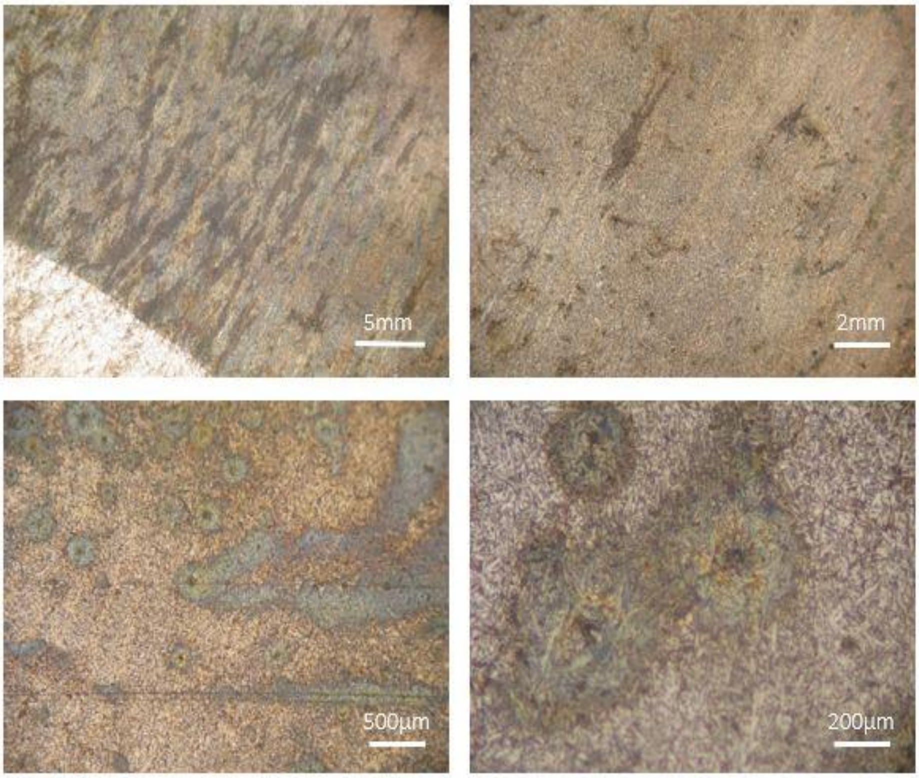

Figure 3.19 Microstructure of sample 3 after tempering

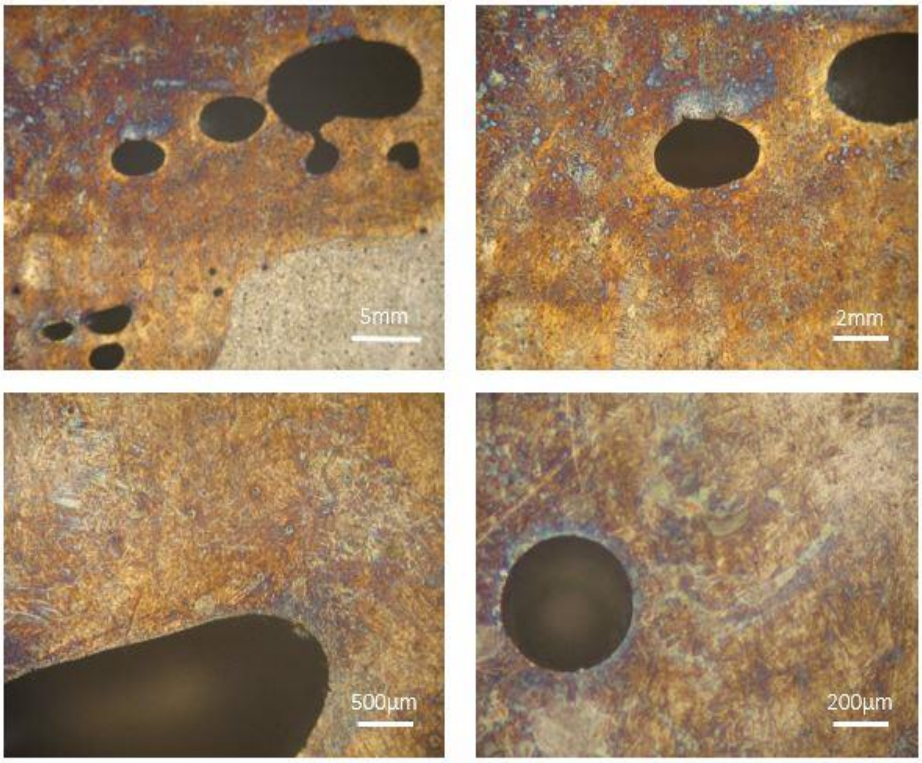

Figure 3.20 Microstructure of sample 4 after tempering

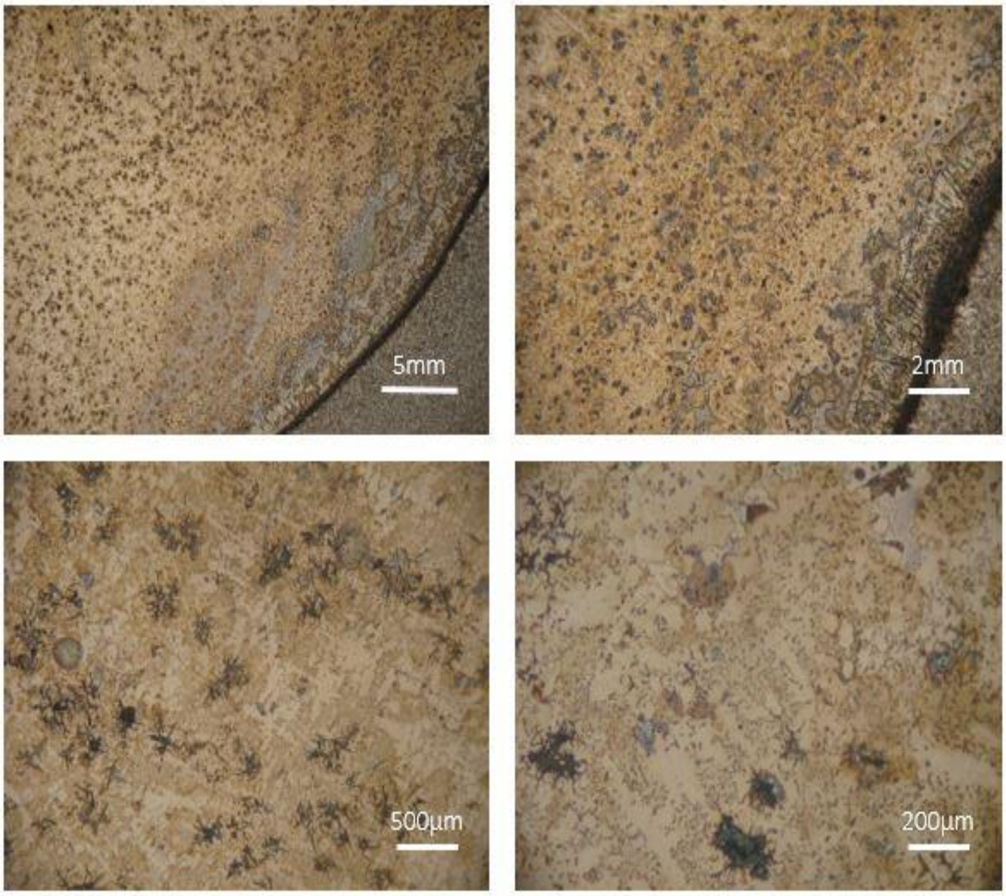

Figure 3.21 Microstructure of sample 5 after tempering

Figure 3.17 to Figure 3.21 shows the microstructure pictures of samples taken after tempering at 550^{o}C. This tempering temperature is chosen because while testing the hardness of the surface layer, in this temperature the hardness seems to be very highly improved for the samples. While examining the microstructures after tempering samples showed a notable changes in the structures.

In samples 1 the carbides are increased in size and amount as expected and it has martensite along with it. Martensite is in tempered form as it is the result of tempering. In the samples 2, 3, and 4 only martensite is mostly identified as this is also the impact of tempering at the temperature 550^{o}C. In these samples it was retained austenite present before tempering is now completely transformed into the martensite crystal structure. Only in sample 4 the porous remained in the structure along with martensite.

In sample 5 as identified earlier before tempering, the same structures are still present. Graphite is present in this structure after tempering in small amount whereas cementite and ledeburite is present with areas of pearlite.

3.3 Wear test results

3.3.1 Wear test values after welding

Wear test values after welding of samples for every 40m sliding contact is mentioned in the Table 3.2. All values are mentioned in grams which is determined after testing several times with every sample. These firm results shows a precise view of how the wear changes in each sample after every 40m sliding contact with the rotating steel rod.

Table 3.2 Wear of samples after welding

Sample name	Wear (weight loss in grams)				
	40meter	80meter	120meter	160meter	200meter
1	0.000216	0.0007	0.000826	0.00135	0.00185
2	0.000583	0.000966	0.0013	0.00148	0.00225
3	0.000316	0.000666	0.00121	0.00163	0.00173
4	0.0002	0.0005	0.000825	0.0009	0.0011
5	0.0017	0.0038	0.0049	0.0059	0.0211

Figure 3.22 Comparison of wear after welding (sample 1-4)

Figure 3.22 and Figure 3.23 shows the comparison of wear values of each sample. Sample 5 is the least wear resistant which is actually hard faced with silicon carbide and calcium carbonate. Even though the hardness of 5 is not much less after welding but its wear resistance ability is very low and so it cannot be compared with other four samples.

Among the other four, sample 4 is more wear resistant and sample 2 is least wear resistant. In between there are 1 and 3 where the values are not more different from each other but when looking at the values it is predictable that 1 is getting worn out at a higher rate than 3.

Figure 3.23 Wear of sample 5 after welding

Sample 1 is hardfaced with silicon carbide, boron carbide, graphite, chromium and sample 3 with P6M5 steel tool powder, ferro manganese, graphite, glass powder. Although carbides have a high strength and low density, it is that ferro manganese and graphite that has more wear resistance than carbides. 4 which as tungsten carbide as one of the material powder with the mixture has higher wear resistance among all. Inclusion of either P6M5 steel tool powder with ferro manganese doesn’t show much impact because sample 2 has the least wear value.

Figure 3.24 shows the comparison of wear test values after 200m of sliding contact. The force acting on the samples is more or less then same at every 40m and it is predominant to be more wear resistant, looking at the values it is 5 that is more worn out and 4 that is less worn out. In other words sample 4’s wear value is much lower which means it is more wear resistant than all the other samples

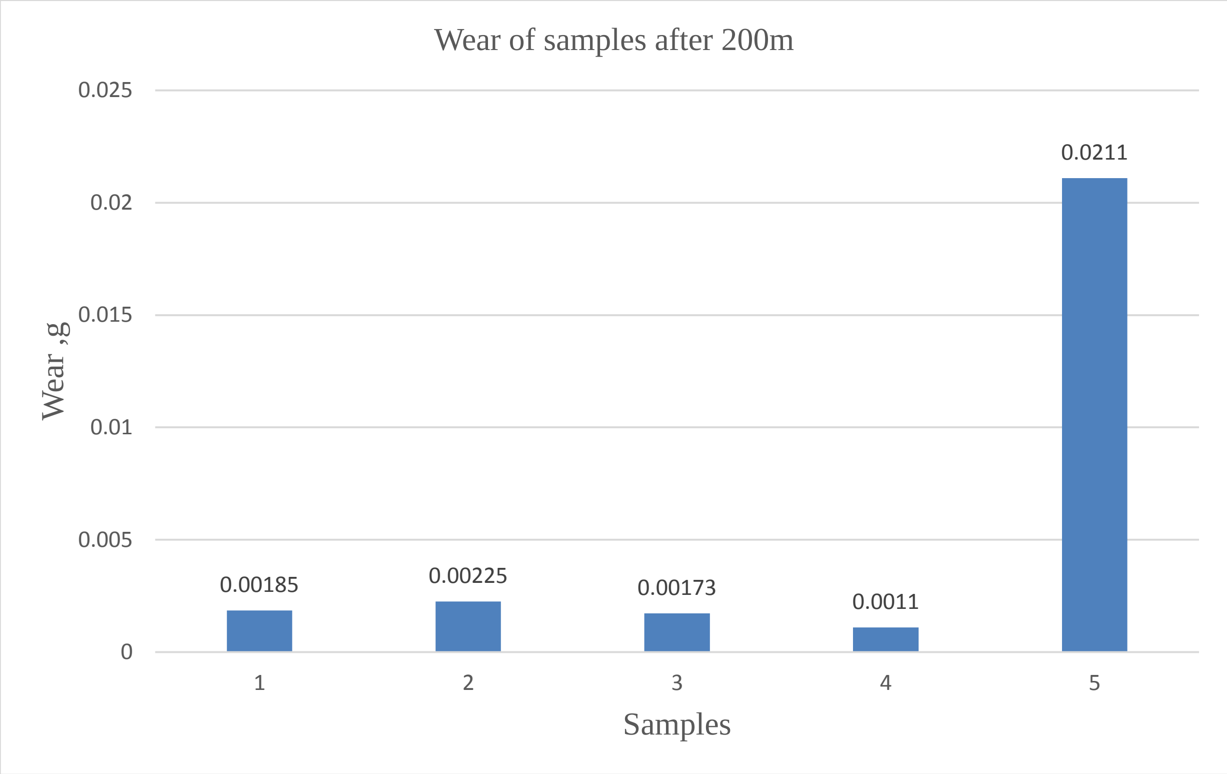

Figure 3.24 Comparison of wear after 200m (after welding)

After 4 it is 3 that is more wear resistant because the surface layer is almost the same except for the tungsten carbide in 4 it's replaced with P6M5 steel tool powder. The value is 0.0011g which is the difference between the mass of the sample before the test with the mass of the sample after 200m sliding contact. Looking at the values of 1, 2 and 3 these three wear values are not so much different from each like 1 little less wear resistant than 3 and 2 is little less wear resistant than 1.

Tempering at a certain temperature increased the hardness of the sample so these samples are then tempered and then checked for its wear resistance values. Wear resistance of the samples are based not only on the hardness of it but also the microstructure of the sample plays a significant role.

3.3.3 Wear test values after tempering

After welding samples are tested for its wear and then they are prone to tempering to analyze whether wear is changing in that case. Table 3.3 shows the wear test values of samples after it has been tempered. Irrespective of the condition of the samples all the other steps are same as done before.

Table 3.3 Wear of samples after tempering

Sample name	Wear (weight loss in grams)				
	40meter	80meter	120meter	160meter	200meter
1	0.000175	0.000375	0.000575	0.0007	0.00095
2	0.000275	0.0005	0.000675	0.00085	0.001
3	0.000675	0.00157	0.00195	0.002	0.0026
4	0.0004	0.000675	0.000975	0.00115	0.00125
5	0.00695	0.01015	0.01685	0.0527	0.07105

Figure 3.25 Comparison of wear after tempering (samples 1-4)

Figure 3.24 and Figure 3.26 shows the wear value comparison of samples from 40m sliding contact to 200m sliding contact.

Sample 1 with carbides, graphite and chromium came out with high wear resistance as it is the least to get worn out by the siding contact of rotating steel rod. Seems like heat treatment of the sample has given more rigidity so the wear values have changed.

After tempering sample 1 is the most wear resistant and sample 3 is the least wear resistant. Even like before sample 5 cannot be compared with other four as it is the least wear resistant of 0.07g after 200m of sliding contact with the rotating steel rod. But what change after this attempt is that sample 4 is the second least wear resistant after 3 with 0.0125g of wear after 200m sliding contact.

When compared with its previous wear after welding which is 0.011g, there is no much change. But what changed is 1 has more wear resistant than before because the graphite mix with carbides has shown more changes in microstructure with more rigidity.

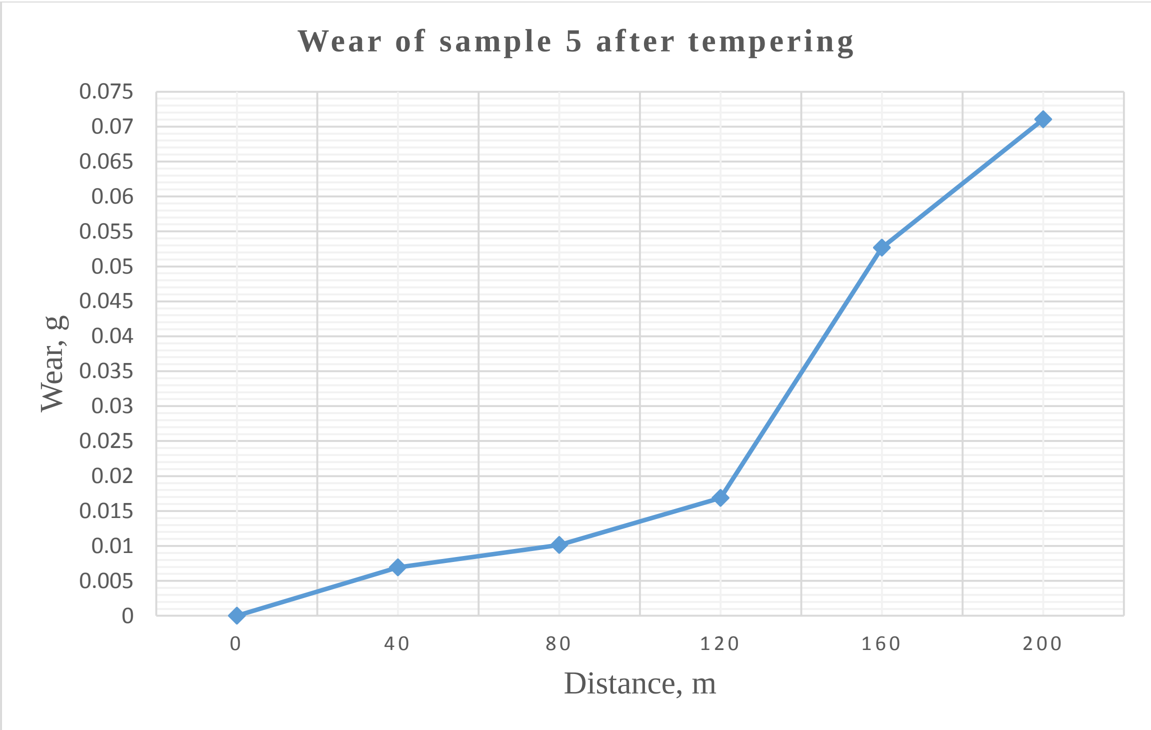

Figure 3.26 Wear of sample 5 after tempering

While in sample 2 the amount of ferro manganese is more in the mixture that was hardfaced than it is in 3 and 4. But 4 has both graphite and ferro manganese in less amount when compared to 1 and 2 so the wear is less but it is not much decreased from its previous wear.

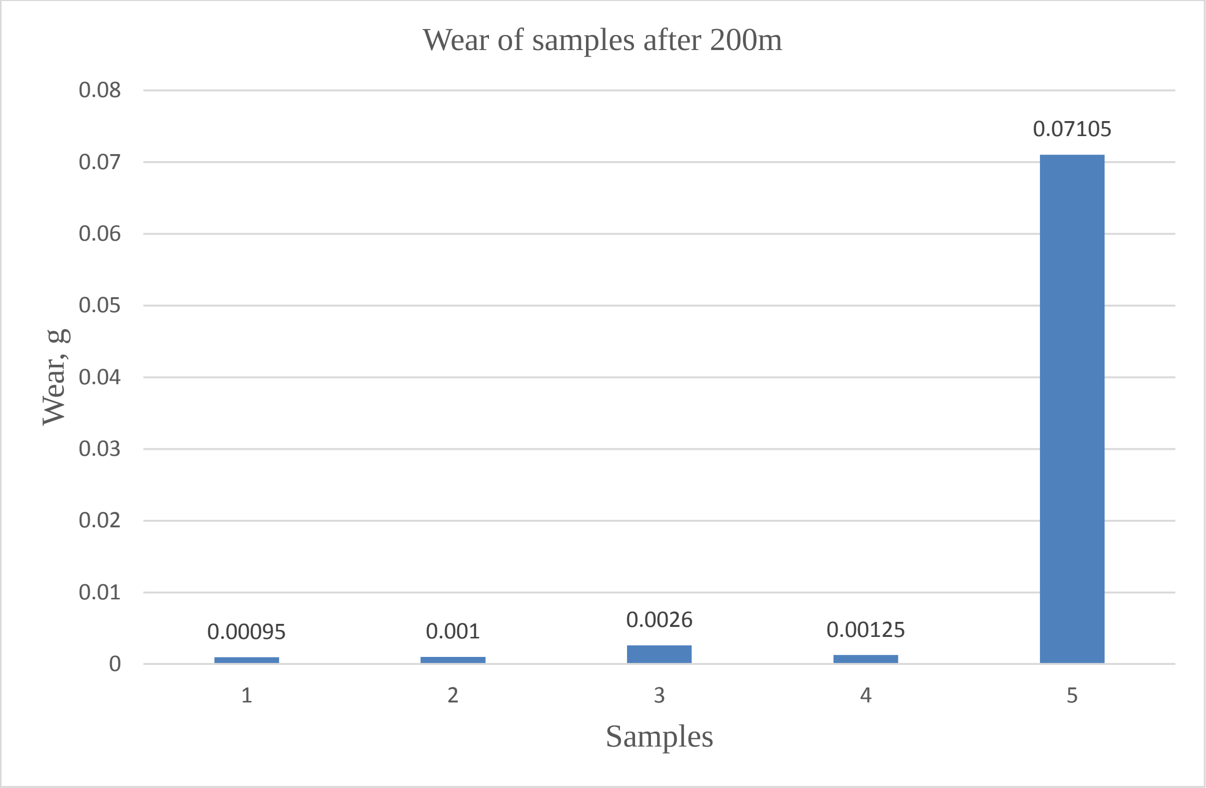

Figure 3.27 Comparison of wear after 200m (after tempering)

Figure 3.27 shows the comparison of wear after 200m of sliding contact with the rotating steel rod. It is clear that the wear of the surface layer is based on the amount of powder added and also the heat treatment favors only some materials among the material powders used in this research.

CONCLUSIONS

With the process of submerged arc weld overlay cladding technique, a good quality of welded layer is obtained that enabled to analyze the hardfaced surface to check its hardness, microstructure and wear resistance Microstructure examination shows that samples 1,2,3,4 has tempered martensite crystalline structure after tempering at 550^{o}C which is formed by the transformation of retained austenite. For sample 5 it has graphite, cementite, ledeburite and pearlite.

1. Hardness of the samples begin to reduce when tempered at 600^{o}C, from the results it is evident that hardness is at its peak for all samples after tempering at 550^{o}C except sample 4. Wear of the samples begins to change after tempering while 5 has the reduced of all at all conditions.

2. Sample 1 resulted with higher hardness of 55HRC after it has been tempered at 550^{o}C and moreover it showed a drastic change in its wear after tempering because it has the high wear resistance.

3. Sample 2 is hardened to 49HRC when it is tempered at 500^{o}C and remained same even at 550^{o}C while it has the second highest wear resistance slightly lesser than 1.

4. Sample 3 showed an increase in hardness and reached 35HRC after tempering at 550^{o}C but it has the lowest wear when compared to 1, 2 and 4.

5. Sample 4 has high hardness of 57HRC after welding and slowly it reduced after each stage of tempering.

6. Sample 5 showed a good hardness increase to 48HRC when tested after tempering at 550^{o}C but when it comes to wear it is the worst of all with very low wear resistance because it contains calcium carbonate which is not proved for its strength.

It is apparent that the waste material powders are highly useful and they can be valuable for overlay weld surfacing of the base metal. Waste material powders can come out with good hardness and wear resistance when tempered at certain temperature like these samples which has higher results at 550^{o}C.

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