

KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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**STUDY OF THE INFLUENCE OF FLUX COMPOSITION ON
PROPERTIES OF SUBMERGED ARC WELDED LAYER**

Master's Degree Final Project

Supervisor

Assoc. prof. dr. Antanas Čiuplys

KAUNAS, 2016

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Master's Degree Final Project
Mechanical Engineering (621H30001)

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**“STUDY OF THE INFLUENCE OF FLUX COMPOSITION ON PROPERTIES OF
SUBMERGED ARC WELDED LAYER “**

”

DECLARATION OF ACADEMIC INTEGRITY

20 May 2016
Kaunas

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Study programme MECHANICAL ENGINEERING - 621H30001**

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Study of the influence of flux composition on properties of submerged arc welded layer

2. Aim of the project

To investigate and study the surface layer obtained by Submerged arc welding and conduct various experimental test to check the reliability of the layer.

3. Tasks of the project

Summary, Introduction, 1. Literature overview, 2. Methodology, 3. Experimental results and discussions, 4. Conclusions, References.

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SUMMARY

In this Master thesis research work, submerged arc welding technique was used to deposit the hard metal on the plain carbon steel base metal. In this research work it was on investigating the flux influence on weld material. Checking their hardness, their resistance to wear, microstructural changes in the structure. Original flux was prepared with silicon carbide, silicon oxide and 50% silicon oxide and 50% silicon carbide. For other half of the specimen along with the flux we use HSS mixture as an alloying element. Once the weld is done the specimens are checked for their hardness and the numbers are noted down. Then the weld specimen is cut into 3 small pieces one for tempering, one for microstructural analysis and one for wear test. The specimens are tempered at different temperature. Then the hardness is noted down. Tempering is made to check whether the specimen hardness increases or decreases or remains the same. The microstructure specimens are prepared by grounding flat, mirror polishing and lastly etching the surface. The surface that is etched are observed under microscope with different magnification. Last experiment conducted is wear test. In this specimens are prepped to conduct wear test. Here the loss of material is analysed. By observing the results obtained on the best flux mixture, will just the flux increase the hardness or is the alloying element is required is analysed.

Jayaramaiah, Anjan Kumar. Fliuso sudėties įtaka apvirintų paviršinių sluoksnių savybėms. *Magistro* baigiamasis projektas / vadovas doc. dr. Antanas Čiuplys; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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SANTRAUKA

Šiame baigiamajame magistro darbe naudojant lankinį suvirinimą po fliusu ant konstrukcinio nelegiruotojo plieno buvo formuojamas kietas paviršinis sluoksnis. Darbe buvo tiriama fliuso sudėties įtaka apvirintų paviršinių sluoksnių savybėms. Buvo matuojamas sluoksnio kietumas, atsparumas dilimui bei tiriama susiformavusi mikrostruktūra. Norint iširti fliuso sudėties įtaką apvirinto paviršinio sluoksnio savybėms buvo pasirinkti įvairių sudėčių fliusai – silicio karbido, silicio oksido, 50 % silicio karbido su 50 % silicio oksido bei lyginami su standartinės sudėties fliusais. Kai kuriems bandiniams, norint įvesti legiruojančių elementų į paviršinį sluoksnį, buvo naudojami greitapjovio plieno milteliai. Bandinių kietumas buvo matuojamas ne tik po apvirinimo, bet ir po atleidimo įvairiose temperatūrose. Atleidimas buvo naudojamas tam, kad išsiaiškinti ar terminio apdorojimo metu neišsiskiria struktūroje karbidai, kurie padidintų sluoksnių kietumą bei atsparumą dilimui. Analizuojant gautus rezultatus nustatyta, kad įmanoma gauti kietą paviršinį sluoksnį naudojant tik fliusą su silicio karbidu, nors geriausias atsparumas dilimui gaunamas į paviršinį sluoksnį įvedus legiruojančių elementų iš greitapjovio plieno miltelių.

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INTRODUCTION

The Wear is the common phenomenon we face in the day to day activities. Every day the every moving part are subjected to wear. The common industrial machines, automobiles, or even the normal tools which we use are subjected to wear. Even the wood working tools are subjected to wear and here each type of materials requires different conditions [1].

When a machine parts wear, generally thing done is to replace the worn out parts. But it's not cost effective. To overcome this, it's possible to harden the surface of the parts that wear out easily, which can be achieved by Hard-facing the surface. This is one of the easiest methods of making the surface hard to resist against wear of the parts that have poor wear resistance. Here because of this iron base surface is generally used to protect from wear or friction and abrasion. This is generally applicable with the metal to metal sliding applications [2].

In this research, we using certain industrial waste materials that are very useful in different ways as a recycled material. In this research HS 6-5-2 (LST EN ISO 4957:2003) as a mixture is used, Ready Flux used are AH-348-AM (GOST 9087-81), AH-20C (FX 761-25) and shielding gases, which is the mixture of Ar, CO₂, NO (MISON 25). Silicon carbide and silicon oxide are also used as a flux in the experiments conducted.

Our main aim in the research is to investigate the layer produced or formed by submerged arc welding and compare the results obtained with the different mixture and flux.

The main objective of the research conducted are:

- to attain the possible quality weld from the samples prepared using the different mixture and the fluxes which are mentioned above;
- to find out the hardness of the surface obtained by the weld, using Rockwell and Vickers hardness testing machine;
- to determine the possible changes in the microstructure of the samples prepared, before and after tempering;
- to conduct experiment on surface wear of the specimen which is over welded.

The research gives us the basic ideas to get the possible highest hard surfaces with good wear resistance. Generally, the hardened surface layer will be deposited on the not so hard base metal. Even though the materials used in the research area is waste materials these have certain properties which are helpful for our research, also acts as an added advantage that is required in the research such as low in cost so that we can use as many numbers of times.

1. LITERATURE OVERVIEW

1.1. SUBMERGED ARC WELDING (SAW)

By the definition given in ‘The American Heritage Dictionary’, “To join (metals) by applying heat, sometimes with pressure and sometimes with an intermediate or filler metal having a high melting point.” The definition found in ISO standard R 857 (1958) states. [3]

“Welding is a process where permanency is attained among the parts for assembly, by several means”. [3]

Primary and the chief essential point are the numerous units are formed into a single unit. Now, permanency indicates the lack of physical disorder in atomic scale, i.e. no breaches/ openings/ cracks/ cavities, unlike the conditions using mechanical fastening where a physical gap, no matter how close-fitting the joint is. A weld can be homogeneous or heterogeneous.

The additional and crucial point is that welding not only relates to metals. It is associated with polymers like thermoplastics, ceramics and glasses. The procedure associated may not always be termed as welding, it may be entitled as thermal bonding for thermoplastics or fusion welding for glasses.

Welding is the product of the collective action of heat and pressure. The general view of welding is that the operation is performed by heating and melting ingredients or materials. But welds can be formed by the various range of amalgamation of heat and pressure. Welding is a vastly adaptable and flexible joining process, assisting in joining many different materials or parts into many assemblies to obtain different properties for different purposes.

The use of filler material of the same type or with the intermediate one. The composition of the filler material may be same as of the base material or may not be required, this totally depends on the type of weld and the type of operation being done.

Welding is used to joining parts, although it does so by joining materials. It is this goal that often places additional constraints and demands on the welding process as it is selected and applied. Creating a weld between two materials requires producing chemical bonds by using some combination of heat and pressure. How much heat and how much pressure is partially dictated by the inherent nature of the material(s) being joined. But, how much heat and how much pressure also depends on the nature of the actual parts or physical entities being joined. Among other things, part shape, critical part dimensions, and part and assembly (i.e., joint) properties must also be dealt with by preventing intolerable levels of distortion, residual stresses, or disruption of chemical composition and microstructure.

The Submerged arc welding (SAW) is one of the type of arc welding process used worldwide (Fig. 1.1. and Fig. 1.2.). As the name suggests the arc produced, the molten metal is covered by the flux (which is molten and a small layer of dry grainy flux).

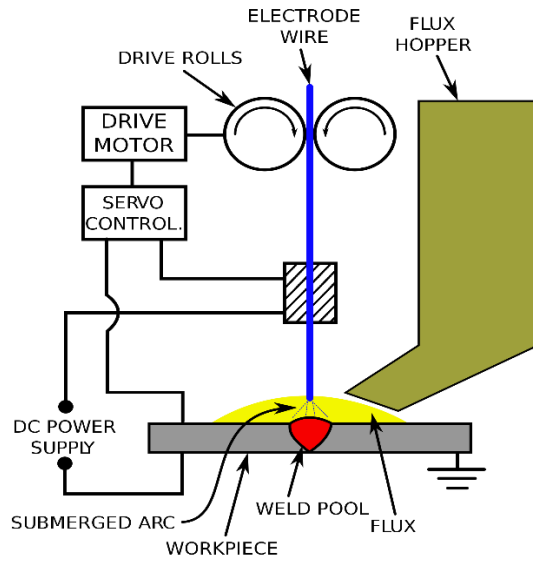


Fig.1.1. Schematic illustration of submerged arc welding [4]

The arc produced is completely shielded by the flux, this protects the molten metal from the atmospheric gases, also the radiation from the arc produced which are generally found in the open arc welding process. The weld produced in SAW process is very clean and uniform.



Fig.1.2. Submerged arc welding [5]

In SAW, we have a continuous supply of the electrode which is used as a filler material in the welding process. This type of welding process has the very high efficiency of energy transfer from

the power or energy source to the electrode as the losses due to the radiation, a spattering of the molten metal is very minimum.

This process is generally mechanised because of a large amount of current is passed through the system usually above 500A and a large amount of material deposition of materials. At the same time, this SAW lacks the visible arc, which is dependent on other open arc process.

The velocities of the weld can be varied depending upon the thickness of the metal. Generally, the velocity for the thin section will be more i.e. up to 500cm per minute. For the thick section, the velocities will be much lower or at very slow rate.

At higher currents which are above 1000A Alternative current is used to avoid the arc blow. Multiple electrodes can be used to deposit the weld materials on the surface to increase the weld deposition rate.

The general limitation of the SAW is the welding is limited to vertical and flat surfaces. This is because of the effect of gravity on the molten metal pool that epitomises the process. The grainy flux is used with the additives, to balance the loss of alloying elements. Here a kilogramme of flux is consumed for every kilogramme of material deposited.

1.2. ADVANTAGES AND DISADVANTAGES IN SUBMERGED ARC WELDING

The advantages are:

- a. We get very high-quality weld while comparing with the other arc welding techniques. [6]
- b. The continuous flow of electrode is there, which is very helpful in the automated process.
- c. Weld deposition rate is high when compared to other welding techniques.
- d. The arc basically covered in flux which shields the radiation. Because of this minimal protective clothing is required.
- e. Because of the flux covering the arc, less or no smoke is produced.

The disadvantages are

- a. The welding can be done on flat surfaces, generally on horizontal and vertical position.
- b. The curved surface has the tendency to accumulate the molten weld metal, which causes the change in thickness of the weld deposition
- c. High heat input and slow cooling have its effect on the metal.
- d. Very limited selection of metals is available for welding.

1.3. THE TYPICAL CHALLENGES FACED IN SUBMERGED ARC WELDING

One of the common challenges faced in the SAW is crossways cracks formed on the over weld or cladding, because of the contraction of the weld during cooling of the weld. They are typically called as the relief cracking, which is acceptable up to certain level. i.e. the crack stays below the given tolerance and does not reach up to the base metal. The another challenge is the dilution of the weld metal because of the high heat input. Because of this, the composition of the overlay becomes leaner, which causes the reduction in the wear resistance. The another drawback of SAW is that the welding can be done only in the horizontal position. [7]

1.4. THE GENERAL CHARACTERISTICS OF THE SAW

SAW are generally operated in an automatic process. This process can be made semi-automatic. The arc stability, current supplied, voltage supplied to the arc, travel speed characterises the SAW which all affect the weld bead, depth of penetration and chemical composition of weld metal. [8]

In SAW, the flux and the molten slag formed while welding cover the weld bead formed and fabricated flux wall shield the flux cavity. During welding, the small amount of flux is consumed which are directly depending on the radiation from the arc, conduction of molten metal and resistance heating of the slag. The flux consumption mainly dependent on any of the three parameters. One of the simple ways to measure the flux consumption is to weight the total mass of flux before and after welding. The flux consumption will be increased with the increase of the current supplied. [11]

1.5. HEAT AFFECTED ZONE (HAZ)

In the submerged welding process, the microstructure in the weldment undergoes changes because of the high heating and cooling of the weld zone in the weldment. These are directly related to the weld parameter, welding process. If the microstructure of HAZ is improved, then this will improve the properties in the weld joint. As there are different process variables and the operating conditions causes the change in the characteristics which influences the hardness, toughness, cracking in the HAZ. Over-heat in the weld increases HAZ, that causes the reduction in the impact strength. This is one of the problems faced in SAW. There is 3 zones in HAZ supercritical, intercritical and subcritical. Coming to supercritical, there are two regions, one is grain growth and the other is grain refinement. The microstructure in this zone influences the properties of the weld zone. While welding

we need to restrict the HAZ in the weld. We need to keep HAZ as narrow as possible. Here compared to other two zones the major microstructure changes happens only in the supercritical zone. [12]

1.6. CLADDING PROCESS IN SAW

The cladding is a process of metal coating bonded to another metal under high pressure and temperature. [13] The above can be said as the metal deposition of metal with the dissimilar properties of the substrate material to obtain the required properties. Here the substrate materials initially don't have the required properties.

The cladding is basically done to improve the mechanical properties, increase the corrosion and wear resistance and lastly to repair and fabricate the metal matrix parts. [14] The one of the main welding process used for cladding is the SAW. For this cladding process we have 4 important zones which are,

- Base metal
- Heat affected Zone
- Weld interface
- Weld metal (fusion zone)

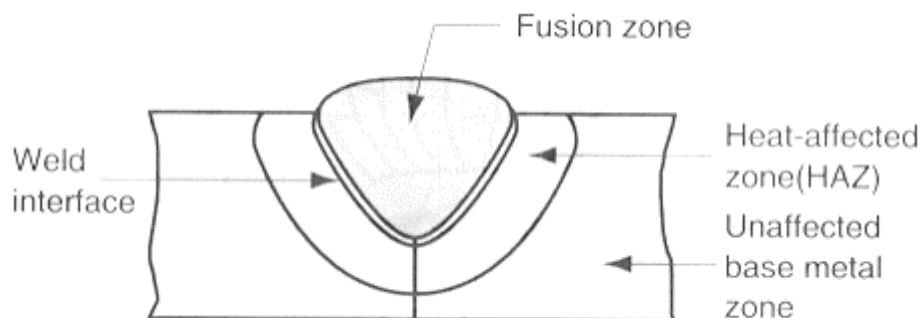


Fig.1.3. Cross section of the welded plate with the different zone [15]

In a typical welding, the metallurgical structure changes in different zones range from fusion zone (weld metal which is deposited), then comes to heat-affected zone (HAZ) and lastly the base metal zone which will have the least or negligible change in the microstructure. These zones have different metallurgical properties because in fusion welding (i.e. SAW) outcome is melting and solidification with high-temperature gradient input in a very small area with a high-temperature in the fusion zone.

In the fusion zone (FZ) can be considered as the concoction of molten base metal and the filler metal as used in SAW with a high degree of uniformity which is initially driven by convection in the molten weld pool. The main driving force for heat transfer and resulting in mixing of molten metal are

- Buoyancy force
- Surface tension gradient force
- Electromagnetic force
- Frictional force

The microstructure in the FZ will change due to re-melting and solidification of metal at the temperature beyond the effective liquidus temperature. The weld interface is the narrow zone consisting of the partially melted base metal which didn't get mixed homogeneously this acts a barrier between the FZ and the HAZ. The heat affected zone (HAZ) is the zone where the second highest temperature will have experienced which will be below solidus temperature, still high enough to change the microstructure in the material. The amount of change in microstructure depends on the amount of the heat input, peak temperature reached, time at the elevated temperature and rate of cooling. This all will influence in a change in the microstructure, in-turn, the mechanical behaviour in the HAZ changes. Generally, this is the weakest section in the weldment. The base metal zone surrounding the HAZ is in the state of residual stress due to the shrinking of the fusion zone. No changes in the microstructure noticed. Here the FZ and HAZ exhibits different mechanical properties. [15]

Cladding by SAW process has high material deposition rate and high surface layering capacity. By the cladding techniques, we can improve surface properties like wear resistance, corrosion resistance and oxidation resistance. The mixture acts as an alloying element can be used to improve the wear and corrosion resistance properties. The alloying elements like Fe, Mn, Cr, Mo, V can be used. [16]

This cladding technology used to improve the weld quality by several means, such as

- Improving corrosion resistance
- Improving wear resistance
- Improving oxidation resistance
- Improving productivity and efficiency

Thinking in the efficient way cladding technique can be used to deposit high-cost materials on the not so costly materials to bring down the cost of the production. The other way of increasing the metal deposition rate is to add the metal powder in the welding. This metal powder acts as an alloying elements and at the same time these will help in less consumption of the welding flux. This method can actually increase the efficiency in the welding. SAW with an addition of the metal powder, this process is capable of production of weld surfaces with high corrosion and wear resistant. Metal powder addition is to alloy the weld with the required chemical elements. But the general drawback is because of the high heat input more probabilities are there that mutilation can be done to the microstructure at the HAZ. This can change the hardness and the wear resistant properties. [17]

1.7. FLUXES IN WELDING

In metallurgy, the word flux is derived from the Latin word *Fluxus* which means flow. Flux is a chemical compound, a flowing compound, also a cleaning agent. The flux has more than one function at a time. They are majorly used in the extractive metallurgy and in the metal joining process that may be welding, forging.

By American Welding Society Flux is defined as “A material applied to the workpiece(s) before or during joining or surfacing to cause interactions that remove oxides and other contaminants, improve wetting, and affect the final surface profile. Welding flux may also affect the weld metal chemical composition”. [9]

From many centuries flux has been used in the metallurgical process, the general flux which are used is calcium (lime), soda ash, potash, charcoal, coke borax. Even iron ore was used as the flux in the metallurgical operation

Now coming to metal joining process that would be welding, brazing, soldering. The primary function of the flux is to shield the metal from the atmosphere i.e. to prevent oxidation of the base metal and weld metal. The other function is like dissipation of heat from the metal.

Flux is a type of material where it remains inactive (inert) state at room temperature, but when it's in contact with the base and weld metal it will become a strong reducing agent which prevents the formation of the metal-oxides. The other uses of the flux are liquefying the metal oxides and aids in wetting by weld metal. Second thing is to become oxygen barrier and preventing the formation of the oxides.

The general characteristics of the flux are

- Slag removal from the metal should be good
- Once welded the flux should be ductile at high temperature and brittle at room temperature as it will be easy to remove the flux.
- Generally, the melting temperature of the flux should be less than the temperature of the weld metal as it will easily facilitate the movement of the flux to cover the weld metal.
- Solidification of flux should be equal to the solidification of the weld metal.
- The viscosity of the flux should be high enough to shield the metal from an atmosphere and enough to prevent the escape of the weld metal.
- Flux should be cost effective.
- Flux should provide the required chemical composition which is required for the betterment of the weld metal.

1.8. TYPES OF FLUXES

The general types are

- **Fused fluxes** where the raw materials that are required for manufacturing flux are dried, heated then melted in the furnace and the final produce is cooled and powdered.
- **Agglomerated fluxes** here the different raw materials are pulverised and then mixed together. The chemical reaction generally takes place. Which is basically the formation of formation of electrovalent or covalent unsaturated bonds. This reaction causes the mixture to be wet and they are passed through the sieve of required mesh size where they take a shape of pellets. Later this is heated at a temperature between 380⁰C to 800⁰C.
- **Mechanically mixed fluxes** these are mixed using a mechanical mixer, here fused and agglomerated fluxes are mixed in different ratios for the desired requirements. [28]

1.9. PROPERTIES OF FLUX

The general physical properties that define fluxes are particle grain size, heat capacity, melting point, thermal and electrical conductivity, surface tension, arc stability, viscosity, basicity index. [3]

- **Particle grain size-** here the particle grain size plays one of the important roles in the welding. Here the size of the flux particle is inversely proportional, as the amperage or the strength of the current increases the particle size should be decreased. When the ampere is high and grain size is coarse then it will cause uneven in the weld bead as the arc won't be stable to sustain. Generally, current above 800 amperes finer grain size is used. For welding on the rusty surface which may be a rusty steel coarse grain are used as to allow gases to escape. The particle size of the flux plays the role in the consumption of flux while welding. As the flux is fine the consumption of flux will be more compared to coarse flux which contributes to less tolerance to rust in the weld bead.
- **Melting point-** the melting point has a role in welding. The flux should be in a liquid state even after the weld metal is hardened or solidifies, so that there is a barrier created between the oxygen and the weld metal and to provide a good surface finish of the weld metal. Consumption of fluxes used will be high during the melting point.
- **Electrical conductivity-** at the initial stage before melting, the flux should be nonconductive of electricity. But once the flux starts to melt it should highly conductive as to maintain a constant supply of current between the electrode and the job to be welded which will improve the alteration region between the weld and parent metal.

- **Arc stability**- this is nothing but the change in voltage to the actual weld voltage during welding. Higher the voltage variation higher the defects in the weld. The stable arc will produce a defect free weld. Here flux should be able to pass ionised atoms towards the arc to provide stability to the arc. The different ingredients will provide arc stability at various level.

- **Viscosity**- It's defined as the property of the fluid which offers resistance of the moment of one layer over the other [10]. Silica in flux unveils high viscosity because of the formation of tendency of silica ions. Flux should have high viscosity as it will restrict the flow of the weld pool, which simultaneously increases the heat input. Thus bringing out the deeper weld.

- **Basicity index**- this is the factor considered to find the relation between the chemical behaviour of the flux and the mechanical behaviour of the weld metal in the system. Generally, this index gives the reaction between the elements present in the flux and once the reaction starts which will split into the metal cations and the oxygen ion present in the atmosphere. [28]

1.10. SURFACE WEAR IN THE SYSTEM

Surface wear is one of the important aspects of the systems. It should be resistant to abrasion to increase the use of the mechanical parts. The wear in the systems depends on the type of metal, its composition, surrounding atmosphere. The harder the metal less the wear in the system. The behaviour of the material majorly dependent on the surface of the material, surfaces contact of the materials and the environment where the materials have to run. The different characteristics of the materials have a substantial effect on the surface wear of the system.

In generally speaking wear is a process of removal of material from one or the both of the solid surfaces in solid state contact, occurring when two solid surface are in sliding or rolling motion together. The rate of removal will be continuous and slow.

The common types of wear in the systems are

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

Wear can be controlled by providing different surface treatments on the materials which increase the surface hardness. General surface coating will improve the resistance against the wear. Multiple surface treatments have a greater impact in providing the desired surface in the system. [18]

Some of the common wear tests conducted to evaluate the resistance of the materials to abrasive wear are by Wearing the surfaces with the fixed abrasives i.e. grinding papers or grinding

wheels or loose abrasive that are fed into the contact between the sample and the counter face. The general setup can be pin-on-disc or pin-on-drum. The general test conducted will be without the lubrication in room temperature Fig-1.4. Sliding wear doesn't specify the wear mechanisms, this only gives the type of contact between the surfaces. Sliding and rolling wear are the common phenomena in many of the machines on the daily basis. Surface interaction and many types of surface damages occur in between the in the sliding contacts. This changes in the different test conditions lead to drastic and strident changes in the wear mechanisms. [19]

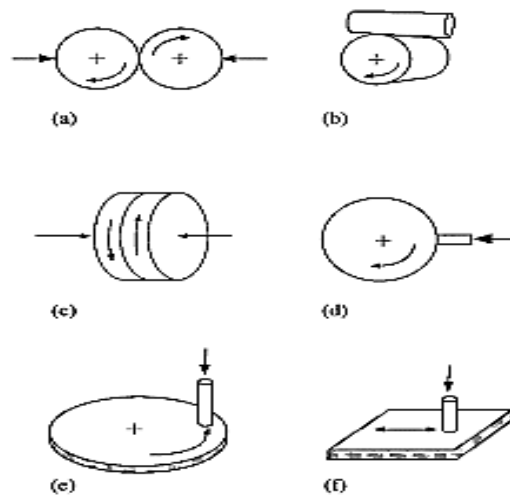


Fig.1.4. Common sliding wear setup. [19]

1.11. HEAT TREATMENT FOR THE MATERIALS

The general heat treatment process we have seen are heat treatment, annealing and tempering. Depending the operations, the materials (metals) may become less or more brittle, less or harder, toughness may increase or it may decrease. The metals may become stronger or weaker. The desired property we require depends on the operation and the characteristics of the materials.

Tempering and annealing are two different heat treatment process. As we know heat treatment is the controlled process which will alter the chemical and the physical properties of the metals. Heat treatment changes the molecular arrangement in the material called as the phase in the metals. Grains in the metals which are like a tiny crystal will tend to shrink or grow, depending on the type of heat treatment we opt. Phases change in the metals because of the heat treatment, as a different type of molecular arrangement will be there in metals. In heat treatment, we can achieve the desired characteristics by budding various phases to our required application and grain size.

Tempering is the process where the required materials is heated below its critical temperature. This increases the toughness and ductility of the metal. Tempering is the operation where generally the material strength decreases.

Tempering is a multi-step operation. First, the steel is generally heated to form austenite, a homogeneous mixture of iron and carbon. Then this formed steel quickly quenched in water, oil, air, to rapidly reduce the temperature. So that martensitic structure will form inside the steel, which is a very strong yet brittle formation. Now the quenched steel is heated to a temperature between 150 to 270, or 370 to 650-degree centigrade. Tempering changes the metal from martensite to bainite or pearlite (cementite and ferrite mixture) formation Fig 1.5. But still traces of martensite will be present which can be neglected. [20]

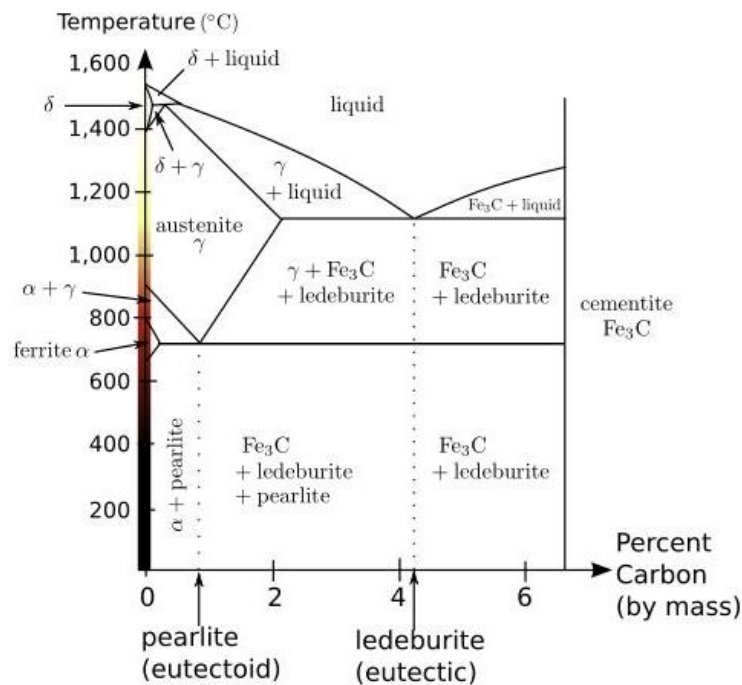


Fig.1.5. Iron- carbon phase diagram [20]

2. METHODOLOGY

2.1. PREPERATION OF THE FLUX POWDER

Concentrating on our current research work, the samples which are in the powdered form are prepared from the industrial waste products. Which we have collected and the required samples are been made. As we look into the samples prepared here each of the sample powder exhibit their own unique properties. In this research work the general sample powder which are been used are silica carbide and silica oxide. These sample powder will be used as a flux and they will replace general flux. The other fluxes are AH-348-AM (GOST 9087-81), AH-20C (FX761-25), inert gas mixture MISON 25 (Ar, CO₂, NO) are has been used.

FLUX SAMPLE	PROPERTIES OF THE FLUX SAMPLE
Silicon Carbide-SiC	Low density High strength Low thermal conductivity High hardness High elastic modulus Excellent thermal shock resistance [21]
Silicon Oxide-SiO	High di electric strength Resistant to many chemicals High temperature stability Low density Used as the blocking material for diffusion of unwanted materials Can be used as shielding agent against the radiation from the welding [22]

Table.2.1. Table of the properties of silicon carbide and silicon oxide

As from the above table-2.1 the properties of the flux used are clearly explained. Each of the flux used has their own important properties. Which are very important for welding of specimen and change in the microstructure. Now coming to silicon carbide, the powder is made by crushing the

grinding wheel, then ground to a coarse consistency and finally the powder obtained are filtered using the sieve no 10. This same procedure is followed for making silicon oxide, whose source is nothing but the recycled regular glass and then filtered with the sieve in which the powder obtained is much coarser compared to the powdered silicon carbide. The equal mixture of silicon carbide and silicon oxide is weighed and mixed together to form a uniform mixture of silicon carbide and silicon oxide (50% SiC+50% SiO), which will have used as the flux along with the other two fluxes made.

Specimen number	Mixture	Flux	Shielding Gas
00	No mixture	100% SiC	-
01	No mixture	50%SiC+50%SiO	-
02	No mixture	100%SiO	-
03	No mixture	No Flux	MISON25(Ar,CO ₂ ,NO)
04	No mixture	AH-348-AM (GOST 9087-81)	-
05	No mixture	AH-20C (FX 761-25)	-
30	HS 6-5-2 (LST EN ISO 4957:2003)	100% SiC	-
31	HS 6-5-2 (LST EN ISO 4957:2003)	50%SiC+50%SiO	-
32	HS 6-5-2 (LST EN ISO 4957:2003)	100%SiO	-
33	HS 6-5-2 (LST EN ISO 4957:2003)	No Flux	MISON25(Ar,CO ₂ ,NO)
34	HS 6-5-2 (LST EN ISO 4957:2003)	AH-348-AM	-
35	HS 6-5-2 (LST EN ISO 4957:2003)	AH-20C	-

Table.2.2. Description of the samples fluxes used along with the specimen.



Fig-2.1- Ground silicon carbide (SiC)



Fig-2.2- Ground silicon oxide (SiO)



Fig.2.3. Equal mixture of Silicon oxide and Silicon carbide (50% SiC+50% SiO)



Fig.2.4. HS 6-5-2 (LST EN ISO 4957:2003)

The Fig 2.1-2.3 are the real time picture pictures of the fluxes used and Fig 2.4 is the HSS powder mixture used. From the table 2.2, we are assigning the specimens with the different flux composition. Specimen 00 has 100% silicon carbide. SiC is a hard material. We need to see whether the addition of this will increase the hardness in the specimen00. Specimen 01 has the equal mixture of silicon carbide and silicon oxide (50% SiC+50% SiO). Specimen 02 has 100% silicon oxide. SiO is not hard material we need to how does the weld metal will react with SiO. Specimen 03 has no flux, in the place of flux we use inert gas mixture MISON 25 (Ar, CO₂, NO) to act as the flux and protect the weld from oxidation. Specimen 04 has the factory specified flux mixture AH-348-AM (GOST 9087-81) and last specimen 05 has AH-20C (FX 761-25). Here each powder has its own property which is highly helpful in obtaining the required hardened layer that will be quality weld. The hardened surface obtained should be good in its properties, which are high wear resistance, density obtained should be low to reduce overall weight, highly corrosion resistant, and the melting point of the weld should be high.

Now with the other specimens along with the flux, we are going to add mixture to the specimen. The mixture we are using is High-speed steel powder (HS 6-5-2 (LST EN ISO 4957:2003)). Now the procedure remains the same form the specimen 30 to specimen 35 with the same order as of from specimen 00 to specimen 05.

C	Cr	W	V	Mo
0.80-0.88	3.80-4.40	5.50-6.50	1.70-2.10	5.0-5.50

Table.2.3. Chemical composition of the HSS powder used.

2.2. WELDING PREPERATION AND PROCESS

The welding setup used is Submerged arc welding (SAW). In our research, we are using the base metal for surfacing is cheap plain carbon steel. The chemical composition of plain carbon steel is as follows, (Carbon 0.14-0.22 %; Silicon 0.12-0.3 %; Manganese 0.4-0.65 %; Sulphur ≤0.05 %; Phosphorus ≤0.04 %) [23]. We are using plain carbon steel as its cheap and easily available. It's one of the highly used materials. The dimension of the base metal specimen strips or pieces used for welding is 135*10*10mm. Now the real time welding technique with automatic setup are as follows Fig-2.5.

- Torch- MIG/MAG EN 500 78
- Welding current 180 – 200 A
- Voltage 22 – 24 V
- Travel speed – 14.4 m/h
- Wire feed rate – 25.2 m/h.

- Electrode diameter – 1.2 mm
- Electrode material- Low carbon steel
- Chemical composition of the electrode- Carbon < 0.1 %; Silicon < 0.03 %, Manganese 0.35-0.6 %, Chromium < 0.15 %, Nickel < 0.3%



Fig.2.5. Real Time Submerged arc welding

The welding setup has the clamp to lock the specimen in place. Once the specimen is locked along with the graphite strips placed around the specimen so that the overlay weld on the specimen doesn't get welded with the clamp. For the specimen 00- 05 we are not using the material mixture HS 6-5-2 (LST EN ISO 4957:2003, only the various flux is being used. Now for the specimen 30-35 material mixture HS 6-5-2 (LST EN ISO 4957:2003 is being used along with the prepared flux. Coming to the specimen 00-05 except 03 wherein the place of flux we use an inert gas mixture. The flux is poured on the plain carbon steel; the weld overlay is performed in a single pass. For the specimen 30-35 mixture is added to the specimen up to a height of 3mm, upon that we cover with the prepared flux, except for specimen 33. Above steps are done in the single pass.

In our research thesis, we use SAW setup. The important principal of this SAW setup is to weld the powdered mixture on the base metal specimen pieces. This is the primary or initial step in the research. The equipment for SAW has a basic setup with the electrode holder with automatic wire feeder, which feeds the electrode wire at a constant set speed. The power supply will be connected to the electrode holder, welding gun, power source (step-down transformer), workpiece holder, emergency stop button. In current research flux is fed manually and finally the earthing connection to complete the circuit.

The arc is produced, when the current is passed between the workpiece and the electrode wire. The powder to be welded may be fed automatically or fed manually. The powder will be welded to the base metal once the arc is started, and the circuit is completed. During welding, flux is fed into the system and will start to melt or liquefy because of the arc temperature and create a barrier between the weldment and the atmosphere. This will solidify and becomes slag. The slag can be broken down once it's solidified.

2.3. HARDNESS TEST FOR THE SPECIMENS

After the welding, the specimens are taken to test their hardness under Rockwell hardness testing machine Fig-2.6. The specimens are grounded smooth and cleaned from the debris to create an even surface for the material testing. These tested specimen hardness numbers are noted down. Hardness is defined as the resistance to indentation. This hardness is calculated by measuring the depth or the area of an indentation on the specimen. By simplifying harder the material lesser the indentation. [24] Some of the known material hardness testing are

- Rockwell's hardness test
- Brinell hardness test
- Vickers's hardness test
- Knoop testing
- Durometer IRHD testing
- Case depth testing

The most common material hardness testing done in the whole world is the Rockwell hardness test. It's denoted as HR (Hardness Rockwell) as the hardness number doesn't have units. In this research, we are using Rockwell hardness test with values measuring as HRC, which denotes that the materials used in this research come from C scale to measure the hardness. As its easier to perform and accurate compared to another type of hardness testing. This test conducted on most of the metals. In this test the permanent depth of indentation is measured. The first minor load is applied on the material to be tested by using a diamond indenter. This initial load will be taken as zero loads (reference position), this load breaks through the surface finish of the material. Once the minor load is applied the major load is applied. This will sum up the total required load. This load will be applied for a pre-determined time called dwell time (take few seconds) for elastic recovery. Now the major load is released, now the difference between the position from the pre-load to the major load i.e. the depth load value between the preload value and the major load value is measured. This difference in the distance is converted into hardness number which will be shown on the dial. The preliminary test load ranges from 3kgf to 200kgf and the total test forces range from 15kgf to 150kgf. [24]

- A= depth reached by indenter after applying minor load
- B= position of indenter during major load
- C= final position reached by the indenter after the elastic recovery
- D= distance measured by taking the difference between the minor and major load.

LETTER	TYPE OF MATERIALS USES FOR MEASUREMENT
A	Carbides, thin steel & shallow case hardened steel
B	Copper alloys, soft steels, aluminium alloys, malleable iron
C	Steel, hard cast iron, pearlitic malleable iron, titanium, deep case hardened steel
D	Thin steel and medium case hardened steel and pearlitic malleable iron
E	Cast iron. aluminium and magnesium alloys, bearing metals
F	Annealed copper alloys, thin soft sheet metals
G	Phosphor bronze, beryllium copper, malleable irons
H	Aluminium, zinc, lead
K,L,M,P,R,S,V	Bearing metals and other very soft and thin metals including plastics.

Table.2.4. Rockwell hardness scale for the different metals.



Fig.2.6. Real time Rockwell hardness Test Machine (digital display)

Different types of indenter is used for different metals. The conical diamond with a round tip indenter for harder metals. Ball indenter for softer metals with ball diameter ranging from 1.5 mm to 12.7 mm.

Here each specimen is broken down to several individual pieces that are to be tempered after the initial readings are taken. The tempering temperature varying from 500°C to 600°C. Again after each tempering temperature, the hardness has been measured for further analysis.

2.4. 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 an austenitic structure, hold it at that temperature and quench in water or oil. Upon cooling by quenching, an extremely rapid rate of cooling is obtained. In steels, if the rate of cooling is faster than the critical cooling rate, microstructure contains martensitic structure, responsible for increasing hardness in steel.



Fig.2.7. The Electric furnace used in the Laboratory

Hardening heat treatment develops extreme hardness in steels but reduces their toughness. They become very brittle and are unsuitable to be used in most of the service conditions. Hence the secondary heat treatment called tempering is imparted into materials before they can put into service. Tempering consist of further heat treating the hardened steel to various sub-critical temperatures and then cooling, at any rate to room temperature. The other reason why tempering has to be carried out on hardened steel is that, austenite which is retained in the microstructure is unstable and tends to change its dimensions with time. This change in dimensions has to be prevented in some components that have to retain their dimensions or, which are manufactured to accurate dimensions. By tempering,

retained austenite converts into non-equilibrium but more stable troostite, sorbate or bainite. The objective of tempering is to relieve internal or residual stresses, to improve ductility, toughness, impact strength, reduce hardness, to convert retained austenite. [26]

Here in this research, the specimens are first cleaned and then prepped for tempering. The Furnace is switched on, and its internal temperature is brought to the required tempering temperature. Subsequently the specimen to be tempered are kept in the oven and left for one hour. After that the specimens are taken out and allowed to cool in still air. The tempering temperature starts from 500°C, 550°C, 600°C. then the hardness test is conducted on the tempered specimen. Later, these specimens are prepped for the microstructure analysis. The furnace which we are using is Nabertherm electric furnace where the max temperature which can reach is 3000°C Fig-2.7. In this furnace not only tempering, but the other heat treatment operations like normalizing, stress-relieving, hardening of ferrous and non-ferrous metals, and other heat treating process are carried out.

2.5. MICROSTRUCTURE ANALYSIS OF THE SPECIMENS

Once all the specimens are tempered with the different tempering temperature. We need to prep them for microstructure analysis. First, these samples are placed in a very small cylindrical container. Then the specimen whose face to be used for microstructure analysis will be placed faced down in the container. One side of the container will be closed using adhesive tape so that the epoxy mixture won't run out of the container. Then the epoxy mixture of 10-part resin and 1-part hardener is mixed and poured in the container Fig-2.8. Then allowed to set. It is better to leave overnight to set. Then all these specimens are removed from the container. Now the face to be analysed will be prepped with coarse grinding, then fine grinding and last polishing. These specimens are mirrored finished for better accurate microstructure. Different stages of polishing will be done, which are as follows in table 2.5.

The specimens are first placed in a holder and fastened tightly. Then the abrasive paper is fixed to the wheel using adhesive spray. Then the holder is placed on the abrasive wheel. This whole setup will be placed in the LamPlan polishing machine Fig-2.10 and run the setup for the required time. Every time different abrasive paper is changed once the setup runs for set time. Last we do the polishing. Here we change the wheel to buffing wheel. A generous amount of diamond polishing agent is applied to the wheel and the process is repeated again until we get a mirror finish on the face to be analysed.

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

Table.2.5. Stages of polishing of microstructure specimen



Fig.2.8. The container containing resin and hardener.

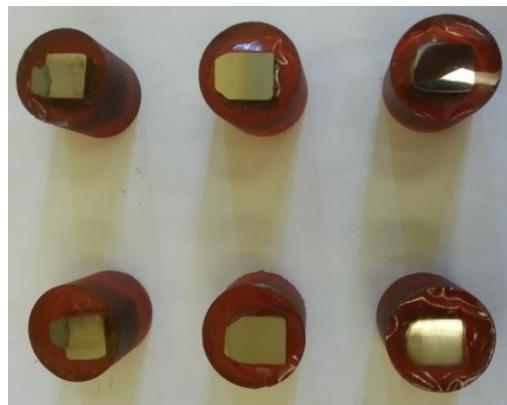


Fig.2.9. Specimen prepared for microstructure analysis and etched

Formerly the polishing is done, these specimens are placed beneath the microscope, before placing the face of the specimen is etched with the solution HNO_3 with 4% alcohol Fig-2.9. Once the face is etched these are placed under microscope Fig-2.11. As etching will reveal the microstructure, where we can see the various patterns hidden. So the impact on this change can be physically

inspected in the product while doing wear test. After the etching, the specimens are examined under different magnification from 25X, 100X, 250X. Then analysed surface photographs are taken for comparison. Before and after tempering specimen's microstructure are analysed and the changes in the different specimens are noted. This gives a clear understanding of structural changes due to tempering which in turn the results may turn out either positive or negative.



Fig.2.10. LamPlan polishing machine



Fig.2.11. Microscope used for microstructure analysis

Now the inspected microstructure is captured by the camera fixed onto the microscope. Here the different magnification is used. The photographs obtained should be assigned with the scale that shows the real-time magnification of the microstructure on the photos. The magnification is showed in the figure Fig- 2.12.

Here the full scaling is 1mm or 1000 μ m. The 10 parts in the scale 100 μ m and the individual scale is 10 μ m.

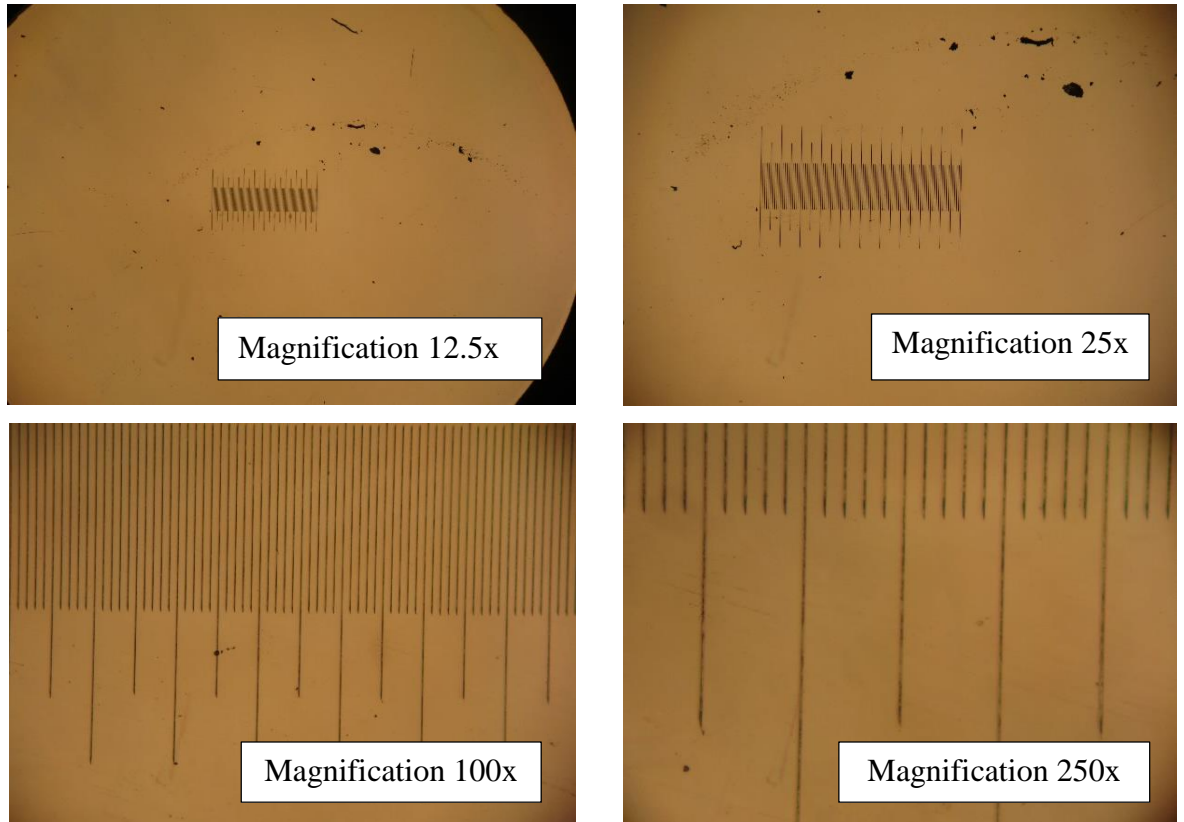


Fig.2.12. Magnification range of microscope with the magnification details in the pictures

2.6. WEAR RESISTANCE ANALYSIS

The wear test is conducted to analyse the wear-resistant property of the specimens prepared. This wear test will give us an idea where the specific applications of the specimen can be decided. In this research's work in the wear test, we analyse the total amount of welded layer getting removed. The amount of loss of the materials would be in 0.0001g. The mass of the samples is weighed after each test. The test will be conducted for every 40m travel of the hard disc wheel. The samples are cut, milled and ground to a required size, i.e. 6mm in width. The diameter of the hardened wheel is 41mm. The specimen is placed on the specimen holder who in turn a holder is fixed along one side of the connecting rod and on the other side balancing-weights are placed. With the setup in place along the force given by the balancing weights can develop a load around 320N force applied over

the surface on the specimen. The rpm of the wheel is fixed to 50 rpm. The complete setup of the system is shown in the Fig-2.13. The time taken from the wheel to travel across 40m is calculated as below.

Velocity = 50 rpm, diameter = 41mm, radius = 21.5mm

$$2\pi r = 2 * 3.14 * 21.5 = 128.8\text{mm}$$

Now by multiplying the velocity with the circumference of the wheel we get the distance travelled by the wheel.

$$128.8 * 50 = 6440\text{mm} = 6.44\text{m distance travelled by the wheel for one minute}$$

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

$$\text{For } 60\text{sec} = 6.44\text{m}$$

$$X \text{ (in seconds)} = (60 * 40) / 6.44 = 372.67 \sim 372.7 \text{ seconds}$$

Converting to minutes we get 6.13 minutes.



Fig.2.13. The actual setup of the wear test analysis.

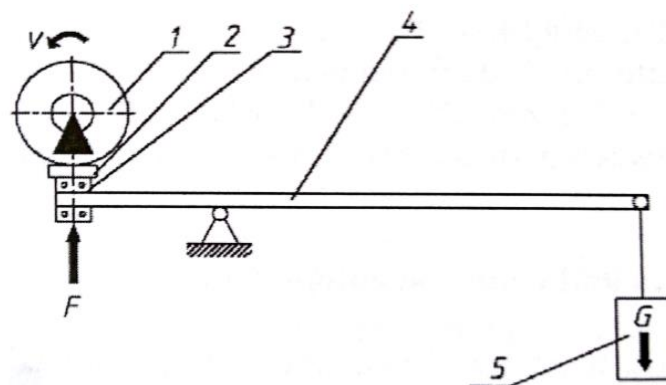


Fig.2.14. Schematic representation of wear analysis setup [27]. 1 - Cylindrical hardened metal disc; 2 - The specimen to be analysed; 3 - Specimen holder; 4 - Connecting rod; 5- Balancing weights

Now the specimen is subjected under test for 6.13 minutes, then need to weigh the specimen for the loss of materials from the surface for every 40 m travel. This will continue until 200m is completed for each specimen. The decrease in weight will give the wear of the specimens. When there is less decrease in weight then wear resistance in the specimens will be more and vice versa. The wear of the specimens will have denoted in grammes. The specimens are weighed in the weighing machine which gives accurate values up to 5th digits in decimal. The specimen prepared for wear test is shown in Fig-2.15. The weighing machine used during the research is shown in the Fig-2.16.

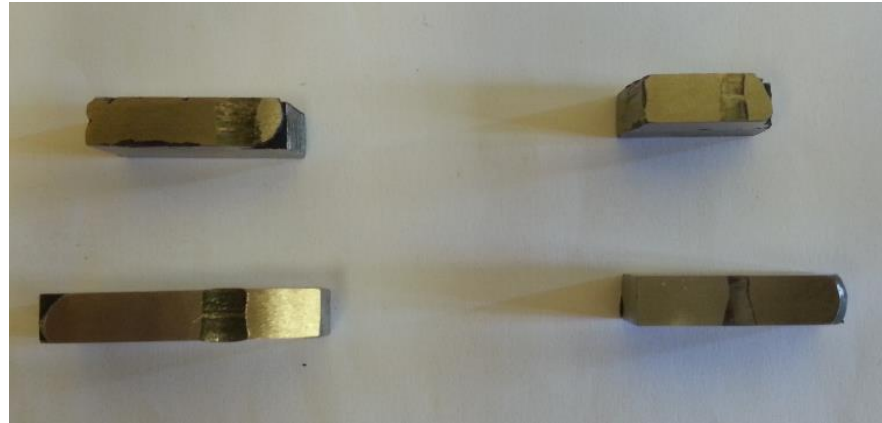


Fig.2.15. Specimen prepared for wear analysis and the surface wear on the specimen.



Fig.2.16. Weighing machine used in the research

3. EXPERIMENTAL RESULTS AND DISSCUSSIONS

Now as per the requirements of the thesis work conducted, the discussion about the results obtained from all the various experiments conducted. From the submerged arc welding, the specimens are over welded and grounded flat for the hardness test. Some of the welding samples of the specimen are shown below Fig- 3.1.

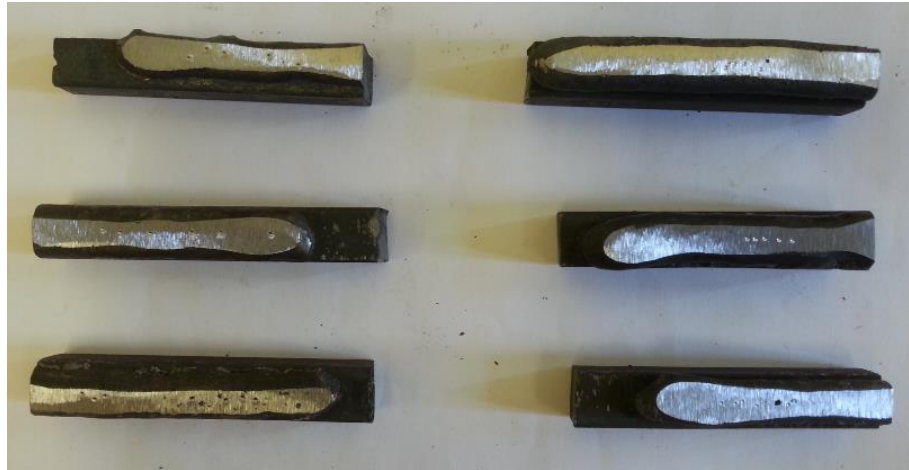


Fig.3.1. Welding specimens prepped and initial hardness tested

Once the initial hardness testing is done, each samples are cut into three parts one part will be used for tempering hardness testing, one is used for microstructure analysis after surface finishing and the last one will be used to make 6mm width wear specimen for wear analysis. In this the results obtained are discussed and compared with each other.

3.1. INVESTIGATION OF HARDNESS TEST RESULTS

The Rockwell hardness HRC test is conducted on the initially welded specimen, the readings are noted down right away after welding, around 8 to 10 readings are taken from each specimen, and the average is calculated. The mixture is added only to specimens from 30-35, and the specimens 00-15 don't have the mixture. The 3 types of flux are being used throughout this research. Mainly being silicon carbide, silicon oxide and last 50% silicon carbide and 50% silicon oxide. These fluxes have their own influence on the specimens. Table- 3.1 shows the different hardness HRC at various conditions.

Specimen number	Hardness over weld, HRC	Tempering temperature		
		500°C	550°C	600°C
00	47	53	51.8	49
01	31.8	25.2	28.6	26.8
02	15	13.6	13	14.6
03	14.4	19	20.2	20.2
04	18	18.2	19	20
05	15.6	13	15.8	12.8
30	53.4	55.4	62	59.8
31	62.6	59.8	62.2	61.4
32	56.4	56.8	60	55
33	43.6	57.8	60.4	60.2
34	56.6	56.6	57.4	55
35	57.4	53.2	57	54.8

Table.3.1. Hardness of the specimens measured at different conditions.

Now from the specimen 00 whose flux is just silicon carbide has the highest HRC. This shows that the silicon carbide influences the increase of hardness. The second hardness is seen in the specimen 01 with the flux mixture of 50% silicon carbide and 50% silicon oxide. Some certain amount of the silicon carbide present in the flux mixture has helped in retaining hardness in the weld. Specimen 02 has 05 HRC, which is one of the least readings were recorded. By this, it's clearly observed that silicon oxide doesn't help or contribute in gaining hardness in the specimen. Specimen 03 has the least HRC number. In the place of flux, the inert gas mixture was used in specimen 03. This mixture didn't help in gaining hardness in the specimen. The specimen 04 and 05 used standard flux but still these two specimens didn't gain significant hardness compared to specimen 00 and 01. By this observation, it can be decided that silicon carbide has influenced in gaining hardness.

Now coming to specimen 30-35, the mixture HSS powder has helped in gaining the hardness. As this mixture acted as an alloying element. In specimen 31, flux mixture 50% silicon carbide and 50% silicon oxide has the highest hardness of HRC 62.6. The other flux mixture with just silicon carbide and silicon oxide has almost similar hardness. Least hardness was found with HRC 43.6 in specimen 33 with the inert gas mixture. Even in the specimen 34 and 35 had hardness almost similar to specimen 30 and 32. By looking over the results obtained the mixture of HSS has acted as alloying element to increase hardness.

Once the specimen's hardness readings are noted, they are subjected to a tempering process to impart toughness in the specimens. During tempering, we may expect an increase in hardness or decrease in hardness or the hardness may remain the same. The tempering temperature varies from 500°C, 550°C to 600°C. All the samples are heat treated for one hour at different temperature. Then it's analysed how much hardness has been increased or decreased. The further explanation can be clearly seen through the graphs.

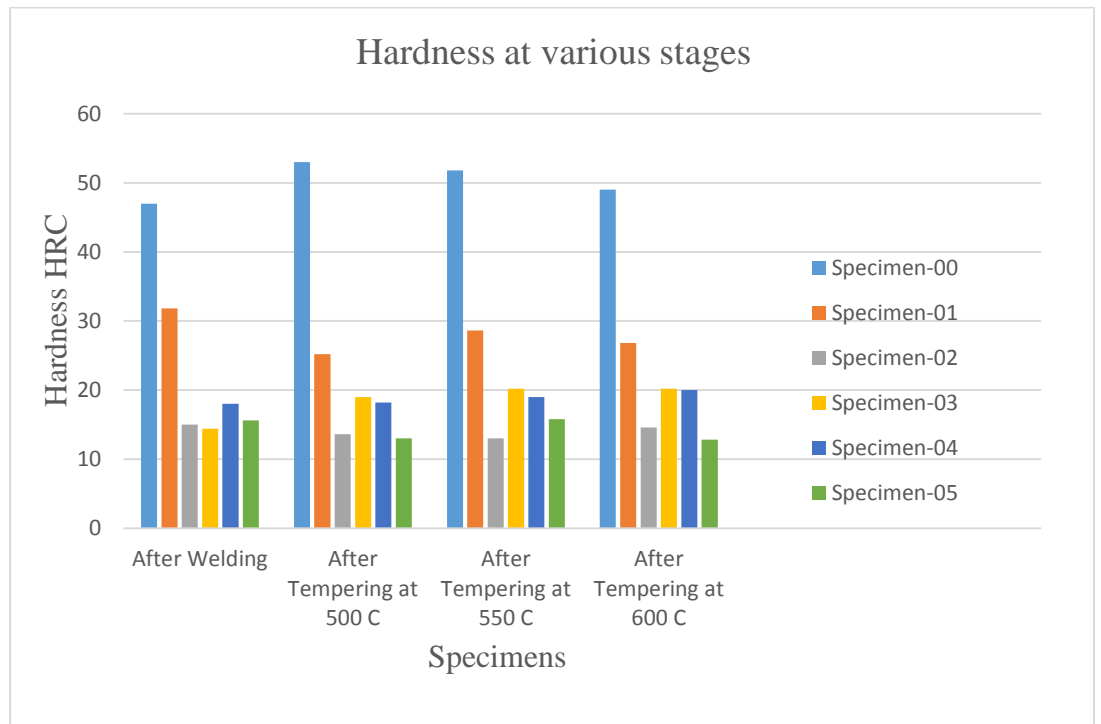


Figure.3.2. Graph of the specimen hardness Specimen 00- 05 at various stages

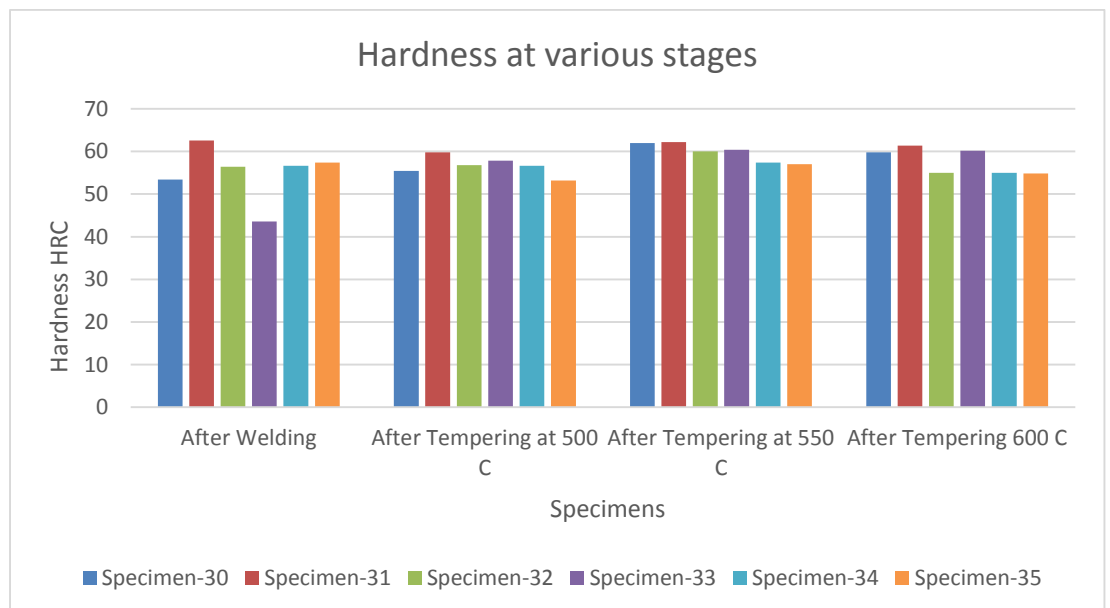


Figure.3.3. Graph of the specimen hardness Specimen 30- 35 at various stages

Fig-3.2 and Fig-3.3 shows the values of the hardness obtained under different tempering temperature, which are tempered for 1 hour. These readings are compared with the initial reading take right away after welding. The clear stage by stage explanations are explained in flowing graphs.

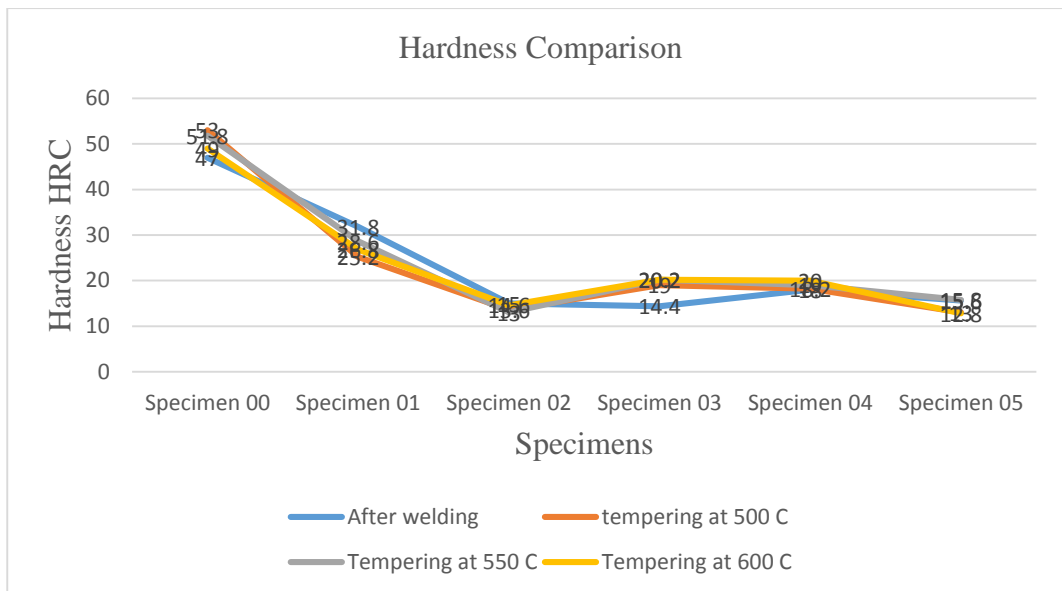


Fig.3.4. Comparison of hardness attained by each specimen from 00 to 05

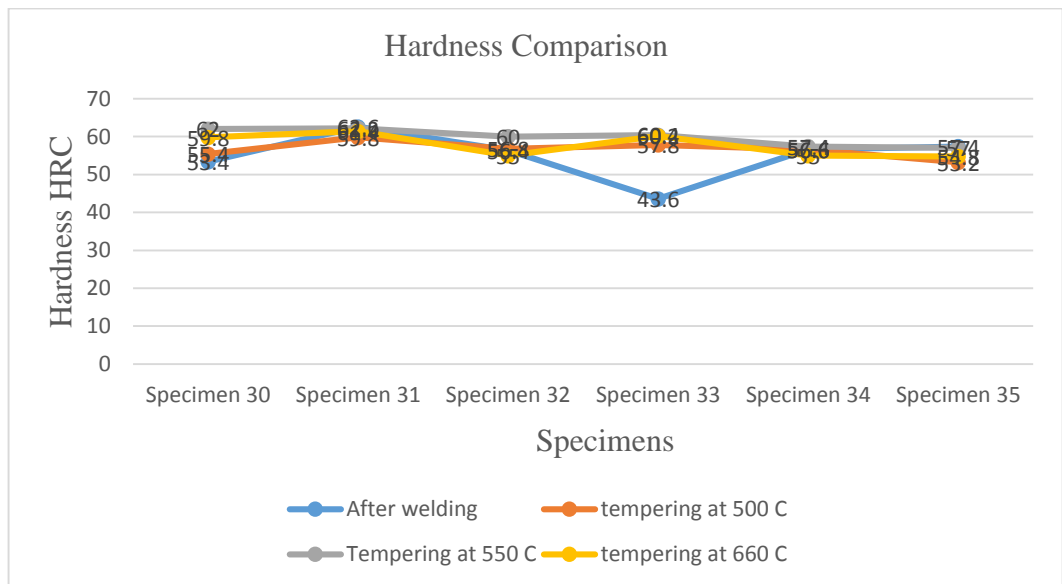


Fig.3.5. Comparison of hardness attained by each specimen from 30 to 35

The Fig-3.6 shows the difference in the hardness obtained by after weld and the tempering of specimen 00-05 at 500°C. Now looking at the graphs Specimen 00 increased in hardness from 47 to 53 HRC. However, the rise in hardness is not so significant. The hardness obtained will be almost similar to each other. For the specimen 01 there was a decrease in hardness after tempering compared to after weld from 31.8 to 25.2 HRC. Coming to the specimen 02-05 the harness obtained is very low. Even after tempering at 500°C the hardness was very low.

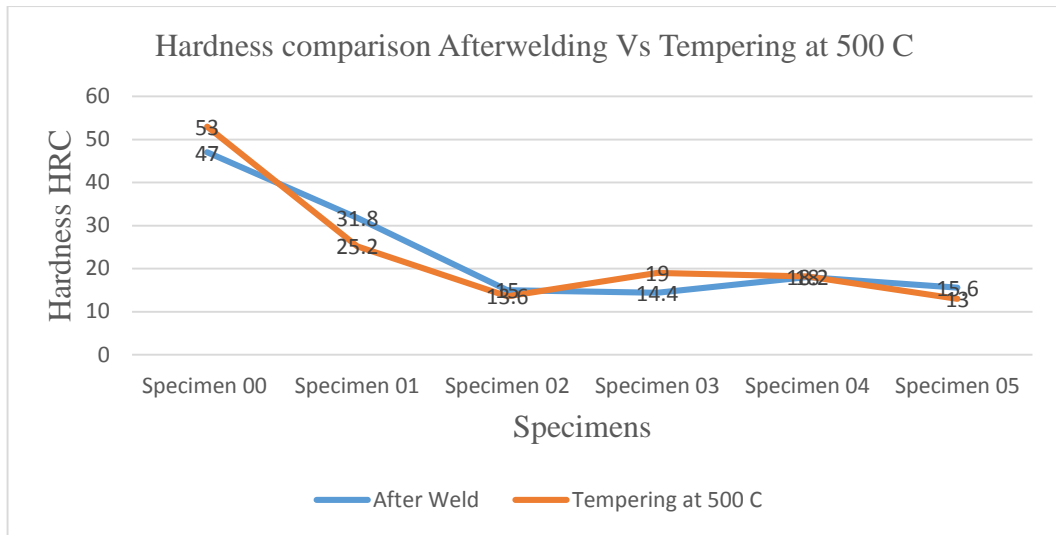


Fig.3.6. Hardness comparison of the specimens 00-05 (after welding Vs 500°C)

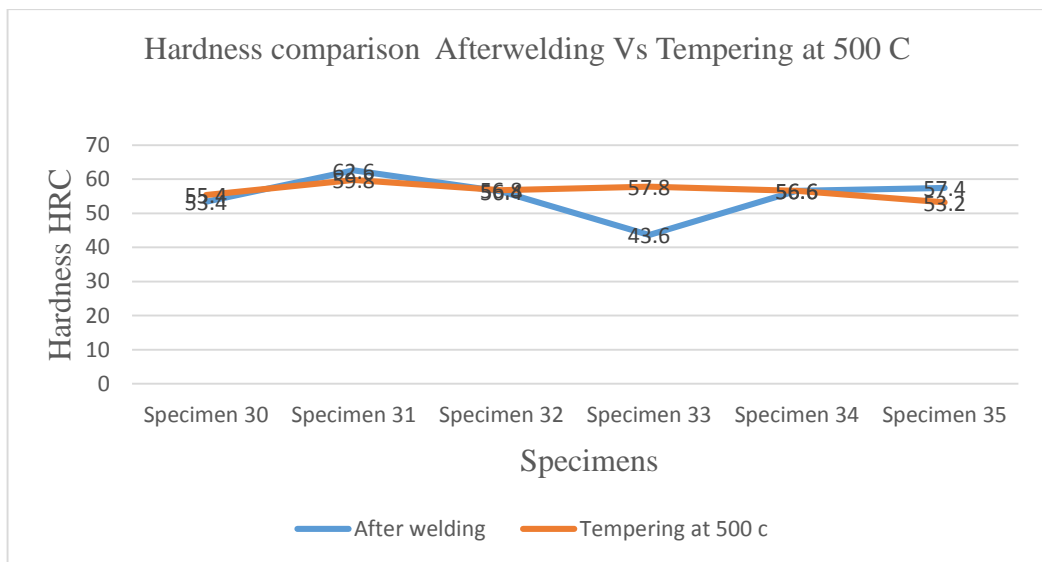


Fig.3.7. Hardness comparison of the specimens 30-35 (after welding Vs 500°C)

From the Fig-3.7 shows the comparison of hardness obtained for the specimen30-35. From the specimen 31, the hardness attained by welding was much higher than tempering, which is 62.6 HRC. The second highest HRC obtained was by specimen 32 with 56.8 HRC where the Hardness remained the same even after tempering. The only specimen which had a major rise in hardness was in specimen 33 where the hardness from 43.6 to 57.8 HRC, which was like almost 14.2 HRC which is pretty significant as we didn't expect.

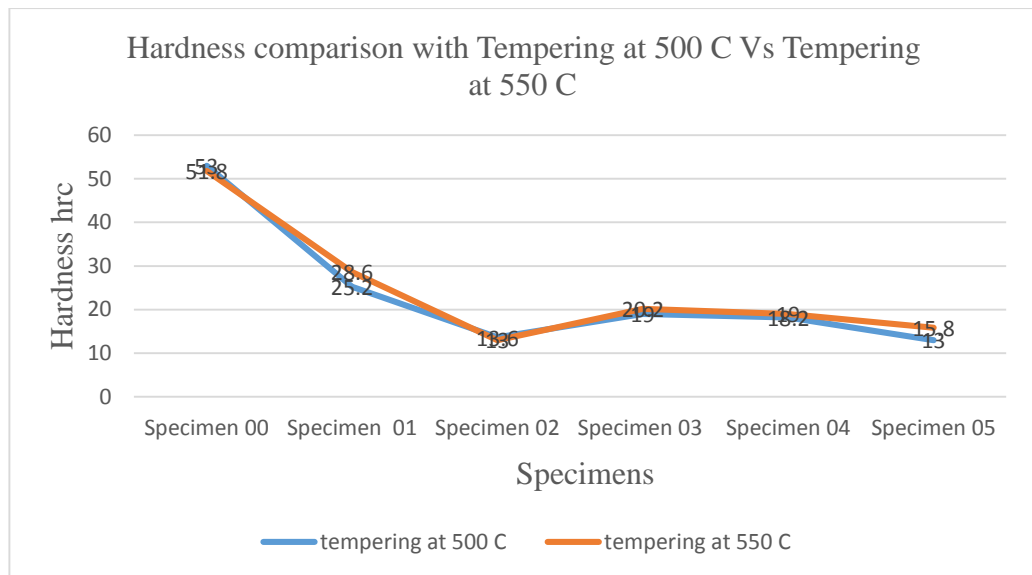


Fig.3.8. Hardness comparison of the specimens 00-05 (tempering at 500°C Vs 550°C)

From Fig-3.8 the values of the specimen hardness compared tempered at 500°C Vs tempered at 550°C. The hardness obtained by specimen 00 is almost the same with 50 to 51.8 HRC. The reduction was just 1.8 HRC this doesn't cause any signification changes in the hardness. In specimen 01, the rise in hardness was noted for 3.4 HRC. As usual, the other three samples didn't show much of the increase in the hardness.

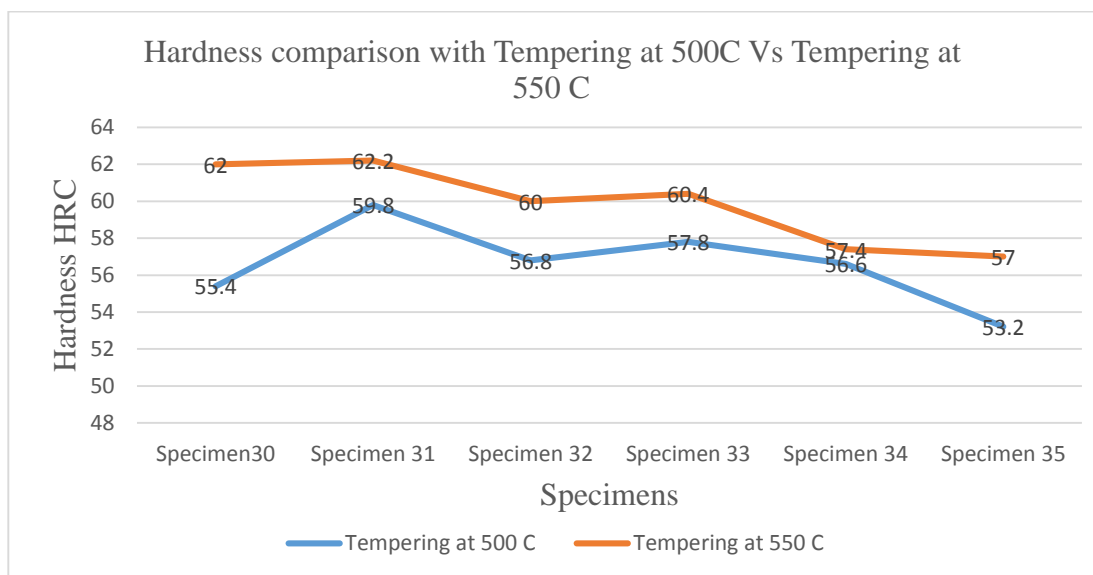


Fig.3.9. Hardness comparison of the specimens 30-35 (tempering at 500°C Vs 550°C)

From Fig-3.9 comparison of hardness HRC with different tempered temperature i.e. 500°C Vs tempered at 550°C for the specimen 30-35 can be seen. In this, every single specimen has increased in hardness significantly. With the highest hardness obtained from specimen 31 with 62.2 HRC that too after, tempering at 550°C. The second highest hardness is from specimen 30 with 62 HRC but in

this significant rise, in hardness was found. Then from the other specimens in the increasing order of the specimen number the hardness number, we obtained are 60.4, 57.4 and 57 HRC.

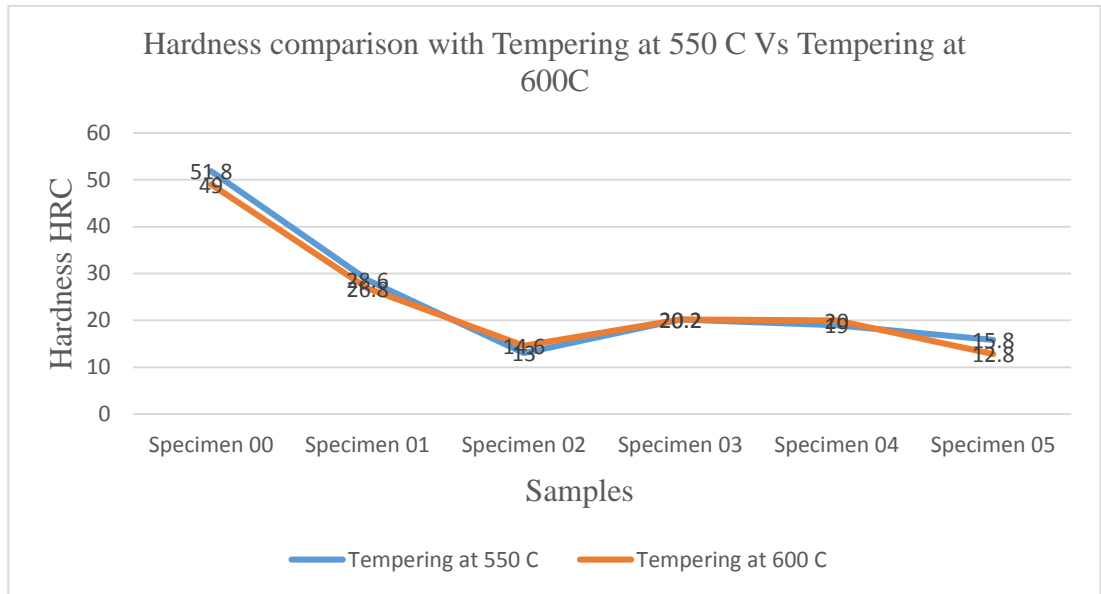


Fig.3.10. Hardness comparison of the specimens 00-05 (tempering at 550°C Vs 600°C)

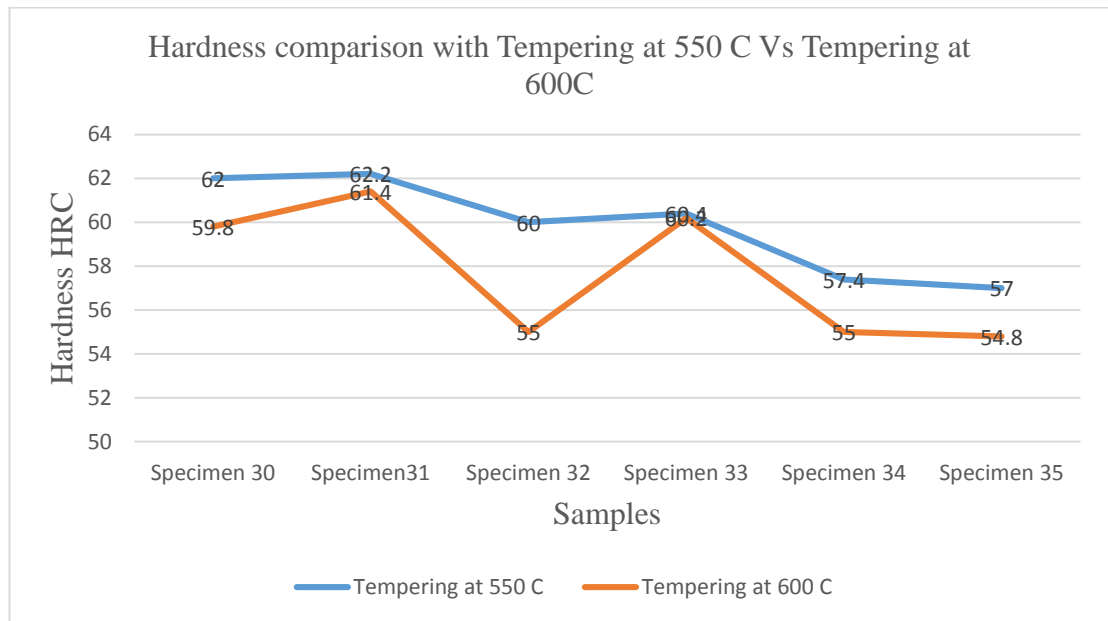


Fig.3.11. Hardness comparison of the specimens 30-35 (tempering at 550°C Vs 600°C)

From Fig-3.10 The comparison of hardness is between the tempered specimen with tempering at 550°C Vs tempering at 600°C. At this temperature 600°C not much 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.

From Fig-3.11 during tempering at 600°C there is a drop in hardness in the specimen. This makes clear with the graphs that the ideal tempering temperature for the specimens is 550°C.

By looking at the graphs and the data collected, can come to a conclusion that the ideal tempering temperature where the hardness will increase is at 550°C.

3.2. WEAR TEST RESULT AND ANALYSIS

Now coming to the wear test conducted on the selected specimen are 00 and 02 and specimen 30 and 32. Here for these specimen the flux used are silicon carbide and silicon oxide. With specimen 00 and 30 the flux used is silicon carbide. For the specimen 02 and 32 the flux used is silicon oxide.

Specimen number	Weight of samples, g					
	0 meter	40 meter	80 meter	120 meter	160 meter	200 meter
Specimen 00	11.78120	11.77850	11.77565	11.77360	11.76730	11.76440
Specimen 02	18.31820	18.31240	18.30770	18.30350	18.29870	18.29360
Specimen 30	8.80675	8.80650	8.80640	8.80605	8.80570	8.80515
Specimen 32	13.97090	13.96900	13.96815	13.96725	13.96635	13.96550

Table.3.2. Wear specimens tempered at 550°C, material weight measured at equal interval.

Specimen number	Wear (weight loss in g)					
	0 meter	40 meter	80 meter	120 meter	160 meter	200 meter
Specimen 00	0	0.0027	0.00285	0.00035	0.00063	0.0029
Specimen 02	0	0.0058	0.0047	0.0042	0.0048	0.0024
Specimen 30	0	0.00175	0.0001	0.00035	0.00035	0.00055
Specimen 32	0	0.0019	0.00085	0.0009	0.0009	0.00085

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

Specimen number	Wear (weight loss in g)					
	0 meter	40 meter	80 meter	120 meter	160 meter	200 meter
Specimen 00	0	0.0027	0.00555	0.0076	0.0139	0.0168
Specimen 02	0	0.0058	0.0105	0.0147	0.0195	0.0246
Specimen 30	0	0.00025	0.00035	0.00070	0.00105	0.00160
Specimen 32	0	0.0019	0.00275	0.00365	0.00455	0.0054

Table.3.4. Wear specimens tempered at 550°C measured with actual material loss from starting in g.

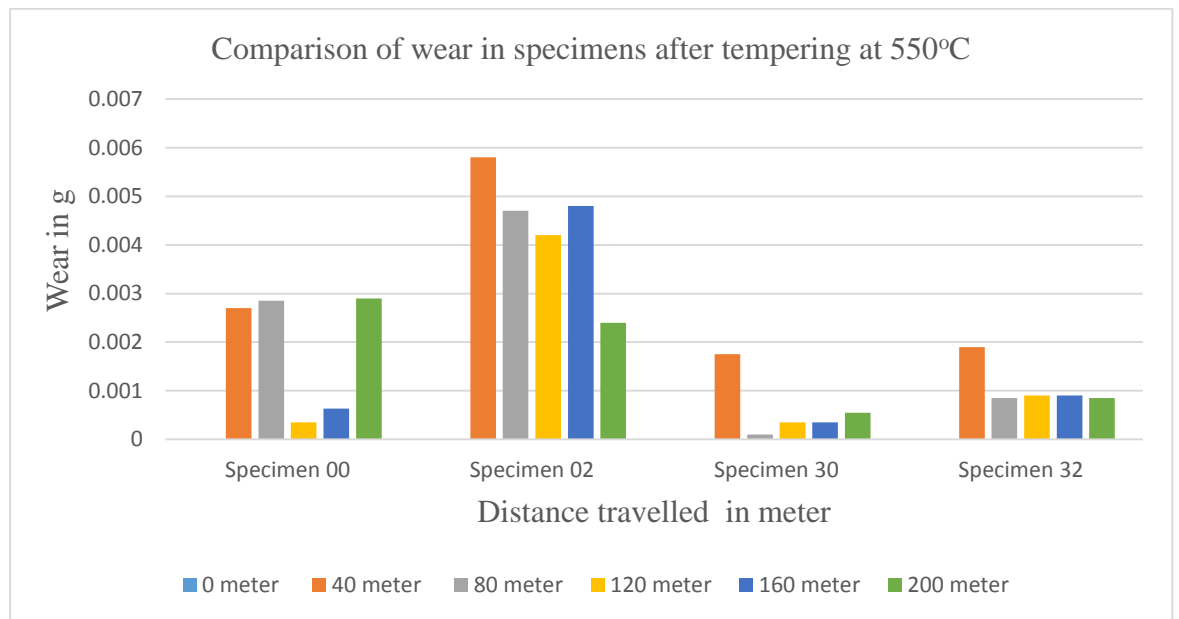


Fig.3.12. Comparison of wear of the different specimens tempered at 550°C

Now looking at the Fig-3.12-3.14 can come to a conclusion that the mixture added to the specimen 30 and 32 have highest wear resistance. The mixture plays an important role as an alloying element which adds extra carbon to the weldment. Now coming to the flux, only flux will not help increase the wear resistance. We need an additional element in the metal for wear resistance. Now looking at the graphs above, it can be seen that initially wear in all the specimen are increased, the readings were taken when the wheel travelled up to 40meter on the specimen. Then there was a decrease in the wear of the specimen.

This may have happened because of the plastic deformation that happened on the specimen. The lowest wear resistance in the specimens is the specimen 00 with the flux as silicon carbide. The second-lowest wear resistance was in the specimen 02 with the flux mixture of silicon oxide. By comparing both the specimen just the flux cannot help in gaining the wear resistance.

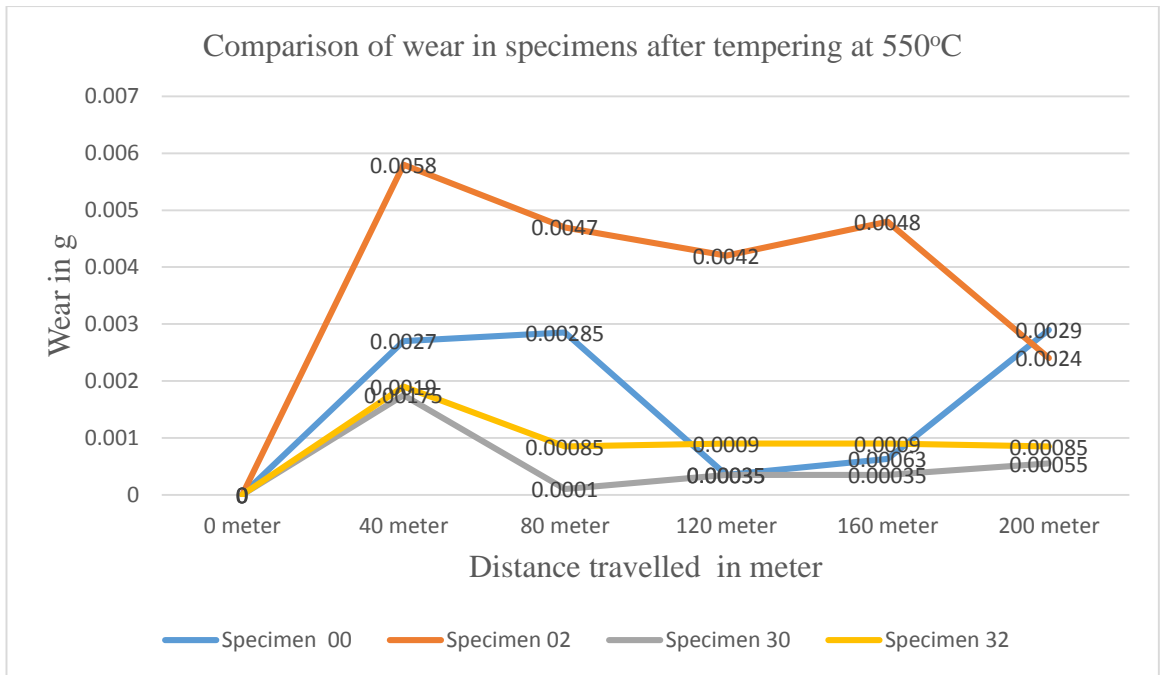


Fig.3.13. Comparison of wear of the different specimens tempered at 550°C

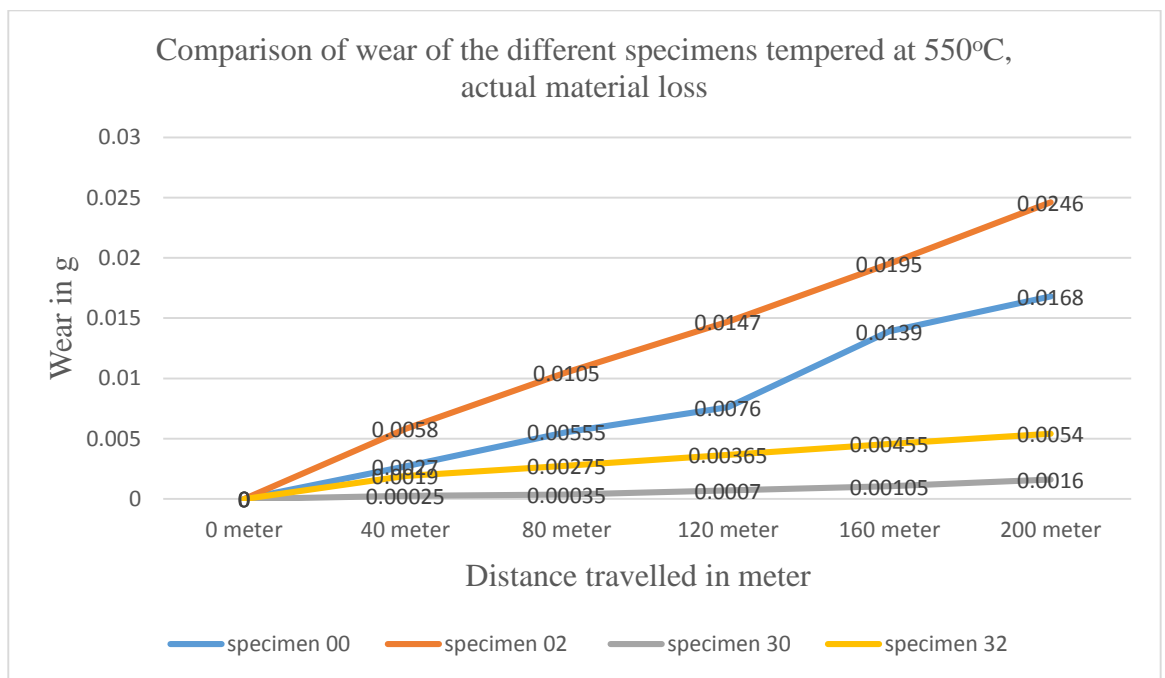


Fig.3.14. Comparison of wear of the different specimens tempered at 550°C, actual material loss

The other two specimens, i.e. 30 and 32 have the highest wear resistance. In this it can be concluded that the mixture added will certainly help in gaining resistance against wear. After 40 metre until 200 metres, the wear of the specimen remained the same. In the specimen 00, there was a gradual decrease in the wear on the specimen surface. However, in the specimen 02, there was a decrease in

the wear after 40 metres till 160 metre but at the end, nearing to 200 metre there was an increase in the wear of surface.

3.3. MICROSTRUCTURE ANALYSIS OF THE SPECIMENS

3.3.1. Microstructure of the specimen after welding

These specimens are taken after welding and rapidly cooled down to room temperature. The surface is smoothed down and polished to a mirror finish. Then the specimens are etched so that the grains are exposed and visible through the microscope. These photos that are obtained from the microstructure observation are used to analyse the structure obtained.

These welded layers are generally magnified under 25x, 100x, 250x. the formation of the microstructures is clearly shown. As in material science, it's known that once the specimen is welded and rapidly cooled. There is the formation of the martensitic structure and retained austenite. This austenite is generally the crystalline structure of iron and steel. This will form because the certain part of the austenite doesn't change into the martensitic structure. The other will be converted into the martensitic structure, because of the rapid cooling of the material. Which doesn't give time to convert into pearlite. The martensitic structure will be the highest hardness structure. This structure will have high strength. But this structure will cause the material to become brittle. At a certain temperature, generally by heat treatment the retained austenite can be changed into martensite or complete austenite. This martensite structure will be formed because of the carbon that is present in the steel. The martensitic structure can be identified by their peculiar dark needle-like structure. Which has the highest strength, but brittle. This can be changed to tempered martensite by tempering at a certain temperature.

From the Fig-3.15-3.17, the microstructure of the specimen 00 after welding can be seen. In this the martensitic formation in the microstructure can be seen. Even the retained austenite can be seen in the structure. Under the magnification of 250x, certain carbide structures in the specimen 00 are seen.

From Fig-3.18-3.20 we can clearly see that the martensitic structure is formed in specimen 30. Here the martensitic structure looks like the needles. Here at certain places a few carbides are formed, which is pretty much unsure.

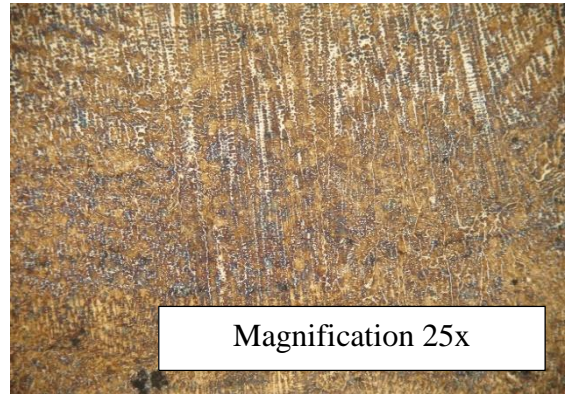
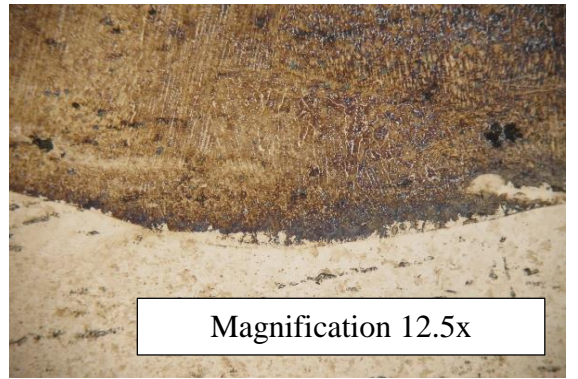


Fig.3.15. Microstructure of the specimen 00 under Magnification 25x

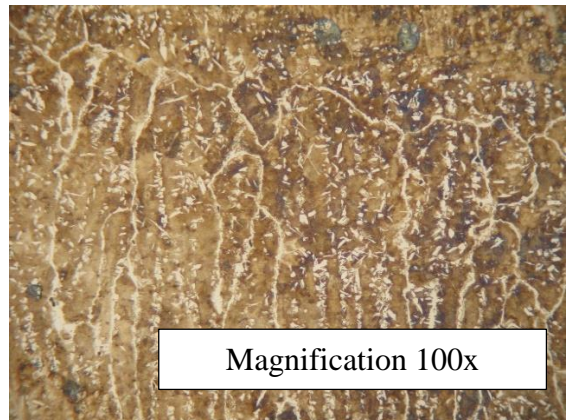
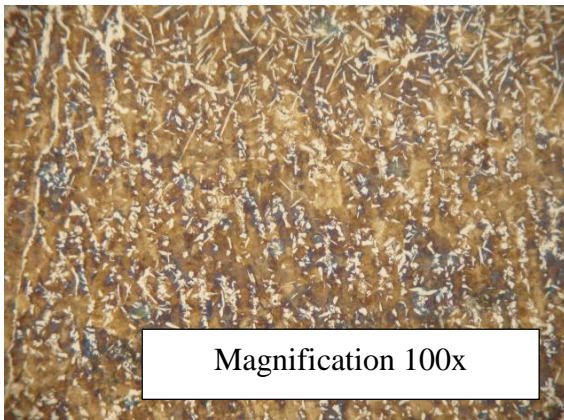
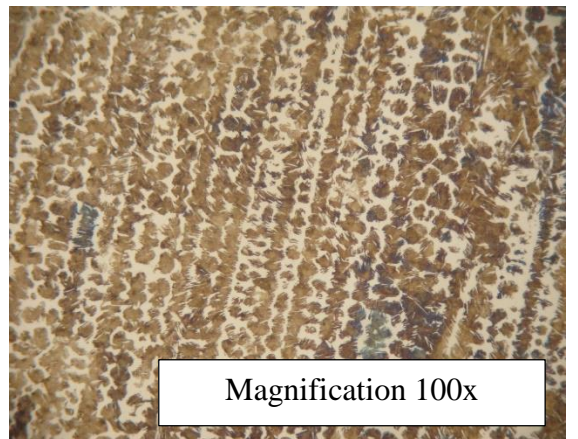
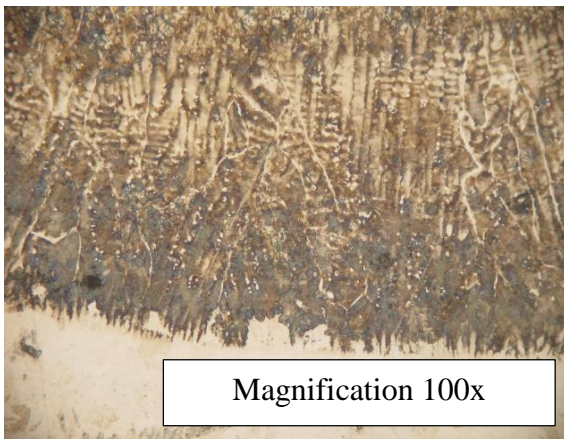


Fig.3.16. Microstructure of the specimen 00 under Magnification 100x

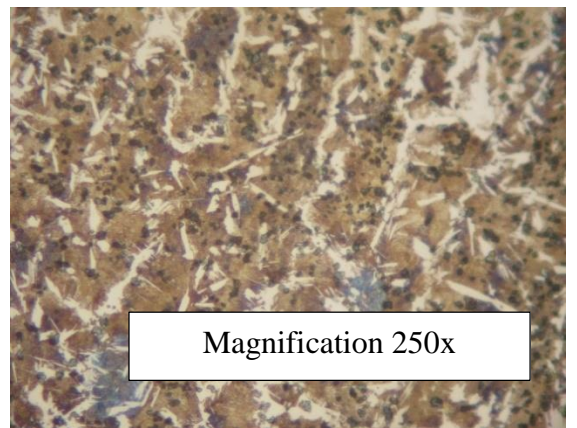
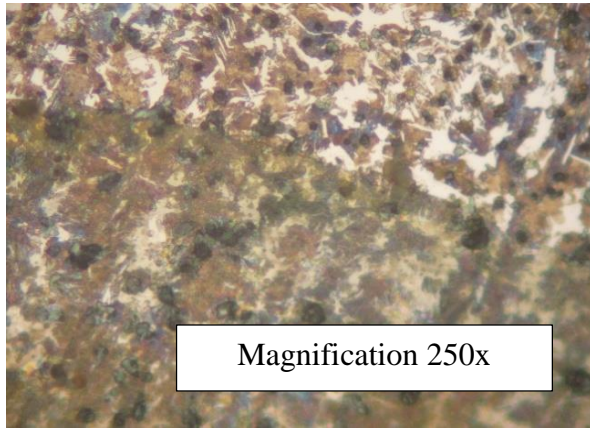
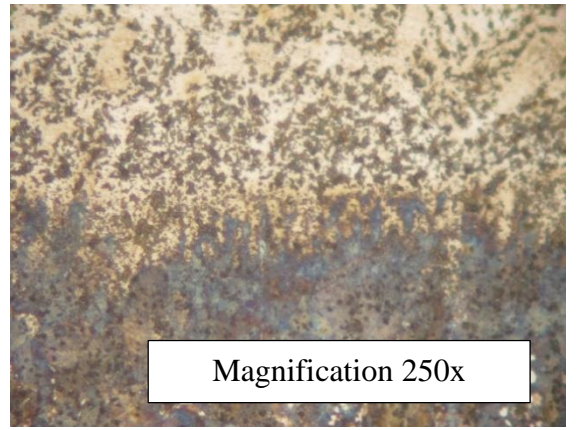
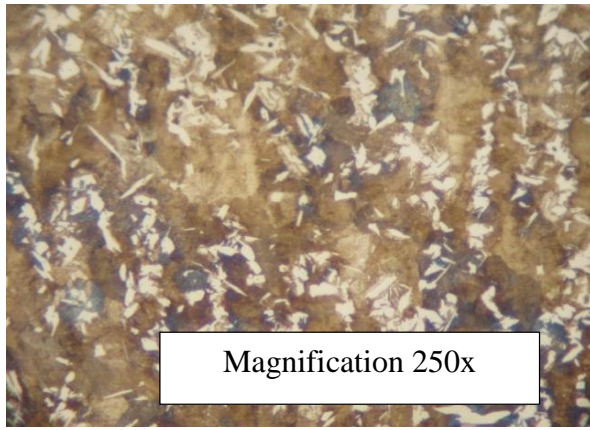


Fig.3.17. Microstructure of the specimen 00 under Magnification 250x

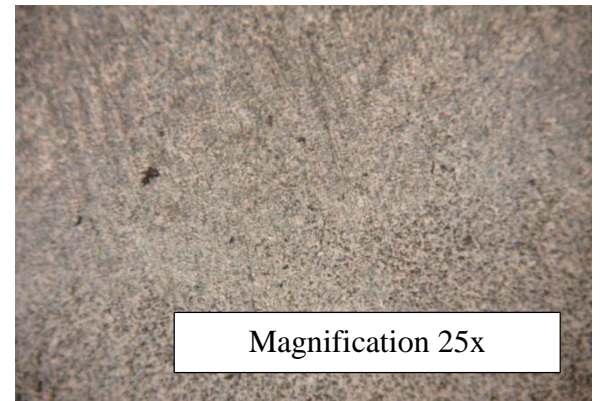
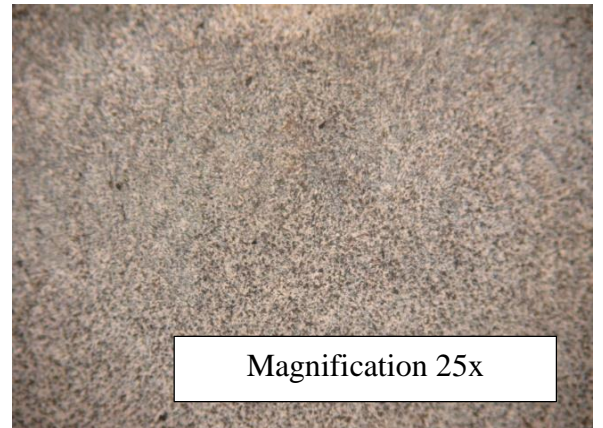


Fig.3.18. Microstructure of the specimen 30 under Magnification 25x

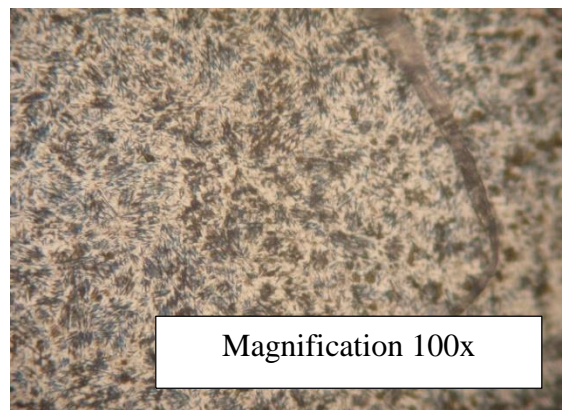
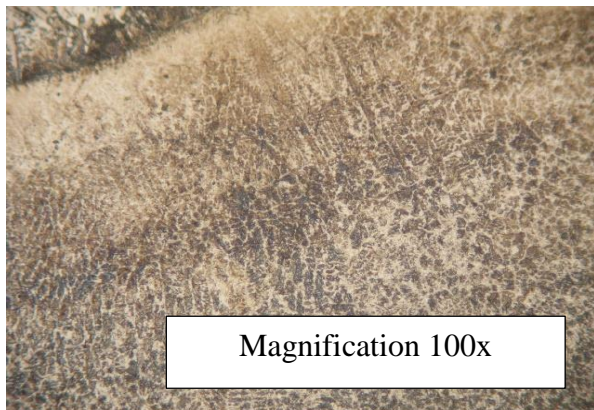
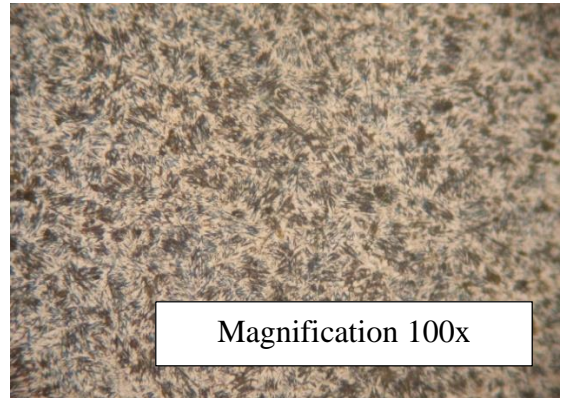
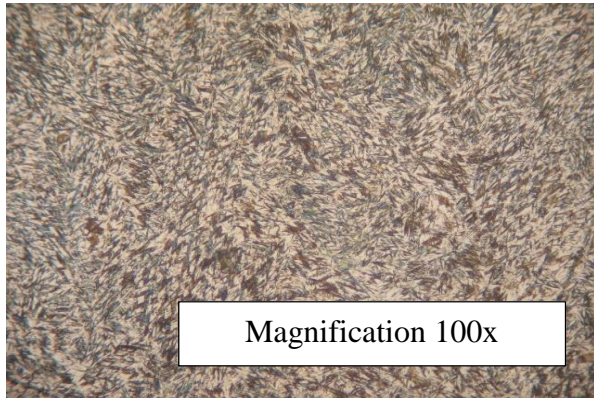


Fig.3.19. Microstructure of the specimen 30 under Magnification 100x

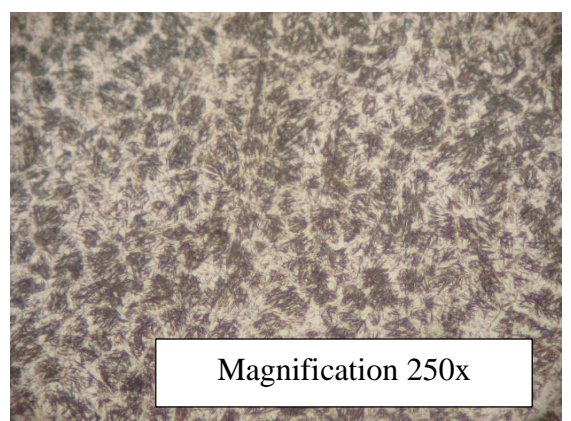
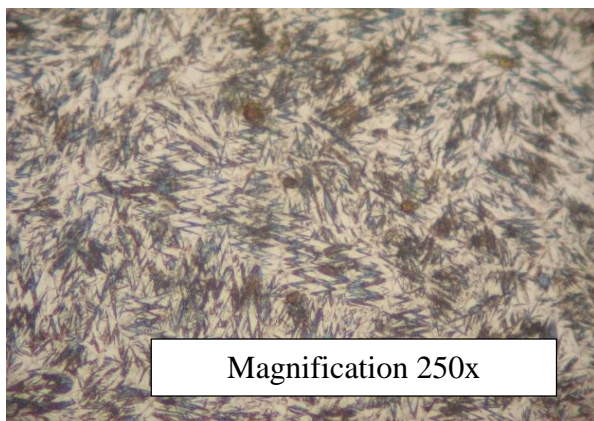
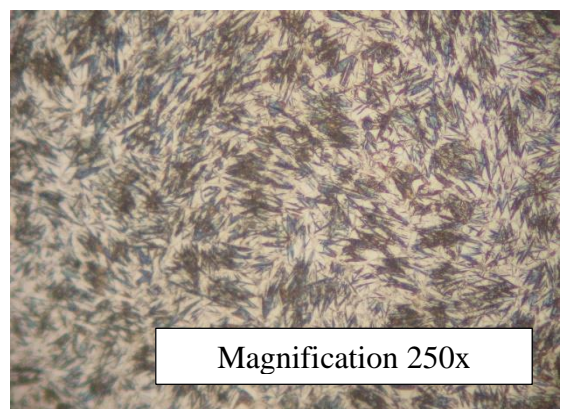
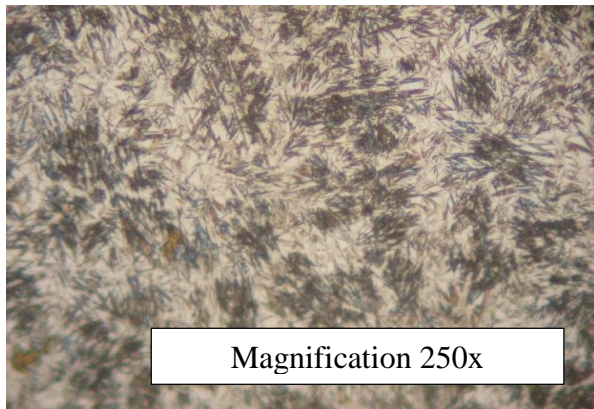


Fig.3.20. Microstructure of the specimen 30 under Magnification 250x

3.3.2. Microstructure of the specimens after tempering at 550°C

Once the specimen is tempered with the temperature 550°C. The transformation takes place from Martensitic structure to sorbite. Which is the phase next to martensite. Where in this state, the toughness of the specimen increases and the hardness decreases. Nevertheless, by comparing the hardness in this stage at 550°C, there is an increase in hardness. After examining the microstructure, there are certain changes in the structure. From the Fig- 3.21-3.23 we can observe the specimen 00 that the martensitic structure has been changed to sorbite structure. At the same time, we can see some carbidic formation in the structure as the flux used was silicon carbide.

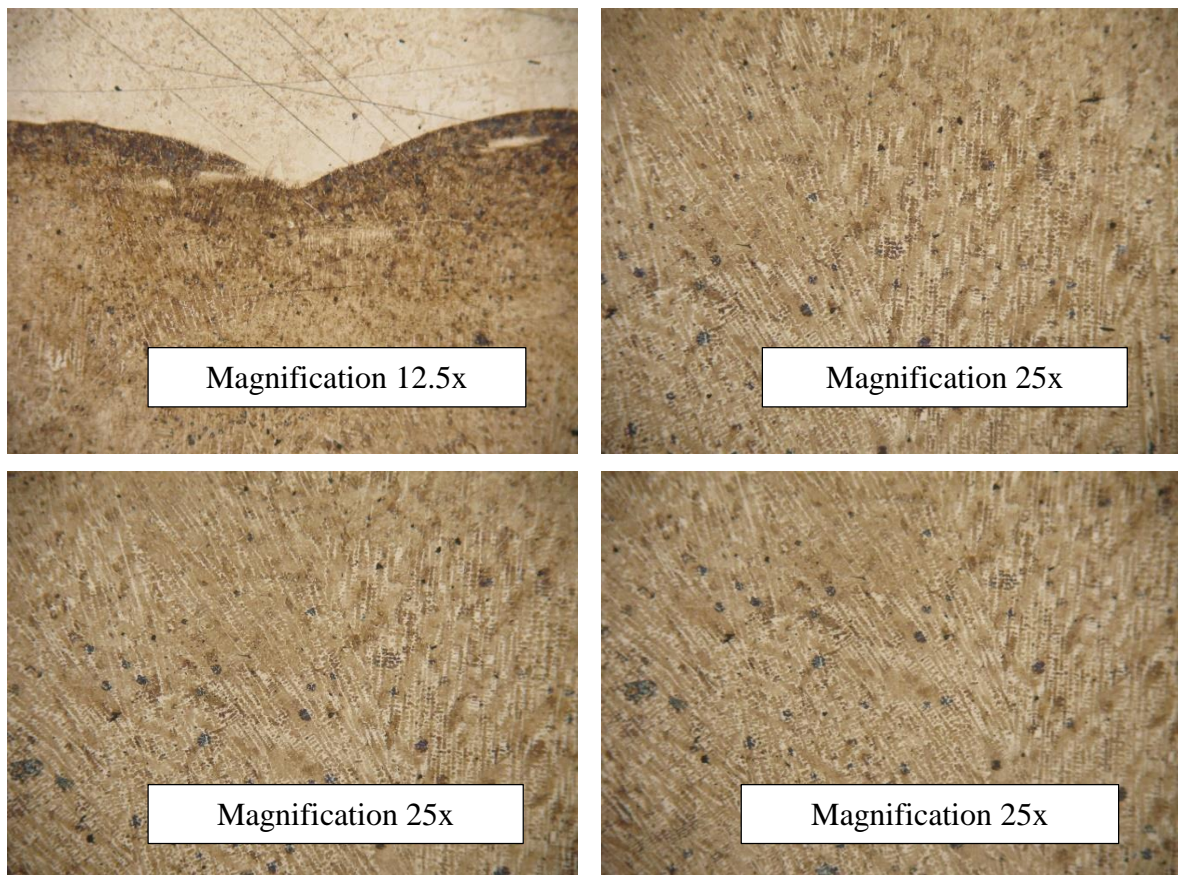


Fig.3.21. Microstructure of the specimen 00 under Magnification 25x after tempering

From the Fig-3.24-3.26 the structure of the specimen 30 after tempering are seen. In this the carbide formation are seen in the structure and the same time the martensitic structure has been changed to sorbite. The formation of carbide has been contributed by the HSS mixture which was added to the structure.

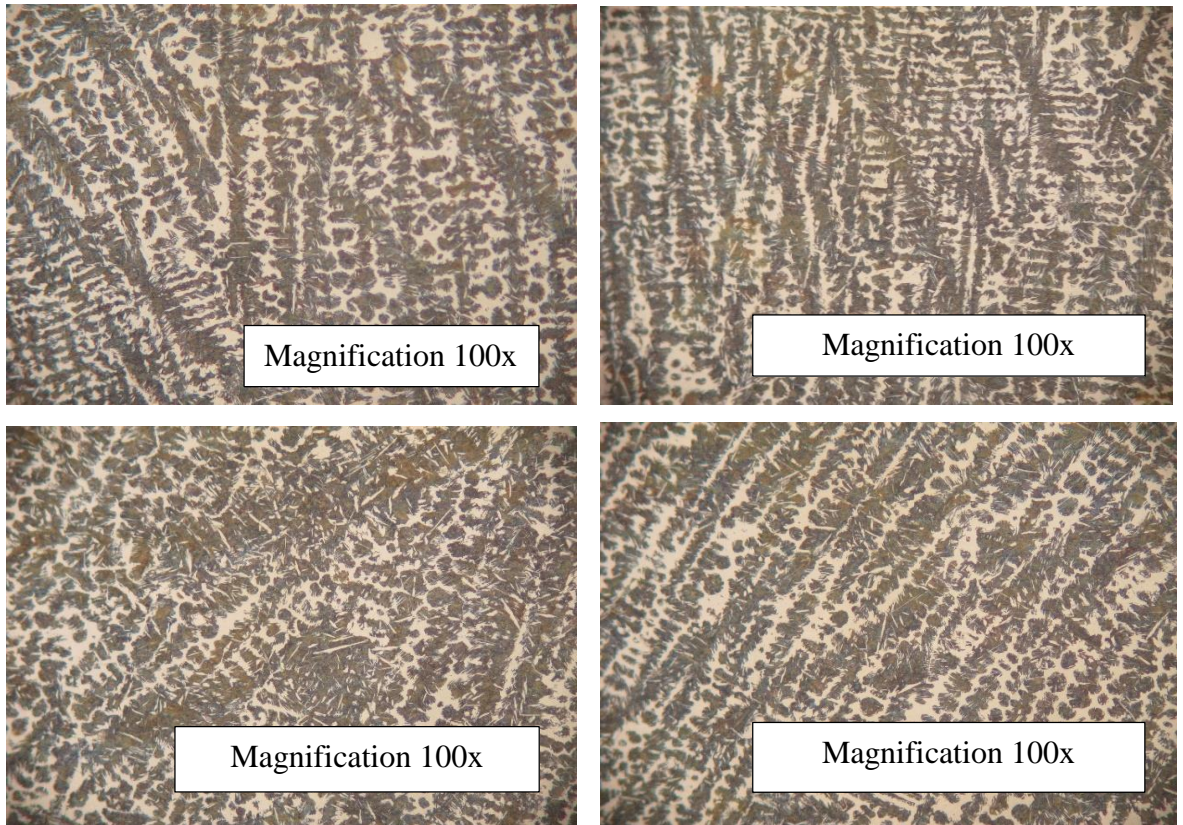


Fig.3.22. Microstructure of the specimen 00 under Magnification 100x after tempering

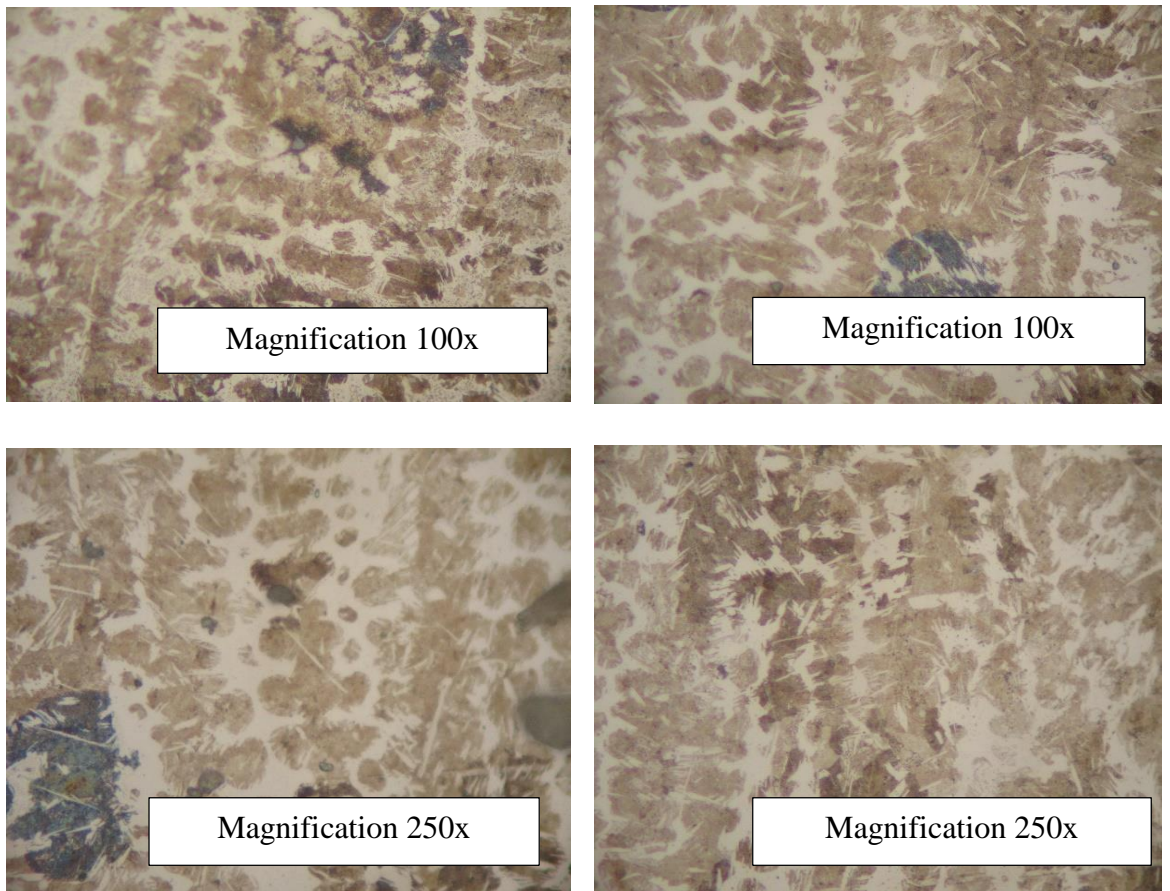


Fig.3.23. Microstructure of the specimen 00 under Magnification 250x after tempering

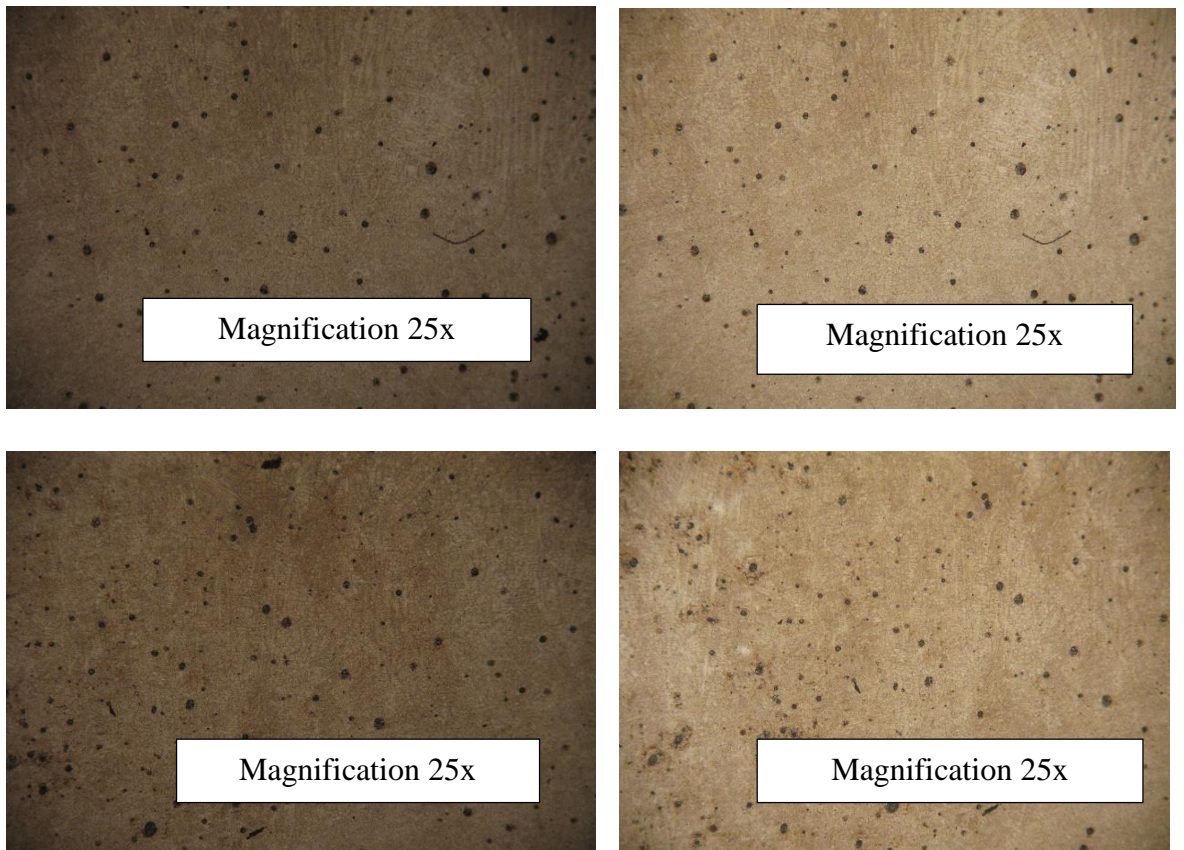


Fig.3.24. Microstructure of the specimen 30 under Magnification 25x after tempering

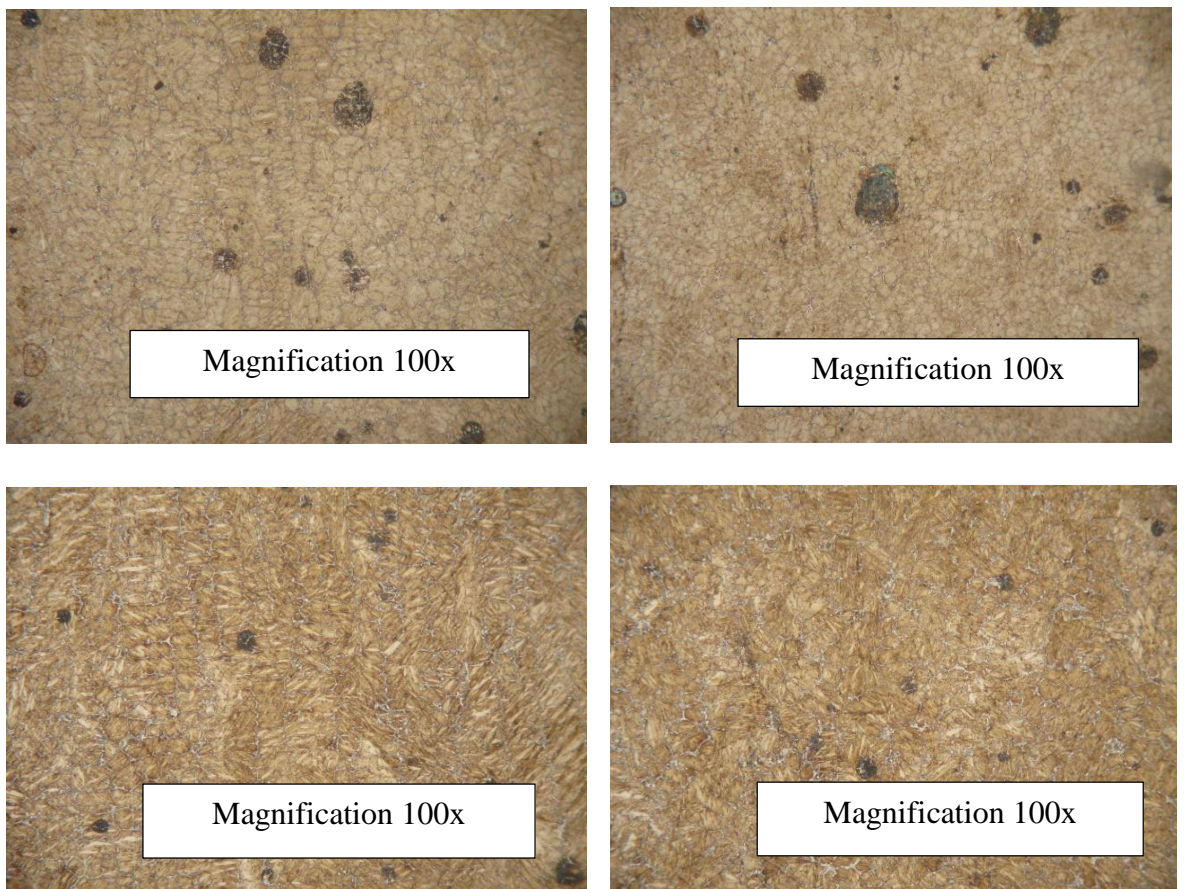


Fig.3.25. Microstructure of the specimen 30 under Magnification 100x after tempering

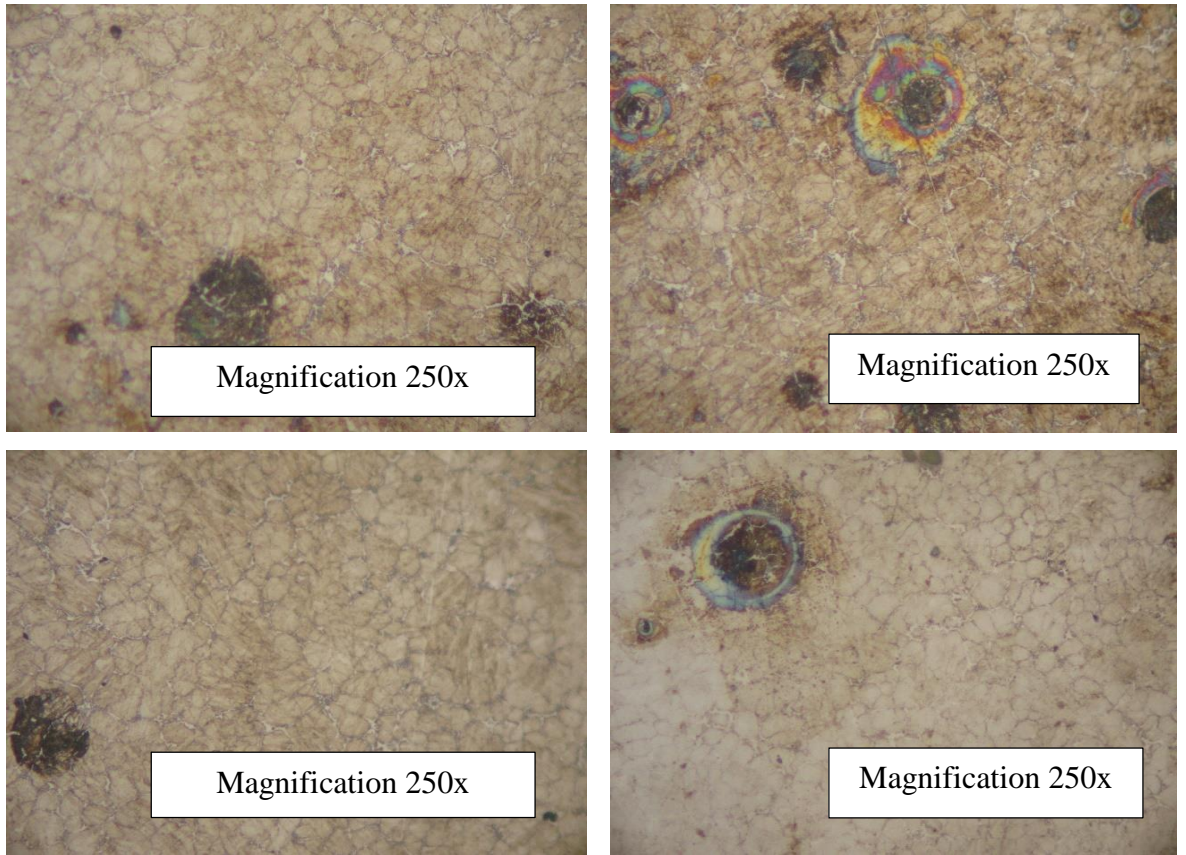


Fig.3.26. Microstructure of the specimen 30 under Magnification 250x after tempering

CONCLUSIONS

1. As it can be seen from the sample 00 hardness results, it is possible to obtain the hardened surface layer without the use of any mixture, only using the flux mixture with silicon carbide. The initially hardened layer can be obtained from the welding process. With the 100% silicon carbide tempering is required to retain the hardness, but the increase of hardness is not so significant. First the hardness obtained after welding is 47 HRC. The hardness obtained after tempering is 51.8 HRC, by tempering at 550°C for the specimen 00.
2. The highest hardness has been obtained by adding the mixture HS 6-5-2. It can be observed that the mixture act as alloying element, with the flux 100% silicon carbide in specimen 30 and the flux mixture with 50% silicon oxide and 50% silicon carbide in specimen 31 and last flux silicon oxide in specimen 32 to get the highest hardness. Even tempering at 550°C has supported in an increase of the hardness in the specimen 30 and specimen 31. By the experiment the initial hardness obtained during after weld is specimen 30 – 53.4HRC, specimen 31 – 62.6HRC, specimen 32 – 56.4HRC. The highest hardness obtained after tempering the specimens at the temperature 550°C are specimen 30 – 62 HRC, specimen 31 – 62.2HRC, specimen 32 – 60HRC. The major hardness changes were seen in specimen 30 and 31.
3. The highest hardness structures obtained by both the specimens are the martensitic structure. Which will have the highest hardness. After tempering at a different temperature, the strength will decrease and the toughness increase. Even so, the hardness may increase or decrease or remains the same. As expected after tempering at the certain temperature it's clearly seen a significant rise in hardness in the specimen 00, 30, 31 32.
4. Specimen 30 and specimen 32 which used HSS mixture showed highest wear resistance and the weight lost obtained are 0.0054 g and 0.0016 g. The specimen 00 and the specimen 02 showed the least wear resistance which just the flux was used in the specimens. And the weight lost obtained for these two specimens are 0.0246 g and 0.0168 g. Among the specimen 30 and 32, specimen 30 had the least material loss.

Now looking into the experiments conducted conclusion can be made that, just a flux mixture won't help in increasing the hardness of the mixture. Generally, it's necessary for an alloying element to increase the specimen strength. The suitable tempering temperature that helps out in all the aspect is 550°C. Where the wear resistance with good hardness is seen.

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REFERENCES

1. **Bendikiene R., Keturakis G., Pilkaite T.** et al. *Wear Behaviour and Cutting Performance of Surfaced Inserts for Wood Machining // Strojnicki Vestnik-Journal Of Mechanical Engineering* 7-8(61) 2015. p. 459-464.
2. **Bendikiene R., Pupelis E., Kavaliauskiene L.** *Effects of Surface Alloying and Laser Beam Treatment on the Microstructure and Wear Behaviour of Surfaces Modified Using Submerged Metal Arc Welding // Materials Science (Medziagotyra) 1(22).* – Kaunas: Technologija, 2016. p. 44-48.
3. **Robert W., Messler Jr.** *Principles of welding: Processes, Physics, Chemistry, and Metallurgy,* WILEY-VCH Verlag GmbH & Co. KGaA, 1999. p 689.
4. https://www.google.co.in/imgres?imgurl=https://upload.wikimedia.org/wikipedia/commons/thumb/9/9e/Submerged_arc_welding_schematic.svg/2000px-Submerged_arc_welding_schematic.svg.png&imgrefurl=https://en.wikipedia.org/wiki/Submerged_arc_welding&h=2303&w=2000&tbnid=UPAdVuDs2Xx1NM:&tbnh=160&tbnw=138&docid=cSXyypLkeXZpfM&itg=1&usg=__zU01xP_1XPhYil-CKtF98EMOEn0=&sa=X&ved=0ahUKewjydugusrLAhUKnXIKHbPbBwUQ9QEINDAA visited on 18-3-2015.time 16.37.
5. <http://www.twi-global.com/technical-knowledge/job-knowledge/submerged-arc-welding-consumables-part-1-087/> visited on 18-3-2015, time 16.37.
6. <http://knowmechanical.blogspot.lt/2013/04/advantages-and-disadvantages-of.html> visited on 29-03-2016, time 12:57.
7. **Patricio F. Mendez, Nairn Barnes, Kurtis Bell, Steven D. Borlea, Satya S. Gajapathi , Stuart D. Guest, Hossein Izadi, Ata Kamyabi Gol, Gentry Wooda,** *Welding processes for wear resistant overlays.* Journal of Manufacturing Processes 16 (2014), p.4–25
8. <http://www.twi-global.com/technical-knowledge/job-knowledge/submerged-arc-welding-process-005/> visited on 08-5-2016, time 22.52.
9. http://www4.hcmut.edu.vn/~dantn/CNH/oa_ref/AWS_Standard%20WeldingTermsNDefinitions.pdf visited on 29-03-2016, time 20:57.
10. **R.K.Bhansal,** *A textbook of fluid mechanic and hydraulic machines,* Publisher: Laxmi Publications (P) Ltd. p.381.
11. **Dae-Won Choa, Woo-Hyun Song, Min-Hyun Cho, Suck-Joo Naa,** *Analysis of submerged arc welding process by three-dimensional computational fluid dynamics simulations,* Journal of Materials Processing Technology 213 (2013) 2278–2291.

12. **YV. Gunaraj, N. Murugan**, *Prediction of Heat-Affected Zone Characteristics in Submerged Arc Welding of Structural Steel Pipes*, welding research, 94-S JANUARY 2002.
13. <http://www.thefreedictionary.com/cladding> visited on 09-05-2016, time 21:20.
14. <http://www.alspi.com/lasercladding.htm> visited on 09-05-2016, time 21:27.
15. http://www.nptel.ac.in/courses/112101005/downloads/Module_4_Lecture_3_final.pdf visited on 10-05-2016, time 00:22.
16. **Lu,S.P.,Kwon, O.Y., Kim, T.B., &K, K.H.**(2004). *Microstructure and wear property of fe-mn-cr-mo-v alloy cladding by submerged arc welding*, journal of materials processing technology, 147(2), 191-196.
17. **Frydman,S.,& P Kalsi, G** (2008). Structure and hardness changes in welded joints of hardox steels.archives of civil and mechanical engineering, 8(4), 15-27
18. **Bhushan and Gupta, 1999**, The Theory and Application of the HVOF Thermal Spray Process, p. 14.
19. http://home.ufam.edu.br/berti/nanomateriais/8403_PDF_CH13.pdf visited on 09-05-2016, time 03:39.
20. <http://www.brighthubengineering.com/manufacturing-technology/74097-heat-treatment-annealing-and-tempering/> visited on 09-05-2016, time 04:49
21. <http://accuratus.com/silicar.html> visited on 11-05-2016, time 21:39
22. <http://www.iue.tuwien.ac.at/phd/filipovic/node26.html> visited on 11-05-2016, time 22:09
23. **Regita Bendikiene, Antanas Ciuplys, Lina Kavaliauskiene**, *Preparation and wear behaviour of steel turning tools surfaced using submerged arc welding technique*, Proceedings of the Estonian Academy of Sciences, (2016), 65, 2, p117–122.
24. <http://hardnesstesters.com/Applications/Rockwell-Hardness-Testing.aspx> visited on 12-05-2016, time 20:53
25. http://sizes.com/units/hardness_rockwell.htm visited on 12-05-2016, time 23:08
26. **Phaneesh R.K.** *Materials and metallurgy*, Sudha publications, 2007. p 250
27. **Edmundas Pupelis**, *Strengthening of steel product surface by overlay welding and laser beam treatment*, summary of doctoral dissertation technological sciences,mechanical engineering(09T) 2013, Kaunas.
28. http://shodhganga.inflibnet.ac.in/bitstream/10603/2065/13/13_chapter%203.pdf visted on 2-4-2016, time 8:39



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STUDY OF FLUX COMPOSITION AND ITS INFLUENCE ON THE PROPERTIES OF WELDS

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1. Introduction

The wear is the common phenomenon we face in the day to day activities. Every day every moving part is subjected to wear. The common industrial machines, automobiles, or even the normal tools which we use are subjected to wear. Even the wood working tools are subjected to wear and here each type of materials requires different conditions [1].

When machine parts wear, generally we replace the worn out parts. But it's not cost effective. To overcome this, it's possible to harden the surface of the parts that wear out easily, which can be achieved by hard-facing of the surface. This is one of the easiest method of making the surface hard to resist against wear of the parts that have poor wear resistance. Here because of this iron base surface is generally used to protect from wear or friction and abrasion. This is generally applicable with the metal to metal sliding applications [2].

The main aim of this research was to investigate the layer produced or formed by submerged arc welding and compare the results obtained with the different mixture and flux.

The objectives of the research conducted are:

- To attain the possible quality weld from the samples prepared using the mixture and different fluxes.
- To find out the hardness of the surface obtained by the weld, using Rockwell hardness testing machine.

The research gives us the basic ideas to get the possible highest hard surfaces with good wear resistance. Generally, the hardened surface layer will be deposited on the not so hard base metal. Even though the materials used in the research area is waste materials these have certain properties which are helpful for our research, also acts as an added advantage that are required in the research such as low in cost so that we can use as many number of times.

2. Methodology

Here in this current research work, the samples of the mixtures and the flux were prepared to be used in the submerged arc welding for forming of the hardened layer. The flux and the mixture prepared were of different quantity.

In this research we used certain industrial waste materials that are very useful in different ways even as a recycled material.

1 table

Chemical composition of mixture

C	Cr	W	V	Mo
0.80-0.88	3.80-4.40	5.50-6.50	1.70-2.10	5.00-5.50

HS 6-5-2 (LST EN ISO 4957:2003) powder was used as mixture. Chemical composition of mixture is given in table 1. Silicon carbide and silicon oxide were used as flux in the experiments conducted.

The flux mixture was prepared from silicon carbide and the silicon oxide. The silicon carbide sample was prepared by crushing the standard grinding wheel using the hammer to a consistency of a coarse powder and the powder is passed through the sieve to get the required size to be used in the welding. The source for the silicon oxide is recycled ground glass which is the rich source of the silicon oxide. The sample preparation of the silicon oxide is same as that of silicon carbide. Here each powder has its own property which is highly helpful in obtaining the required hardened layer that will be quality weld. The hardened surface obtained should be good in its properties, which are high wear resistance, density obtained should be low to reduce overall weight, highly corrosion resistant, and the melting point of the weld should be high.

The 2 table shows the general properties of the flux powder used in the specimen preparation.

Properties of the materials used for flux

Powder	Properties
Silicon Carbide (SiC)	Good wear resistant; good high temperature resistant; low density
Silicon Oxide (SiO)	High chemical resistivity; low density; can be used as a shielding agent against radiation in the welding [3]

From the table 3 it can be seen that two types of samples have been made, one with the mixture and the other without. The general welding process which have been used was Submerged Arc Welding (SAW) [4]. The experiments were conducted on the plain carbon steel with the dimensions of 100×10×10. The general chemical composition of the plain carbon steel is (C 0.14-0.22 %; Si 0.12-0.3 %; Mn 0.4-0.65 %; S≤0.05 %; P≤0.04 %). A single 1.2 mm diameter electrode of low carbon wire was used in the submerged arc welding. The real time submerged arc welding was carried out with an automatic welding device (torch MIG/MAG EN 500 78), using correctly chosen welding parameters: welding current 180-200 A, voltage 22-24 V, travel speed – 14.4 m/h, and the wire feed rate – 25.2 m/h.

Details of the sample

Sample number	Mixture	Flux
00	No mixture	100% SiC
01	No mixture	50% SiC+50% SiO
02	No mixture	100% SiO
30	HS 6-5-2	100% SiC
31	HS 6-5-2	50% SiC+50% SiO
32	HS 6-5-2	100% SiO

The welding is done on the plain carbon steel without the mixture on three specimens with three different flux mixture. The second set of specimens are welded with the mixture added on the plain carbon steel up to a depth of 3mm. Then the flux mixture is added on the top of the specimen. Here additional flux is not added along with the mixture as this prepared mixture will act as an alloying and shielding element which is required for the hardened layer. After the weld the specimens are prepped for hardness testing by grounding the weld flat. The hardness was measured with the general Rockwell Hardness tester and the initial readings were noted down. The specimens were tempered at different temperature to impart toughness. Heat treatment such as hardening develops extreme hardness in steels but reduces their toughness. The steel becomes very brittle and unsuitable to be used in the most of the service conditions. Hence the secondary heat treatment process is done that is called as tempering [5]. The hardness may increase or decrease or remain constant during the tempering.

3. Results and discussion

After tempering all the specimens are subjected to hardness testing. The average values of hardness are shown in table 4.

Hardness result of the specimen after welding and after various tempering temperature

Sample number	Hardness over weld, HRC	Tempering temperature		
		500°C	550°C	600°C
00	47	53	51.8	49
01	31.8	25.2	28.6	26.8
02	15	13.6	13	14.6
30	53.4	55.4	62	59.8
31	62.6	59.8	62.2	61.4
32	56.4	56.8	60	55

1 fig. Comparison of hardness (after weld Vs tempering at 550°C)

By looking at the fig. 1 we can identify that specimen 00 has the highest hardness 47 HRC after welding only with the flux mixture of 100% silicon carbide. Now coming to the specimen 30 which has the hardness of 53.4 HRC with the mixture and the flux mixture of silicon carbide. Comparing both specimens we can note that with the silicon carbide flux we can obtain hardness without the mixture. Specimen 01 has the flux mixture of 50% silicon carbide and 50% silicon oxide. The hardness of this sample obtained was 31.8 HRC which was the second highest with this flux mixture. At the same time the hardness obtained by specimen 31 along with the mixture and with the 50% silicon carbide and 50%

silicon oxide was 62.6 HRC. This shows the promising and required hardness this particular flux mixture and the HS 6-5-2 mixture has the right condition to obtain hard surface. Lastly with the specimen 02 with the flux 100% silicon oxide the hardness obtained was pretty low comparing with the number 05. This shows that without the mixture this combination is very weak. With the specimen 32 the flux mixture of 100% silicon oxide the hardness obtained is 56.4 HRC. We can come to point that with the mixture added during the welding the mixture acts as a purely alloying element and providing the required hardness. After tempering at the temperature 550°C we have clearly seen that the increase of hardness in specimen 00 (51.8 HRC), but there was decrease of hardness in the specimen 01 (28.6 HRC) and in the specimen 02 (13HRC). The most promising specimens were the specimen 30 and 32 as their hardness obtained were 62 and 60 HRC. The specimen 31 didn't show significant rise in the hardness it had retained the same hardness which was 62.2 HRC.

4. Conclusions

As can be seen from the sample 00 hardness results, it is possible to obtain the hardened surface layer without the use of any mixture, only using the flux mixture with silicon carbide. The initial hardened layer can be obtained from the welding process. With the 100% silicon carbide tempering is not required to retain the hardness, as the increase of hardness is not so significant.

The highest hardness has been obtained by adding the mixture HS 6-5-2. It can be observed that the mixture act as alloying element with the flux mixture of 50% silicon carbide and 50% silicon oxide to get the highest hardness. Even the tempering at 550°C has supported in increase of the hardness in the specimen 32.

Further research will be conducted on wear resistance of welded surfaces. Also microstructure analysis will be conducted for studying of the distribution of the austenite structure and formation of the carbides.

Reference

1. **Bendikiene R., Keturakis G., Pilkaite T.** et al. *Wear Behaviour and Cutting Performance of Surfaced Inserts for Wood Machining // Strojnicki Vestnik-Journal Of Mechanical Engineering* 7-8(61) 2015. p. 459-464.
2. **Bendikiene R., Pupelis E., Kavaliauskiene L.** *Effects of Surface Alloying and Laser Beam Treatment on the Microstructure and Wear Behaviour of Surfaces Modified Using Submerged Metal Arc Welding // Materials Science (Medziagotyra)* 1(22). – Kaunas: Technologija, 2016. p. 44-48.
3. **Phaneesh R.K.** *Materials and metallurgy*, Sudha publications, 2007. p 250.
4. **Robert W., Messler Jr.** *Principles of welding: Processes, Physics, Chemistry, and Metallurgy*, WILEY-VCH Verlag GmbH & Co. KGaA, 1999. p 689.
5. **George E.** *Steel heat treatment: equipment and process design*, Totten. Boca Raton [Fla.]: CRC Press, 2007. p. 883.