International Journal of Advanced Research Foundation
Website: www.ijarf.com (ISSN: 2394-3394, Volume 4, Issue 3, March 2017)

Investigation of Mechanical Properties of a Composite Tubular Electrode Based Hard coating on Mild Steel Substrate

B.Balaji[1]
Research Scholar, Department of Mechanical Engineering,
Jawaharlal Nehru Technological university college of Engineering,
Ananthapuramu, India.
baluboyalla@yahoo.co.in

C.Yuvaraj[2], M.L.S Devakumar[3]
Professor's, Department of Mechanical Engineering,
[2]Madanapalle institute of Technology &Science, Madanapalle,
[3]JNTUCEA, Ananthapuramu.
India
drcyuvaraj @gmail.com, devakumar.mech@jntua.ac.in

***Abstract*— The objective of the paper was to investigate effect of electrode composition, baking temperature and duration on mechanical properties and microstructure of the specimens. Preparations of metal powders mixed with C, Mn, Si, Cr, Ni, and Mo with iron powder to form a composite mixture of filler powders. Filler powders were packed in hollow electrode with varying composition of chromium, baking temperature and time. Nine different composite mixtures of tubular hard facing electrodes were employed to investigate the effect of the microstructure on mild steel plates by a shielded metal arc welding process. The microstructure of the hard facing layers on the mild steel were examined by means of optical microscope, scanning electron microscopy (SEM) and subsequently mechanical properties were investigated in terms of hardness, tensile and shear strength. The result reveals that inter metallic component formed during welding process on mild steel surface enhances surface and mechanical properties.**

***Index Terms*— Tubular Electrode, Mild steel, SMAW, Microstructure,**

I.INTRODUCTION

Hard facing is a low cost technique of deposition hard and wear resistant material on metal components which are exposed to high abrasion environment to extend their service life [1]. The use of hard facing is increasing rapidly because of the increasing costs of the components. It is used primarily to restore worn parts to usable condition. It is also applied to new components before being placed in the service [2].The various hard facing techniques such as metallic arc deposition, oxy-acetylene braze, atomic hydrogen arc, spray-weld, thermal spraying, plasma metal deposition and high velocity oxygen fuel (HVOF) coating were used in the industry for unique applications [3]. Among the above techniques, hard facing by manual metal arc deposition technique is preferred, because of its greater flexibility and simple and economical equipment. Bhanu.et.al [4] describes coated composite tubular electrode deposition on mild steel through Shielded metal arc welding SMAW Method. From this process, those complex chromium carbides were formed in iron rich ferrite matrix. The tubular electrode weld deposit produces a small heat affected zone due to the low heat input, resulting in little damage to base material. Preheating of mild steel plates for deposition tubular electrode is not essential and also post-heating and stress-relieving of plates after hard facing are not required. The welding parameters has been found to affect the properties of hard facing deposits [5-7]. The weld deposition of hard facing alloys is commonly employed in industry to increase the service life of components subjected to abrasive wear [8].work done by several researchers includes the comparison with different hard facing processes [9]. The hard facing deposits on the base metal are usually characterized by single or double layers, triple or multiple layers without pre-heating of base metal usually results in the formation of cracks due to welding contraction strain. Buchely et.al [10] studied the comparison of the microstructure and abrasive wear resistance of hard facing alloys reinforced with primary Cr-C. The hard facing alloys were deposited onto ASTM A36 carbon steel plates by SMAW Method. The microstructure of the studied hard facing alloys having two layers first (Cr-rich) and second (Cr-rich deposits having a eutectic matrix with pro eutectic M7C3 type chromium carbide). Although many researchers [11,12] worked on tubular electrode but no research work optimize the tubular electrode process parameters such as composition of chromium, baking temperature and time. Development of chromium carbide-based tubular electrodes with pre-formed chromium carbide particles enclosed in a stainless steel tube appears to have promise in the area of wear resistance. Hence the present work has been made to investigate the effect tubular electrode process parameters on microstructure and mechanical properties on hard faced mild steel substrate.

II.EXPERIMENTAL DETAILS

A. Material Selection

The chemical composition and mechanical properties of mild steel are given in the Table 1. The hard facing was carried out on mild steel (MS). MS plate of 5 mm thickness was selected as the base metal.

TABLE I. *CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF MS.*

Wt. %		Hardness	Tensile Strength (MPa)	Yeild Strength (MPa)
Co	0.2	18 HRC	485	275
Mn	0.9			
Si	0.2			
S	0.04			
P	0.03			
Fe	Bal			

Nine different types of specimens were prepared by depositing nine different compositions of composite mixture hard facing electrodes on mild steel as described in earlier work [9]. A short arc length (4.8 mm) was maintained to prevent loss of alloying elements and dilution of the hard facing deposit by the base metal. The variation of parameters involved in the preparation of chromium carbide tubular electrodes were Cr from 20-30% in a step of 5%, baking temperature from 300-400 °C in a step of 50° C and time 2-3 h in a step of 0.5 h. Table.2. Shows the nine different combinations of hard facing electrodes were fabricated.

TABLE II. *DIFFERENT COMBINATIONS FOR THE PREPARATION OF HARD FACING ELECTRODES*

Name	**Level 1**	**Level 2**	**Level 3**
Baking Temp. (°C)	300	350	400
Time of Baking (in Hrs)	2	2.5	3
% of Cr	20	25	30

B. Welding Parameters

Hard facing electrodes were deposited on the MS plate (without preheating) in the flat position by the shielded metal arc welding using direct current. Shielded metal arc welding using alternating current can be used in case rectifier based welding units are not available. The welding parameters employed for depositing the layers on the MS specimen are given in Table 3.

TABLE III. WELDING PARAMETERS

Avg. Voltage (V)	20
Avg. Current (A)	110
Avg. Speed (mm/s)	3.0
Weld. Arc Efficiency (%)	85
Heat input (KJ/mm)	0.623
Welding Current	DC

Welding current of 110 A was used to deposit the hard facing layer, which is very low compared to other conventional hard facing electrodes, which would require around 250 A current for a 6.3 mm diameter electrode. The welding heat input, which is proportional to the welding current, is therefore low in the case of tubular electrode. In hard facing, minimizing the heat input is absolutely essential in order to obtain the best hardness in the deposit. As tubular electrodes involve burning of thin MS tube of 0.4 mm thickness, the required current density is obtained at low amperage. The precautions are taken before hard facing such as current were used to avoid dilution, low heat input technique, slow cooling and wet grinding.

The hard-faced samples were ground with a series of emery paper (up to 2000 grit size) and polished with diamond paste (1-2 microns size). The samples were etched with Marble’s reagent on polished samples using ASTM 112-96 standard method[13]. The microstructure observed with an optical microscope and scanning electron microscopy Hardness tests were conducted on thoroughly polished samples. All the samples were applied with a load of 150 kg for a period of 15 s using Rockwell hardness apparatus. The test was carried out at 5 different locations on one specimen. The same procedure is carried out for all other specimens and Rockwell hardness number is calculated. An adequate spacing was maintained between multiple indentations. Mild steel plate of thickness 6mm with the required length and width was sent to the Amoda FO3015nt laser cutting machine is computer operated and works by auto-cad programs. Specimen dimension were feed through the program and laser beam cuts the mild steel plate to required dimensions. Milling operation were carried out on edge of laser cut pieces with an angle of 400 and 1mm root face gap in the milling machine and then base plate prepared for butt joint. The plates to be welded together were arranged to form an 80º V groove with 1mm root face. Tensile test and shear test carried out as per ASTM E8 standards. Fig.1. shows the specimen dimensions as per ASTM E8. Fig.2. shows actual specimen prepared for tensile and shear specimens.

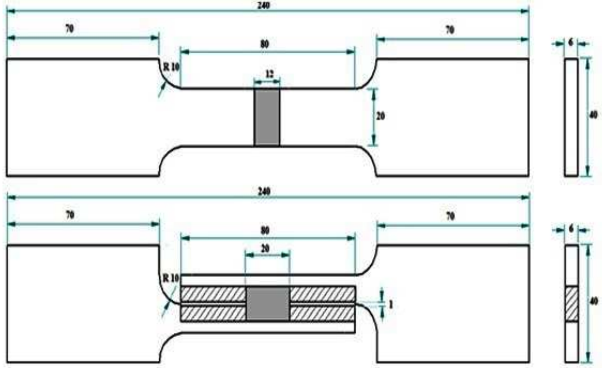


Fig. 1. Specimen dimensions as per ASTME8 standard

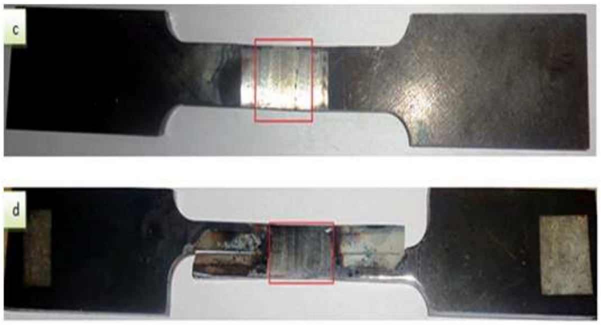


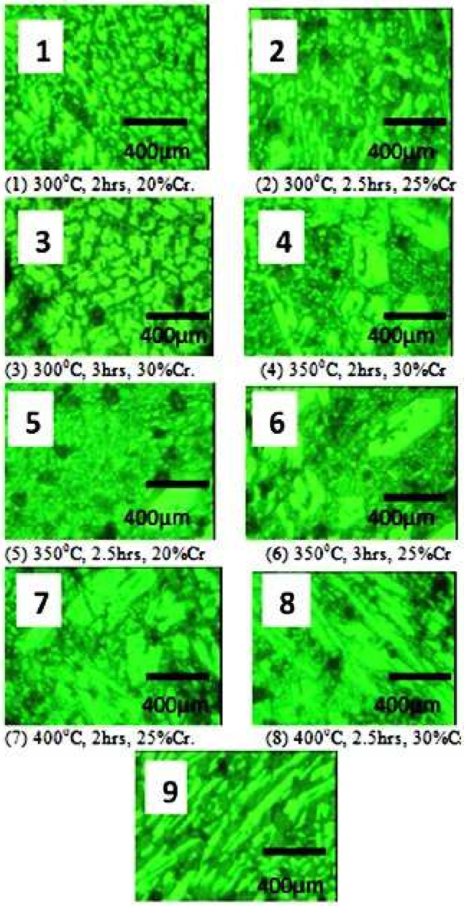
Fig. 2. Actual specimen cut through laser beam as per ASTME8 standards

III. RESULTS

A. Micro structure

Fig.3. (E1 to E9) shows the optical microscope photograph of nine specimens. The Hard facing deposits were uniform and homogenous on the surface of mild steel with no crack /Pores visible in weld nugget. The microstructure of hard faced surface of nine specimens, on comparison, the grain size has increased from specimen (E1-E4), that is irregular in shape and size but in specimen E4 and E5, we can observe the hexagonal-shaped M7C3 type chromium carbides. Similar microstructure which includes hypereutectic chromium-rich M7C3 and niobium-rich MC carbides can be observed in specimen E3, E4, E7 and E8. In specimen 8 and 9 it is observed the long spine like shapes of chromium carbides.

The presence of coarse chromium rich carbides (M7C3 type) with uniform dispersion in primary solid solution can be seen from Fig. 3 (specimen-E5, E6). M7C3 is chromium-rich carbide in which Mo, Fe and Mn are soluble. The chromium content may range for 20 to 40 mass %, Molybdenum between 4 and 13%, iron between 30 and 50 mass % and manganese up to 12 mass %



(1) 300°C, 2hrs, 20%Cr.
(2) 300°C, 2.5hrs, 25%Cr
(3) 300°C, 3hrs, 30%Cr.
(4) 350°C, 2hrs, 30%Cr
(5) 350°C, 2.5hrs, 20%Cr
(6) 350°C, 3hrs, 25%Cr
(7) 400°C, 2hrs, 25%Cr.
(8) 400°C, 2.5hrs, 30%C

Fig.3. Hard facing microstructure of nine different specimens

The coarse carbide particles are needled as well as irregularly-shaped. This study reveals that uniform dispersion of coarse chromium rich carbides (M7C3 type) in primary solid solution. The low current (110 A) and low heat input used for tubular hard facing is responsible for the uniform dispersion. The coarse M7C3 carbide particles provide a barrier against micro-gouging and micro-cutting, thereby improving abrasion resistance.

By using tubular electrode base metal heat affected zone remains in the transformation zone for longer period of time than regular, which promotes the transformation of austenite to ferrite and pearlite, instead of martensite. The Cr-rich deposits are of a eutectic matrix with pro-eutectic M7C3 type chromium carbides. As observed by previous investigators [14,15] the primary carbides exhibited a range of shapes in the plane of polish from a hexagonal platelet to a long spine-like structure as shown in above Fig.3 (specimen-8,9).

The Cr alloy content exceeds the solubility limit of the bcc matrix phase and therefore Cr-Mo is a multi-phase material under equilibrium conditions. The excess alloy content exists in the form of carbides distributed throughout the ferrite matrix. The alloy carbides can dissolve significant amounts of other alloying elements to form non-stoichiometric alloy carbide phases. When heated to service life. The stable phase eventually reached is dependent on several factors, such as, initial structure and compositional isolation. Studies have shown that after the typical service cycle of this material the carbides are of the M6C or M23C6 type where the M symbolizes the sum of all metallic species in the carbide. The progression towards the stable carbide structure involves several steps through intermediate carbide phases. This result is contrary to the trend of the carbides progressing towards structures with a higher metal content. M23C6, M6C and M7C3 phases can all exist simultaneously in the same alloy sample. Different grains can progress along the carbide evolution path at different rates due to small-scale heterogeneity. The rate of degradation and the morphology of the precipitated and re-precipitated carbides show a complex response to temperature and initial microstructure. Since the carbide development is dependent on the initial microstructure, a heterogeneous microstructure such as a weldment will exhibit a variety of carbide distributions throughout its different zones.

B. Hardness

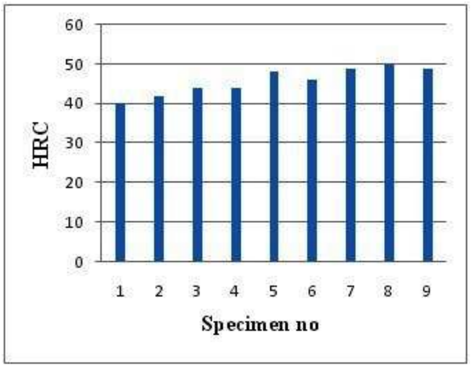


Fig.4. Rockwell hardness number v/s specimen number

Fig. 4. shows the changes in hardness number in the specimens. Tubular hard facing electrodes deposit pre-formed chromium-carbides in a MS matrix and the base material is also MS, resulting in very less dilution. Therefore, hardness of 50 HRC is obtained on the surface of hard faced surface. Welding current of 110 A was used to deposit the hard facing layer, which is very low compared to other conventional hard facing electrodes, which would require around 250 A current for a 6.3 mm electrode. In hard facing, minimizing the welding current is absolutely essential in order to obtain the least dilution of the hard facing layer by the base material and best hardness in the hard facing deposit.

Therefore, the required hardness of 50 HRC has been obtained in the hard facing layer. As per Oberlander et al.[16] and Jong-Ning [17] the high value in hardness is caused by complex chromium carbides formed on hard faced surface. In Fig.4. It can be observed that the hardness value rises linearly till 5th specimen, then, the value dips for 6th specimen and then increases up to the 8th specimen and then again drops for ninth specimen. From the investigation, it was observed that baking temperature of tubular electrode increases hardness. As we increase the baking time we get increase in the hardness, but at 350°C for 3 hours the hardness value is decreased. Overall, it appears to have stable hardness throughout.

C. Tensile strength and Shear strength

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE and SI do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

a)Tensile Strength

Fig. 5 shows the bar graph for tensile strengths vs composite tubular electrodes of different welded joints, where E1, E2….E9 are different composite tubular electrodes used for the weld joints of specimen

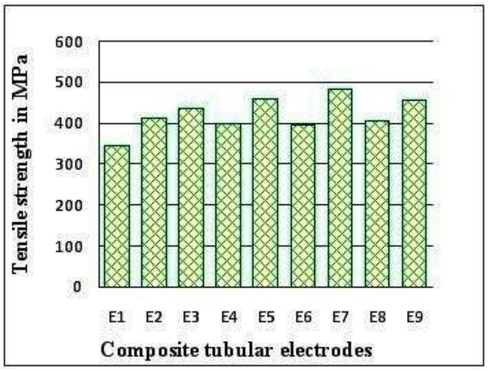


Fig.5. Tensile Strengths vs. Composite Tubular Electrodes

From the Fig.5 it was observed that the highest tensile strength values were due to the specimens E5, E7 and E9 and lowest tensile strength E8, E1 and E6 electrodes deposited on weld joints. From the investigation, it was observed that as the percentage contribution of chromium increases the tensile strength of the tubular electrode also increases. With increase in the baking temperature and baking time, there was increase in tensile strength. Overall, the major factor influencing the tensile strength was % of Cr, then baking temperature and time was very less influencing factor as mention in [18].

b)Shear Strength

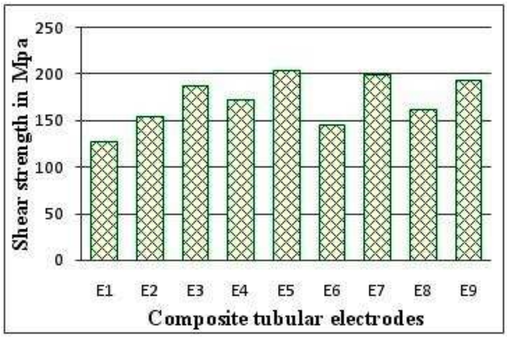


Fig.6. shear strengths vs. composite tubular electrodes

Fig.6. shows the bar graph for shear strengths vs composite tubular electrodes of different welded joints. where E1,E2….E9 are the different composite tubular electrodes used for the weld joints of specimen. It was observed that the highest shear strength values were due to the specimen E5, E7 and E9 and lowest shear strength E2, E1 and E6 electrodes deposited on weld joints. From the investigation, it was observed that as the percentage contribution of chromium increased, shear strength of the composite tubular electrode also increases. With an increase in the baking temperature and baking time increased shear strength was obtained. Overall, the major factor influencing the shear strength is Cr, then baking temperature and baking time is very less influencing factor.

C. Fractured Surface Morphology

The fracture surfaces were observed by SEM. A typical fracture surface of SMAW specimens tested at UTM is shown in Fig.7 (a-c) and Fig.8. (a-c). It was observed that cracks were initiated from both the sub surfaces voids and the surface inclusion clusters. In the inclusion clusters, elements like Mo, Mg, Ni, Si, and Fe were detected. There was no obvious de lamination along the interface between the weld coating and the substrate. From Fig.7. (a-c), it was clear that the fracture surface exhibited dimples and cleavage pattern. The brittle nature of the joint was observed. This was due to the presence of cleavage planes with different alignments and here ductile area is limited. In the centre region of the substrate, the river pattern can be observed, indicating a brittle fracture during final stage of the failure process. Cracks were first initiated from the surface or subsurface defects due to the high stress intensity factors, and propagated from the edge of the brittle hard facing coating, and then crossed the interface without the delamination along the interface, finally gathered into the centre. Specimens failed after the cleavage fracture of the centre substrate during the final stage. All the tensile specimens during fracture began to break at the centre of the weld metal, because of the low strength of weld metal

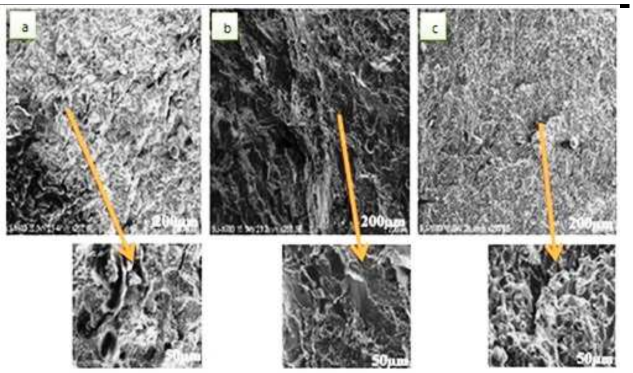


Fig. 7. Fractured surfaces of tensile specimens weld joint were welded by the composite tubular electrodes

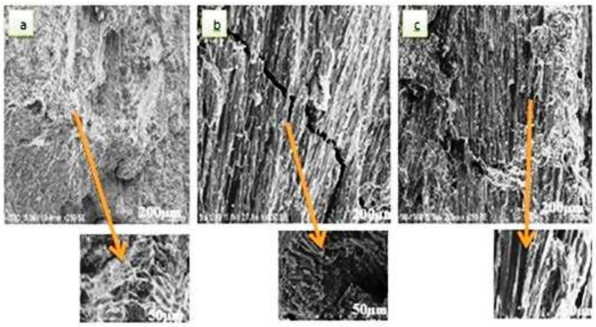


Fig.8. Fractured surfaces of shear specimens weld joint were welded by the composite tubular electrodes

Fig.8. (a-c) shows the presence of cleavage patterns and river like pattern in the fractured surface of shear tested weld specimen. Shear fracture involves the initiation of voids and its growth in the tri axial stress field. On application of strain, a plastic zone was produced and as the strain increased, cavities initiate around the carbides in the matrix. At the micro structural level, the increase in strain may be visualized as an increase in the dislocations and it exerts stress on the particle /matrix interface. This results the particle may fracture, shear from the matrix.

It has been widely accepted that a higher volume fraction of carbides is beneficial to enhance the hardness and provides improved resistance to severe abrasive and sliding wear [19,20]. However, a higher volume fraction of carbides leads to a reduction in ductility, strength and impact toughness as well. It was also concluded that large or long and thin carbides on the whole seem to be susceptible to fracture, and carbides that are locally clustered and aligned perpendicular to the tensile axis are particularly susceptible to fracture. In our work, it was thought that the higher amount of carbides enhanced the hardness but together with reduction in ductility.

IV.CONCLUSION

1. Successfully deposited the hard facing tubular electrode composite mixture on the mild steel substrate with varying composition of chromium, baking temperature and time.

2. Microstructure of different compositions, temperature and time shows that carbide particles exhibit a range of shapes from irregular, hexagonal platelet to long spline like structures.

3. Hardness value is increased due to chromium rich carbide precipitates in matrix.

4. In both cases, the tensile strength and shear strength increases with an increase in chromium content, baking temperature and Time. The ultimate tensile strength of 485 MPa is obtained for 400^0C, 2.5 Hrs and 20% Cr ,where as ultimate shear strength of 198.366 MPa is obtained for 400^0C, 2.0 Hrs and 30% Cr.

5. Due to the addition of higher volume of carbide in matrix. it reveals that the fracture probably starts from carbide particles and propagates through the specimen, which leads to reduction of ductility and impact toughness in mild steel substrate.

REFERENCES

[1] Jen-Ting Wang, Ming-Der Jean,(2006) Optimisation of cobalt-based hardfacing in carbon steel using the fuzzy analysis for the robust design, The International Journal of Advanced manufacturing Technology, vol 28, (9), pp 909-918

[2] J.H Bulloch, J.L.Henderson(1991) Some consideration of wear and hardfacing materials, Int.J.Pres.Ves. & Piping, Vol 46 pp.251-267.

[3] J.L. Henderson, J.H Bulloch (1991) Alloy classification of hardfacing materials, Int.J.Pres.Ves. & Piping, Vol 47) pp.127-158.

[4] V. T. Bhanu Kiran, M. Krishna, Praveen M., Niranjan Pattar(2012), "Development & characterization of an electrode deposition procedure for crack-free hardfacing of low carbon steel", International Journal of Advanced Manufacturing Technology, , Vol. 4, No. 1, 2012

[5] W.R.Thope, (1980) The effect of welding variables in automobile open arc hardfacing with an austenitic chromium carbide alloy,Met Forum,Vol 3 (1) pp.62-73.

[6] Amado Cruz Crespo, Americo Scotti, Manuel Rodriguez Prez (2007), "Opperational Behaviour assessment of coated tubular electrodes for SMA hardfacing,", Journal of Materials Processing Technology, vol.199, pp.265-273.

[7] T.Ellis, G.G Garrett (1986) Influence of process variables in flux cored arc welding of hardfacing deposits, Surf.Eng. Vol.2 (1) pp.55-66.

[8] S.Chatterjee, T.K.pal(2003) wear behavior of hardfacing deposits on cast iron, wear Volume 255,pp.417-425.

[9] J.R Davis, Davis and associates, Hardfacing, weld cladding and dissimilar metal joining, in: ASM Handbook- welding, brazing and soldering vol.6,10th ed., ASM metals park, OH 1993,pp.699-828.

[10] M.F Buchely, J.C Gutierrez, L.M.Leon, A. Toro,(2005) "The effect microstructure on abrasive wear of hardfacing alloys". Wear, 259,52-61.

[11] Yilmaz Bayhan, Reduction of wear via hardfacing of chisel ploughshare, Tribology International 39, pp.500-574, 2006.

[12] Ke He, Jie Cheng, Yuehua Wen, Wenwen Cai, YuSheng Yang, (2016) Study of Tubular Nickel Oxide Electrode, Advances in Engineering Research, open access.

[13] T. Sakthivel , G. S. Sengar J. Mukhopadhyay, (2009) Effect of welding speed on microstructure and mechanical properties of friction-stir-welded aluminum, The International Journal of Advanced ManufacturingTechnology vol, 43,(5) pp 468-473

[14] B. Balaji, C. Yuvaraj and M.L.S Devakumar, (2014), "Optimization of welding process of composite chromium carbide based tubular electrode for hardfacing" Int.Jour.Of Mechanical and Production.vol4, issue 1, pp 39-46.

[15] R.J.Dawson, C.B Thompson((1989) Applications for hardfacing in pulp and paper industry, Corrosion 89, pp58

[16] B.C.Oberlander, E.Lugsheider, Comparison of properties and coatings produced bylaser cladding and conventional methods, Material Science and Technology,

[17] vol.8, pp.657–665,1992. A. Jong-Ning, J. Chen, On the wear characteristics of cobalt based hardfacing layer after thermal fatigue and oxidation, Wear Volume 205, pp.611–620, 2001.

[18] A.S.C.M., D‟Oliveira, R.Vilar, C.G.Feder, High temperature behavior of plasma transferred arc and laser Co-based alloy coatings, Appl. Surf. Sci., vol.201, pp.154–160, 2002.

[19] Know-Yeong Lee, Sung-Hoon Lee, Yangdo Kim, Hyun Seon Hong, Young-Min Oh, Seon-Jin Kim, the effect of additive elements on the sliding wear behavior of fe-based hardfacing alloys, Wear Vol255.2003, pp.481-488.

[20] Min-Woo lee,Yoon-Kab Kim, Young-min oh, Yangdo Kim, Sung-hoon lee,Hyun-Seon Hong, Seon-in Kim, Study on the cavitation erosion behavior of hardfacing alloys for nuclear power industry, Wear Volume 255, pp.157-161.