WEAR BEHAVIOR OF WELD OVERLAYS ON OIL EXPELLER WORMS

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ABSTRACT

Oil expellers uses a horizontally rotating metal screw in which the friction created by the products being squeezed, wears down the worm shaft (EN8 steel) and other internal parts. The friction created during squeezing generates enormous heat of the range of 60^0C to 90^0C and three body abrasion wear which results in to uncertain failure of main shaft. Hard facing by welding is the most economical way to enhance the life of the components which are exposed to different modes of wear. In the present study, an alloy of high carbon-chromium content was used for hardfacing EN8 steel specimens by the use of shielded metal arc welding (SMAW).The taguchi based grey relational analysis method was used for parametric optimization of shielded metal arc welding (SMAW). The Hardness of specimens was analyzed by Rockwell Hardness Tester (C scale) and the wear rate was measured by the three-body abrasive wear tests conducted using a dry sand rubber wheel abrasion tester as per ASTM G65.The microstructure study was performed by using metallographic optical microscope. The effect of heat treatment (hardening and tempering) was analyzed on the base metal (EN8) specimens. The comparative wear tests and the microstructure analysis were performed on heat treated EN8 base metal specimen, and the hardfaced specimens.

Keywords - Dry sand rubber wheel abrasion tester, Grey relational analysis method, Heat treatment, Oil expellers, Parametric optimization, Shielded metal arc welding.

1. INTRODUCTION

Degradation of any material whether occurred by wear or corrosion cost a very high loss in the form of financial as well as reputative to the developing countries like India. Although considerable attention has already been paid by the researchers to develop the modern and latest techniques and methods to arrest and control the problems resulting from wear and corrosion, still there is a need for further research to minimize the losses due to wear. These wear and corrosion related problems can be minimized mainly by two methods, by using high cost wear and corrosion resistant alloys or by improving the wear and corrosion resistance of the existing metals and alloys by applying certain modifications to the surface [1].

However there are many techniques like coatings, thermal spraying, cladding, hardfacing by welding and heat treatment methods widely used to improve the metallurgical and mechanical properties but hard facing by

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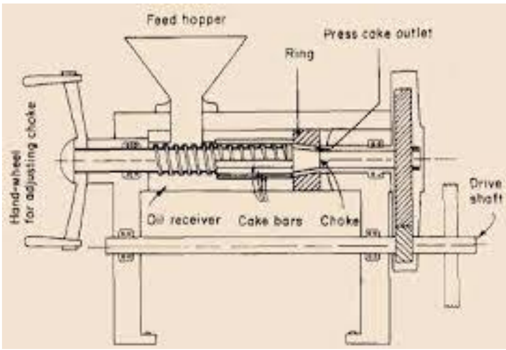
welding is comparatively the economical one. It is a process of depositing a homogeneous layer of special alloy over base metal or substrate either to improve surface characteristics like corrosion resistance, wear resistance etc. Hard facing is one of the most useful and economical ways to improve the surface characteristics of the components prone to severe wear condition like agriculture tools, components for mining operation, soil preparation, concrete mixing and crushing equipments etc. A wide variety of hard facing alloys is commercially available for protection against wear and can be applied using almost any welding process [2].Experience has proven that, to select the best hard-facing alloy, one need to know the working conditions in which the component operates, i.e. about wear factors and the base material of parts etc.

A large number of wear factors exist in different working applications, acting alone or in combination [1].The main wear factors comes in existence in most practical applications are metal to metal (adhesive), impact, abrasion, high temperature wear, erosion wear etc.Abrasive wear occurs is the major wear factor occurring in the typical components like pulverizers, roll crushers, mixing paddles, dredging operations, mineral transportation, agricultural components and scraper blades.The weld metals which are used to resist it include austenitic-manganese, martensitic and some carbide-containing alloys.[3].In the past the main works performed on the hardfacing by welding for different wear factors are summarized in the reference papers [4 to 11].

a



b

Fig.1. oil expeller worm machine (a) worm shaft (b) expeller machine

In the present study, the wear behavior of oil expeller worms is evaluated. An oil expeller is a screw-type machine that presses oil seeds such as Cotton Seed, Peanut, beans, rape seeds, sesame, sunflower seeds, copra through a caged barrel-like cavity as shown in Fig.1 (b). In operation, the machine conveys, crushes, grinds and presses the oilseed inside the cylindrical barrel (casing) with the aid of the worm shaft as shown in Fig.1 (a). The friction and the pressure involved in expeller pressing, creates heat in the range of 60^{o}C to 115 °C which wears down the worm shaft and other internal parts and results in uncertain failure of main shaft [12]. With small machines this occurs often after expressing little, after which parts have to be replaced or repaired through resurfacing by welding. EN8 medium carbon steel is preferred in the manufacturing of worm shaft over Mild Steel due to more hardness, good tensile strength and excellent wear resistance properties. EN8 steel can be further surface-hardened to produce component with enhance wear résistance [13].But in the present study, a high C-Cr content alloy is deposited to improve the wear properties of oil expeller worm shaft made of EN8.

A wide variety of hardfacing alloys are commercially available for the protection against wear. Deposits with a microstructure composed by dispersed carbides in austenite matrix are extensively used for abrasion applications. Chromium-rich electrodes are widely used due to their low cost and availability, however, more expensive tungsten or vanadium-rich alloys offer, a better performance due to a good combination of hardness and toughness [6]. However there are many welding techniques that can be used in the hardfacing process but shielded metal arc welding (SMAW) is ideally suited to this work due to the low initial and operating costs of the process and the ease of transporting the equipment [9].The important operating variables for SMAW are welding amperage, welding voltage, welding speed, electrode size, electrode work angle, arc gap,polarity,meltingrate[3].

II. EXPERIMENTATION

In the present study of oil expeller worm, the field investigations reported that grinding abrasion is the primary wear factor and impact and heat also play a secondary role in the scenario [14].

2.1. Selection of Base Metal

EN8 steel is used for manufacturing of oil expeller worm shaft [12]**.** It is a medium carbon steel having tensile strength of about 750 MPa and 17-18 HRC Rockwell hardness. It is equivalent to US Grades SAE (AISI) 1040 steel also known as 080M40 steel. The Chemical composition of the base metal is shown in table 1.

Table 1. Chemical composition of base metal

Material	C%	Mn%	P%	S%	Si%	Rest	BHN	UTS(N/MM^2)	Elongation
EN8	0.42	0.90	0.05	0.05	0.25	Fe	200	750	16% Min

2.2 Selection of Hardfacing Alloys

The hard facing electrode used in this work is 'Carbo-Chrom' having high carbon chromium content carbide rich alloy [16]. This is a special electrode with basic type of coating designed for surfacing of parts subjected to heavy abrasion and marginal impact. The electrode used for buffering having named LH106 is a low heat input welding alloy of Cr, Ni and Mn having high strength and crack-resistance. Buffer layers are used as intermediate deposits between the base material and the actual hard facing weld metal for the aspect of good bonding with the base material and avoiding hydrogen-induced under bead cracking. The chemical composition of hardfacing electrode Carbo Chrom is shown in table 2.

Table 2. Chemical Composition of Electrodes by weight %

Electrode	C%	Mn%	Cr%	Si%	Size(mm)
Carbo Chrom	2.00	1.00	20.00	0.60	4x350

2.3. Design of Experiment (Selection of OA)

Selecting three leveled four parameters L9 (3^4) orthogonal array is used to determine experimental plan [15]. The values of welding current, welding voltage, electrode angle with the normal to the weld specimen and welding speed are taken on the basis of literature review, field expert suggestions and field trial [20]. On the basis of the above, the nine experiments are designed as per taguchi L9 orthogonal array as shown in table 3.

2.4. Welding operation

In the welding operation first of all the base metal specimens (EN8 steel) were preheated to reduce cracking & stresses at about 200^{0}C for two hours in a muffle furnace as shown in Fig.3(b) and the electrodes are also dried

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for relieving absorbed moisture at the same temperature [3,21]. Then a single layer of buffering alloy LH106 is deposited on the preheated specimens by using inverter based single phase shielded metal arc welding rectifier machine (DCRP) as shown in **Fig.2(a).**

Then two Layers of hardfacing electrode were deposited on buffer layered specimens. The second hardfacing layer was deposited by taking 50% overlap of the previous layer [17]. The Samples were cut from welded specimens and grinding is done on the upper surface of specimens for further wear testing analysis as shown in **Fig.3 (a).**

a  **b** 

Fig.2. Welding Operation (a) specimens Welded by SMAW (b) Electronic Weight Measuring Machine

a  **b** 

Fig.3. Welding Operation (a) Specimens after Surface Grinding (b) Heating of Specimen in Muffle Furnace

2.5. Testing and Analyzing Work

The following are the three tests carried out to achieve the objective:

1. Rockwell hardness test (HRC)
2. Wear test (sand abrasion test)
3. Microstructure study (optical microscope)

2.5.1. Hardness Testing

Hardness test is performed at Central Tool Room, Ludhiana of the hard faced specimens by digital Rockwell hardness testing machine. Rockwell Hardness Scale C is used with diamond cone indenter applying a total load of 150 Kgf.

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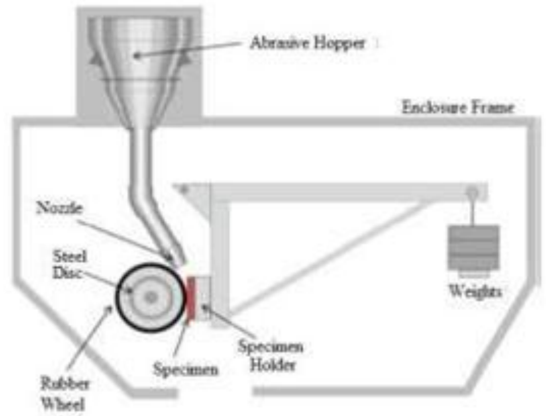
2.5.2. Dry Sand Abrasive Wear Test

The three-body abrasive wear tests were conducted using a dry sand rubber wheel abrasion tester as per ASTM G65 [9,18] at Saint Longowal Institute of Engg. And Technology (Sliet), Sangrur as shown in Fig.4 (b).The weights of specimens after and before wear test was done by electronic weight measuring balance as in Fig.2(b). The testing conditions are as Size of samples: 75 x 26 x 15(mm), Speed of wheel: 200 ± 5 rpm,Diameter of rubber wheel : 228.7 mm ,Sample test duration: 30 min, Abrasive used: loose silica sand having particle size 400 - 450µm (50 AFS), Applied Load: 5 Kg for all the samples.

2.5.3. Microstructure study

The microstructure of a material indicate the mechanical and metallurgical properties of materials such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance etc. The specimens having size (25x15mm) were prepared by conventional mechanical belt grinding machine through a series of emery papers and polishing as shown in Fig 5(a).



a

b

Fig.4. Wear Testing Process (a) Sand Abrasion Tester (Principle) (b) Sand Abrasion Tester Machine

The specimens were metallographically analyzed at the cross section with an optical microscope (100X) as shown in Fig 5(b) in the material and metallurgy lab at Saint Longowal Institute Of Engineering And Technology (Sliet) [19].

a

b

Fig.5. Microstructure Testing (a) Samples for Microstructure Test (b) Optical Microscope

III. RESULTS AND DISCUSSION

3.1. Results of Hardness Test

The hardness (HRC) measurements were carried out on five different locations on the specimens. The average of these values was taken as the hardness obtained for a specific specimen. As shown in Fig. 6,the results of rockwell hardness showed that specimen 7 obtained the largest hardness value i.e. 53.1 and the specimen 3 obtain the least hardness value. The Fig 6 shows the comparison of HRC values of all the nine specimens hardfaced at different combinations of process parameters.As from the table 11 in the later part of this study ,we concluded that welding voltage and welding current are the most significant process parameters which influences the wear properties of hardfaced specimens.It has been reported that on the constant value of welding voltage as the welding current increases,the hardness value decreases.It has been again reported that on the constant value of welding current,as the welding voltage increases ,the hardness value also increases [9].

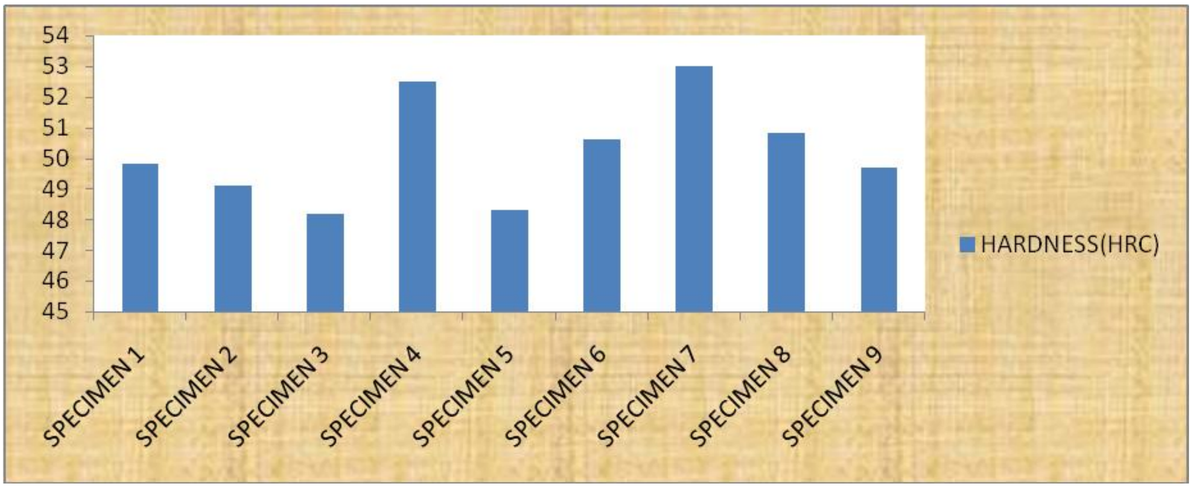


Fig 6.Comparison of Hardness (HRC) of hardfaced Specimens

3.2. Results of Sand Abrasion Wear Test

The results of sand abrasion wear test were obtained by worn out each specimen for 30 minutes and the differences in weight of specimens before and after the wear test indicate the wear rate of all specimens. As shown in Fig.7, the results of wear tests indicate that specimen 5 has largest wear rate and specimen 4 has minimum wear rate.This indicates that the importance of microstructural parameters, such as the amount and size of the carbides, toughness and type of phases will determine the wear résistance. The development of Fe-Cr-C hardfacing indicates that good wear resistance is obtained with materials having a high volume fraction of hard phases present in a tough matrix [6].

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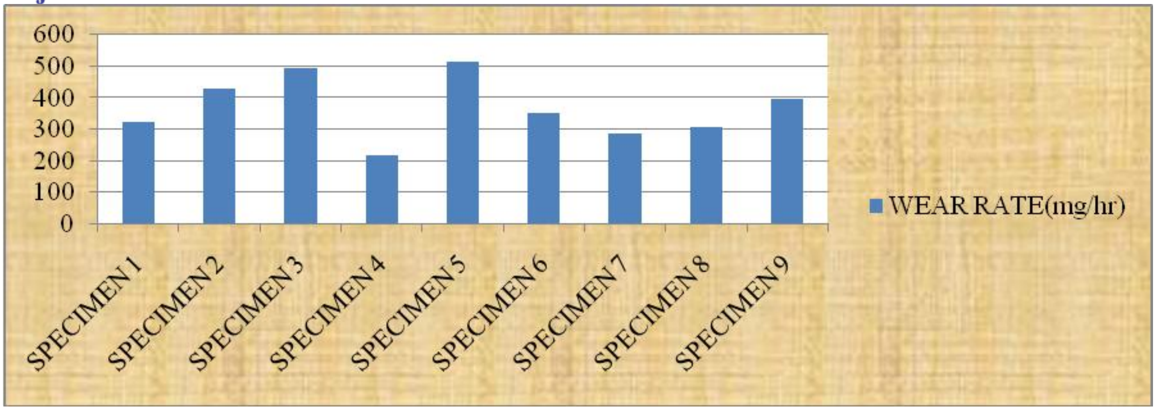

Fig 7. Comparison of Wear Rate of hardfaced Specimens

3.3. Results of Multi Response Characteristic Parameter Optimization

For better performance of a hard facing deposit by welding, the hardness should be high whereas the wear rate should be low. Thus, it is a case of multi response optimization. For the solution of multiple performance characteristics, taguchi based grey relational analysis method is used [20].

3.4. Results of Taguchi Based Grey Relational Analysis Method

In order to optimize the multiple responses simultaneously using grey relational analysis (GRA), the following results were obtained [22].The results of response values of all nine experiment runs are shown in table 3.

Table 3. Parameter Values and Corresponding Response Values

Ex.No.	Trial No.	Process Parameters				Response Values	
		Voltage (Volts)	Current (Amp)	Angle (Degree)	Speed (mm/min)	Hardness (HRC)	Wear Rate (mgs/hour)
1	3	16	120	15	120	49.8	324
2	5	16	150	30	180	49.1	427
3	1	16	180	45	240	48.2	492
4	2	20	120	30	240	52.5	217
5	8	20	150	45	120	48.3	514
6	6	20	180	15	180	50.6	352
7	9	24	120	45	180	53.1	284
8	4	24	150	15	240	50.8	307
9	7	24	180	30	120	49.7	396

3.4.1. Data Pre-Processing

Data pre-processing is a process of transferring the original sequence to a comparable sequence. For this purpose the experimental results are normalized in the range between zero and one.

1. The original sequence for hardness is normalized based on the 'the larger is the better' criterion as follows.

$$x_i^*(k) = \frac{x_i^0(K) - \min x_i^0(K)}{\max x_i^0(K) - \min x_i^0(K)}$$

2. The original sequence for wear rate is normalized based on the 'the lower is the better' criterion as follows.

$$x_i^*(k) = \frac{\max x_i^0(K) - x_i^0(K)}{\max x_i^0(K) - \mathrm{Min}\, x_i^0(K)}$$

Where $x_i^*(k)$ is the value after the grey relational generation (data pre-processing), max $x_i^0(k)$ is the largest value of $x_i^0(k)$, min $x_i^0(k)$ is the smallest value of $x_i^0(k)$ and x^n is the desired value. The deviation sequence (Δ_{oi}) for all runs is calculated by deducting comparability sequence from reference sequence i.e. taken as equal to 1 (one).Table 4 shows the generated values of Comparability Sequence and Deviation Sequence.

3.4.2. Grey Relational Coefficient and Grey Relational Grade

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The grey relational coefficient can be expressed as follows:

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta . \Delta_{max}}{\Delta_{oi}(k) + \zeta . \Delta_{max}}$$

where $\Delta_{oi}(k)$is the deviation sequence as calculated in grey relational generation.

Δ_{min} is the minimum value of deviation sequence i.e. equal to 0 and Δ_{max} is the maximum value of deviation sequence i.e.equal to 1. ζ is distinguishing or identification coefficient = 0.5 is generally used.

The overall evaluation of the multiple performance characteristics is based on the grey relational grade, i.e. after obtaining the grey relational coefficient, we normally take the average of the grey relational coefficient of both performance characteristics as the grey relational grade.

Table 4.Comparability Seq and Deviation Seq (Data Pre Processing)

Ex. No.	HRC Exp.Value	Wear Rate Exp.Value	HRC (comp. seq.)	Wear Rate (comp. seq.)	HRC (Dev. seq.) $\Delta_{oi(H)}$	Wear Rate (Dev. seq.) $\Delta_{oi(W)}$
1	49.8	324	0.3076	0.6397	0.6923	0.3602
2	49.1	427	0.1730	0.2929	0.8269	0.7071
3	48.2	492	0	0.0740	1	0.9259
4	52.5	217	0.8269	1	0.1730	0
5	48.3	514	0.0192	0	0.9807	1
6	50.6	352	0.4615	0.5454	0.5384	0.4545
7	53.4	284	1	0.7744	0	0.2255
8	50.8	307	0.5002	0.6969	0.4998	0.3031
9	49.7	396	0.2884	0.3973	0.7115	0.6026

The values of Grey Relational Coefficient and Grey Relational Grade are tabulated in table 6. The grey relational grade is defined as follows

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

It has been shown that experiment 4 has the best multiple performance characteristics among the 9 experiments as shown in Fig.8 because it has the highest grey relational grade as shown in table 5.Thus the parametric levels A_2, B_1, C_2 and D_3 are closer to the optimal.

Table 5. Grey Relational Coefficient and Grey Relational Grade

Exp. No.	Grey relational coefficient (hardness) $\xi_{i(H)}$	Grey relational coefficient (wear rate) $\xi_{i(W)}$	Grey relational grade γ_i	Rank
1	0.4193	0.5812	0.5002	4
2	0.3768	0.4142	0.3955	7
3	0.3333	0.3506	0.3419	8
4	0.7429	1	0.8714	1
5	0.3376	0.3333	0.3354	9
6	0.4185	0.5238	0.4711	5
7	1	0.6891	0.8445	2
8	0.5001	0.6226	0.5613	3
9	0.4127	0.4534	0.4331	6

The mean of the grey relational grade for each level of the welding process parameters and the total mean of the grey relational grade for the nine experiments is summarized and shown in Table 7.

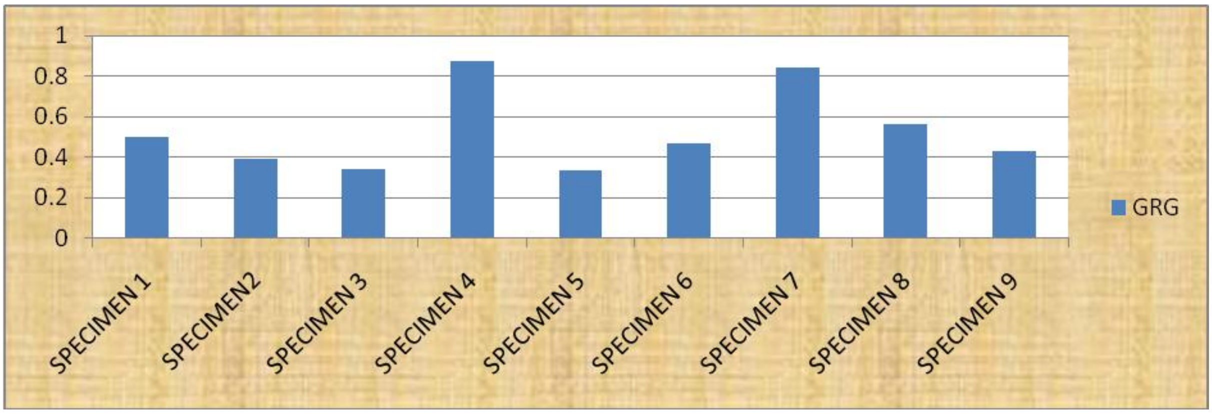

Fig 8.Grey Relational Grade (GRG) For All Nine Runs

As shown in the response table 6,the difference between the maximum and minimum value of GRG for any parameter gives a numeric value. As in the case of welding current ,the difference is 0.3234 which is maximum among all differences. It means that welding current obtained rank1.This indicates that welding current is the

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most significantly influenced parameter among all followed by welding voltage,welding speed and electrode angle.

From the table 6 we can conclude that the optimum levels of all four process parameters are which having the largest GRG value in the table i.e. A_3, B_1, C_2 and D_3. The difference between the max and min value of GRG for Electrode angle gives a very low numeric value i.e.0.0594 it means we can neglect this parameter for further concern.

Table 6.Response Table For Grey Relational Grade

Process Parameter	Grey Relational Grade				
	Level 1	Level 2	Level 3	Max-Min	Rank
Welding Voltage	0.4125	0.5593	0.6129*	0.2004	2
Welding Current	0.7387*	0.4307	0.4153	0.3234	1
Electrode Angle	0.5108	0.5666*	0.5072	0.0594	4
Welding Speed	0.4229	0.5703	0.5915*	0.1684	3
*Indicate Optimum Levels Total Mean Value Of GRG = 0.5282					

3.5. Confirmation Experiment

Once the optimal level of process parameters is selected the final step is to predict and verify the improvement of the performance characteristics using the optimum level of the welding process parameters [20].

The estimated grey relational grade using the optimum level of the welding parameters can be calculated as

$$\gamma_e = \gamma_{mt} + q(\gamma_{mo} - \gamma_{mt})$$

q is the number of welding parameters that significantly affects the multiple performance characteristics = 3.

The mean of the GRG at the optimum level of all three significantly effecting process parameter, γ_{mo} = (0.6129 + 0.7387 + 0.5915) /3 = 0.6477

The total mean of the GRG of all nine runs, γ_{mt} = 0.5282, γ_e = 0.5282 + 3 (0.6477- 0.5282) = 0.8867

Table 7 shows the results of the confirmation experiment using the comparison of experimental results using initial and optimal welding process parameters. It will be noted that the wear characteristics has been greatly improved through this study.

Table 7. Results Using Initial and Optimal Welding Process Parameters

	Initial welding parameters in grey relational analysis	Optimal welding parameters	
		Prediction	Experiment
Setting level	A_1 B_1 D_1	A_3 B_1 D_3	A_3 B_1 D_3
Hardness(HRC)	49.8		53.3
Wear Rate(mg/hr)	324		256

Grey relational grade	0.5002	0.8867	
Improvement in GRG = 0.3865			

3.6. Heat Treatment of Base Metal

In the present study, two EN8 steel specimen (base metal) is given Cyaniding heat treatment process by preheating and dipping the specimens in hot Potassium Cyanide (KCN) solution for the addition of both carbon and nitrogen and heated the specimen to a temperature of 910^{0}C in a muffle furnace for two hours for homogenous heating. Then out of these two specimens, one specimen is quenched in water and other quenched in mineral oil suddenly for about 15 minutes [23]. Both the specimens are again heated to a temperature of 300^{0}C for 15 minutes and cooled in still air for tempering process.

3.7. Results of Heat Treatment

The wear properties of both heat treated specimens are compared with hardfaced specimen prepared in the confirmation experiment. The quenching and tempering results showed that hardness and wear resistance of specimens quenched in water was large than the specimen quenched in oil [24] as shown in table 8. The reason will be explained later in microstructure study.

Table 8. Results of Hardness and Wear Rate of All Heat Treated Specimens

Specimen	HRC	Mean(HRC)	Initial weight	Final weight	Wear Rate (mg/hr)
1(HFO)	53,54,53	53.3	302.408	302.152	256
2(HTW)	45,44,45	44.6	248.911	248.308	603
3(HTO)	24,23,24	23.6	251.693	250.503	1190

1(HFO) indicate hardfaced specimen prepared in confirmation experiment, 2(HTW) indicate water quenched specimen and 3(HTO) indicate oil quenched specimen.

3.8. Microstructure Results

The microstructure results of above three samples i.e. 1(HFO), 2(HTW), 3(HTO) were analyzed by optical microscope. As shown in the Fig.9, the investigations of Fe-Cr-C alloy microstructures have shown that these types of materials have hypoeutectic, eutectic, and hypereutectic dendiritic structures. M7C3 primary carbides form in large amounts at higher carbon concentrations. These types of microstructures possess good wear resistance properties. M7C3 is surrounded by austenite, which is relatively soft compared to M7C3[6, 18, 19, and 26].

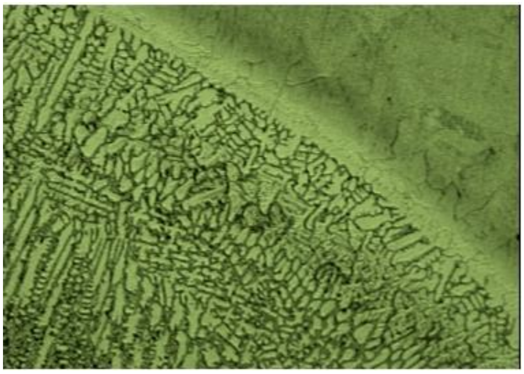


Fig 9.Microstructure of Specimen1 (HFO)

When discussing microstructural results of heat treated samples as shown in Fig.10, it is found that at the hardening temperature the steel is very soft and the Structure consists of austenite and residual carbides. After quenching the steel was hard and brittle. The transformation of austenite to martensite by a diffusionless shear type transformation in quenching is responsible for higher hardness obtained. After the hardened steel tempered the prevalent martensite is an unstable structure and the carbon atoms diffuse from martensite to form a carbide precipitate and the concurrent formation of ferrite and cementite.This allows microstructure transformed into sorbite or troostite caused reduction in hardness level while increased the ductility. These are fine dispersions of carbide in a ferrite matrix [25].

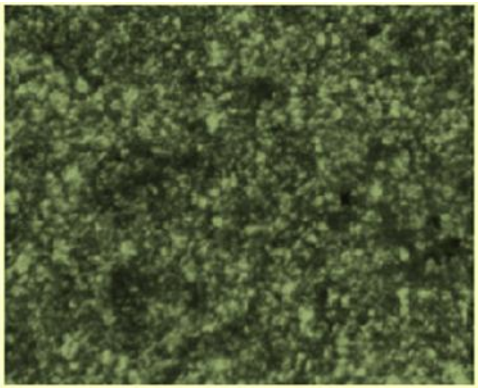
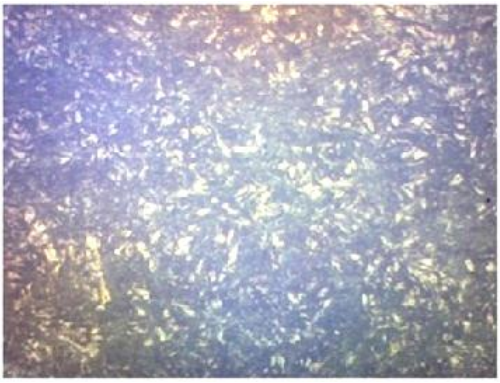
a  **b** 

Fig10. Microstructure of (a) water quenched specimen 2(HTW) (b) oil quenched of specimen 3(HTO)

The microstructure of 'water quenched' specimen 2(HTW) clearly showed needle like structures due to faster cooling rate of water. This has been resulted in highest free car-bon in martensite, that's why it has more wear resistance than oil quenched specimen. Furthermore, presence of fine dispersion of small particles in the pro-eutectoid ferrite and pearlitic ferrite, which will hinder the dislocation movement, may have also contributed to higher hardness value of the water-quenched sample [27]**.**

IV. CONCLUSIONS AND FUTURE WORK

4.1. Conclusion of Present Study

The overall study of improving the wear properties of oil expeller worm shaft made of EN8 steel by hard surfacing and heat treatment concluded the following points to be noted:

- The optimized levels of process parameters are welding voltage(A_3),welding current(B_1) and welding speed (D_3) which have the values 24 volts,120 amp and 240 mm/min.

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- Electrode work angle have very little affect on wear properties of hardfacing deposits so that we can neglect it.
- Hardening and the quenching(water or oil) process is also beneficial for improving the hardness and wear properties of the EN8 steel at lower expenditure than hardsurfacing method but have small improvement in wear properties than hardfaced one.

4.2. Scope for Future Work

On the basis of the work presented in this study, the large research work in the future can be performed efficiently on the following points:-

- The composition of carbon and chromium in the hard facing alloy can be varied and wear properties may be compared with present study.
- The another elements like tungsten, vanadium, molybdenum, titanium, boron etc. can also be added in addition to C and Cr for improving mechanical and thermal properties of the hardfacing deposit [28].
- The hardening and quenching heat treatment processes can also be performed on the hardfacing deposit discussed in the present study [7].
- Scanning electron microscope (SEM) can also be utilized for detailed study of the microstructure of worn out surfaces.

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