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ANALYSIS OF WEAR BEHAVIOUR OF DUAL PHASE STEEL USING TAGUCHI METHOD

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Abstract: **The Present study deals with to analyze the Tribological wear behaviour of dual-phase steels containing different weight percentages of carbon from 0.2 to 0.6, volumetric wear rates have been investigated. All the specimens were quenched at 723^{o}C to obtain specimens containing about 25, 50 and 75% martensite for weight percentage of carbon from 0.2, 0.4 and 0.6 respectively. wear tests have been conducted on dual-phase steels using a pin-on-disc wear testing machine under the normal load of 9.81, 29.43 and 49.05 N, sliding speeds of 1, 3 and 5 m/s at room temperature for a fixed sliding distance of 20,000 meters. Weight loss has been measured for each specimen at the end of the experiment. Using the L9 orthogonal array all the experiments was conducted. Volumetric wear rate has been calculated on the basis of volume loss after converting weight loss into volume loss by considering the density of the material. The analysis of volumetric wear rate, with respect to the sliding speeds and normal load have been explained by using taguchi technique and analysis of variance. Wear properties have been found to improve with the increase in martensite volume fraction in dual-phase steels. Among the investigated specimens, the critical parameters were found to be 0.4% of carbon content, 29.43N of normal load and 5 m/s of sliding speed.**

Keywords: **Orthogonal Array, Taguchi Technique, Volumetric wear rate, Regression analysis.**

I. INTRODUCTION

Materials for utilization in plane motors and gas turbines must fulfill numerous criteria, expense, weight high temperature quality, creep resistance, low and high temperature sway sturdiness, weldability, machinability, consumption resistance, wear resistance and so on. Subsequently such materials can't be outlined solely for wear resistance and, regardless, in perspective of the moderately deficient comprehension of wear procedures, endeavors to plan profoundly wear safe super alloys would be impracticable as well as likely unsuccessful [1]. Numerous tribologists are acquainted with the work of Welsh on the sliding wear of steels, and they connect moves between gentle wear and serious wear in different metals with the arrangement or decimation of oxide film. Interestingly, Kragelskii et al. have contemplated different conceivable outcomes, for example, moves including changes from flexible to plastic twisting, plastic distortion to miniaturized scale cutting, arrangement and break of different movies, disintegrating of surface material from evolving structure, contact softening, spreading and other phenomena [2].

Tribology is the science and technology of interacting surfaces in relative motion. It is a broad field that includes friction, lubrication and various forms of wear. Wear can be defined as displacement or removal of material as a result of tribological processes [3].

Wear is a progressive loss of material from the mating surfaces of a pair of bodies in relative motion (sliding, rolling or impact). It occurs as a natural consequence and mostly through surface interactions at asperities. When sliding occurs, touching asperities in relative motion finally give rise to wear particles out of the dislodged tips of the members. The process is slow, but continuous. Wear is very deleterious as it causes damage to working parts and loss of mechanical efficiency [4].

V.Abouei et.al.,**[**5**]** carried out their studies on the wear behaviour of 0.2% carbon content dual-phase steel in 2007, for 4-different amounts of martensite content ranging from 43 vol% to 81 vol%. It is found that the mechanism of wear is primarily delamination. Also, wear properties have been found to improve with the increase in martensite volume fraction in DP steel. Anand Prakash Modi **[**6**]** investigated on the effect of microstructure and experimental parameters on high stress abrasive wear behaviour of a 0.19% carbon dual-phase steel. The aim of this investigation was to understand the influence of the size and quantity of ferrite plus martensite on mechanical and abrasive wear properties in a 0.19 % carbon dual-phase steel. It has been found that the mechanical properties like strength, ductility and impact as well as abrasion resistance of the samples are greatly influenced by the martensite content and test conditions.

J. Adamczyk and A. Grajcar **[**7**]**, in 2007, studied on the heat treatment and mechanical properties of low carbon steel with dual-phase microstructure. The aim of this investigation was to design appropriate heat treatment conditions of dual-phase steel and to determine their influence on the structure and mechanical properties of steel. It was found that an initial structure influences essentially the morphology of martensite in an obtained dual-phase structure. It can occur as a network, fine fibers or islands in a ferrite matrix. It was found that martensite in the form of fine fibers gives the best combination of strength and ductile properties to DP steels

M. Sawa nd D.A. Rigney **[**8**]** undertook studies on sliding behaviour of dual-phase steels in vacuum and in air in 1987. In this study, sliding behaviour of two dual-phase steels, one containing martensite islands in a ferrite matrix (type A) and another containing ferrite islands in a martensite matrix (type B) have been investigated in vacuum and in air for various sliding distances. It is found that wear rates of both type A and B samples were similar in vacuum. However, in air, the wear rates of type B samples were increased by about 100 times

Weyl (I946) suggested that in many cases the adhesion of metals to glass could be improved if there was a continuation of the glass structure, which might be in the form of an intermediate oxide film, thus acting as a transition layer. Weyl (I950) also suggested that when a fresh glass surface is formed there is a reaction between the surface and the atmosphere resulting in the formation of a neutral layer of hydroxyl groups on the surface

Influence of martensite carbon content on the cyclic properties of dual- phase steel has been investigated by A.M. Sherman and Davies R. G. **[9]**, in 1991. It is found that at constant martensite levels, higher the carbon content in the steel, better are the fatigue properties

Wang Huaming et. al., **[9]** investigated the two body abrasion behaviour of the newly developed austenite-bainitic ferrite dual-phase steels. The results show that the dual-phase steel with good combination of high yield strength, toughness and strain-hardening ability possesses excellent wear resistance in high stress two-body abrasion system. It is observed that the dual-phase structure is much more abrasion resistant than the quenched and tempered structure of the same steel with equivalent hardness. It is found that the outstanding wear resistance of the dual-phase steel is attributed to the excellent combination of the high work-hardening ability and the good toughness. This paper deals with the evaluation of dry sliding wear behaviour of Dual Phase steel by using taguchi approach.

II. TAGUCHI TECHNIQUE

Robust design is an “engineering methodology for improving productivity during research and development so that high-quality products can be produced quickly and at “low cost. Taguchi method is a part of the robust design for evaluating the process parameters [10].

Dr. Genichi Taguchi bases his method on conventional statistical tools together with some guidelines for laying out design experiments and analyzing the results of these experiments. Taguchi defines a standard orthogonal array to conduct the experimentation and experimental results are analyzed using analysis of variance to study the effect of parameters [11].

III. MATERIALS AND METHOD

In this study, the given compound arrangement of hypereutectoid steel in Table 1 was utilized as a test material. The hypereutectoid steel test was subjected to distinctive heat treatments to accomplish diverse microstructures. The changes in the microstructure and wear performance were contemplated as a component of cooling. Wear qualities of these pin specimens were examined. Experimental procedure took after as described below.

Dual-phase steel that may be developed from the diverse hypo-eutectoid steels quenching from the lower critical temperature of 723^{0}C and getting different volume distinctive of primary solid solution on the premise of rate of carbon in the steel material. For this examination of DP steels, 10 mm diameter 0.2, 0.4, and 0.6 wt% plain carbon steels were acquired from the local special steel suppliers in industrial estate, Hubli and chemical compositions were analyzed by optical spectrometer and the chemical compound of the materials is given in the table 1.

Table 1: Chemical composition of specimens

Sp.Nos	C %	Si %	Mn %	P %	S %
1	0.20	0.25	0.46	0.025	0.02
2	0.40	0.28	0.65	0.028	0.023
3	0.60	0.32	0.68	0.025	0.03

For our present investigation, l0 mm diameter plain carbon steel pins were subjected to heat treatment as under:

Plain carbon steel pins containing 0.2, 0.4 and 0.6 wt % carbon were subjected to controlled heating to reach inter-critical temperature of 723+05^{0}C, isothermalized for 30 minutes and subsequently were quenched to produce the following specimens 1, 2 and 3 containing different volume fractions of ferrite and martensite (Table 2).

Table 2: Details of Specimen.

Specimen No.	% C	% Ferrite Vol.	% Martensite vol.
1	0.20	75	25
2	0.40	50	50
3	0.60	25	75

Table 3: control and noise factor

Sl. No	Process Parameters	Codes	Level 1	Level 2	Level 3
01	% of Carbon content	A	0.2	0.4	0.6
02	Load (N)	B	9.81	29.43	49.05
03	Sliding speed (m/s)	C	1	3	5

Table 4: Control Log for wear test –L9 Orthogonal Array

Expt. Run	% of Carbon content (A)	Load (N) (B)	Sliding speed (m/s) (c)
01	1	1	1
02	1	2	2
03	1	3	3
04	2	1	2
05	2	2	3
06	2	3	1
07	3	1	3
08	3	2	1
09	3	3	2

In the Table 3 the process parameters with their different levels and codes were shown. In the table 4 an L9 orthogonal array for this experiment is shown.

Table 5: Results of Experimental Runs for Wear test

Expt. Run	% of Carbon content (A)	Load (N) (B)	Sliding speed (m/s) (c)	Volumetric wear rate (mm^3/m)	S/N Ratio For Volumetric Wear rate (db)
01	0.2	9.81	1	0.00136	57.329
02	0.2	29.43	3	6.775E-4	63.382

03	0.2	49.05	5	2.2575E-4	72.927
04	0.4	9.81	3	3.20252E-8	149.890
05	0.4	29.43	5	1.38124E-8	157.195
06	0.4	49.05	1	3.3894E-7	129.398
07	0.6	9.81	5	3.6325E-4	68.796
08	0.6	29.43	1	5.695E-4	64.890
09	0.6	49.05	3	4.91E-4	66.178

Table 6: Response Table for Signal to Noise Ratios of volumetric wear rate

Level	A	B	C
1	64.55	92.01	83.87
2	145.49	95.16	93.15
3	66.62	89.50	99.64
Delta	80.95	5.65	15.77
Rank	1	3	2

Table 7: Response Table for Means of volumetric wear rate

Level	A	B	C
1	0.000754	0.000574	0.000643
2	0.000000	0.000416	0.000390
3	0.000475	0.000239	0.000196
Delta	0.000754	0.000335	0.000447
Rank	1	3	2

IV. RESULTS AND DISCUSSION

A. Signal-to-Noise ratio of volumetric wear rate:

The Taguchi method uses the signal-to-noise (S/N) ratio to scatter around target value. A high value of S/N implies that the signal is much higher than the random effects of the noise factors. The noise is usually due to the uncontrollable factors, which exist in the environment, often cannot be eliminated and cause variations in the output[12]. Hence, in the context of this study, the noise is attributed to different subjects used for experimental analysis. Table 5 shows the results of Signal-to-noise ratio. In the table 6 the response table for signal to noise ratio for volumetric wear rate is plotted and in the table 7 response table for mean of volumetric wear rate is shown. Fig 1 shows main effect plot for signal to noise ratio and mean for smaller the better. The optimal parameters were found are A_2, B_2, and C_3.

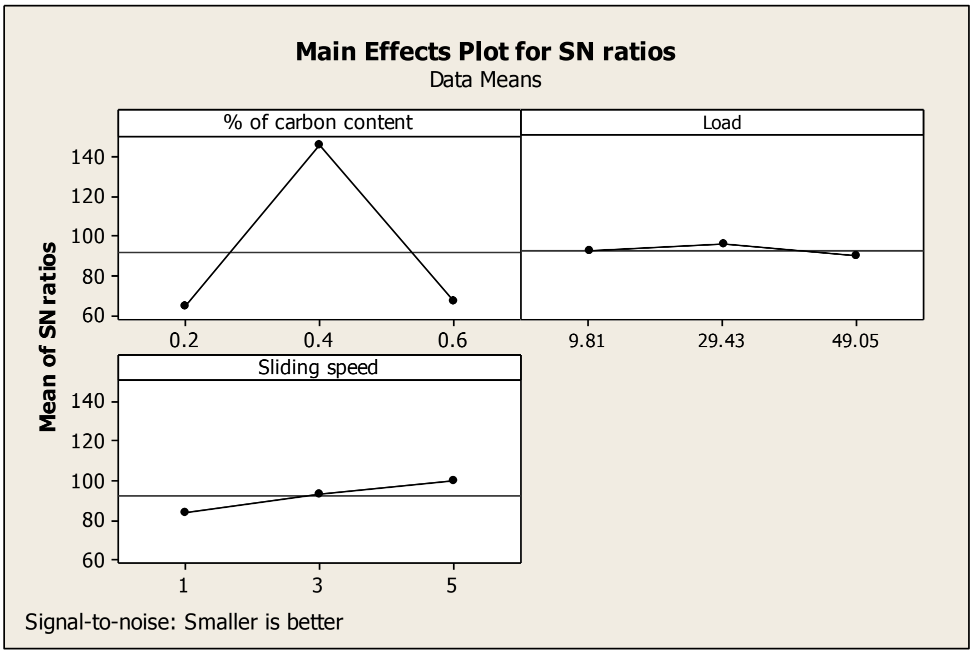

Fig 1: Main Effects Plot for SN ratios of volumetric wear rate

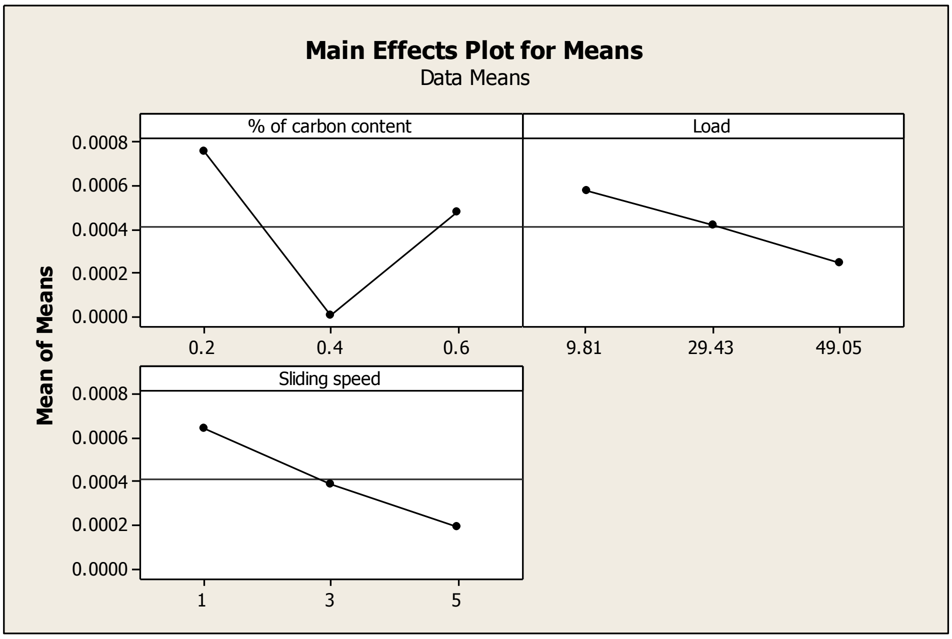

Fig 2: Main Effects Plot for Means of volumetric wear rate

B. Anova for Volumetric Wear Rate:

The experimental results were analyzed with ANOVA which is used to investigate the influence of the considered wear parameters namely, % of carbon content, applied load and sliding speed that significantly affect the performance measures. ANOVA plots of the experimental data have been created to calculate the significance of each factor for each response. Volumetric wear rate was calculated for all the 9 experimental runs. α= 0.05 was selected for all statistical calculations. From the Table 8, that the % of carbon content has the highest influence (Pr = 60.00%) on volumetric wear rate. Hence % of carbon content is an important parameter to be taken into consideration during wear process followed by sliding speed (20.00%) and load (13.33%) respectively.

Table 8: Analysis of Variance for Volumetric wear rate, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr(%)
% of carbon content	2	0.0000009	0.0000009	0.0000004	4.29	0.189	60.00
Load	2	0.0000002	0.0000002	0.0000001	0.83	0.546	13.33
Sliding speed	2	0.0000003	0.0000003	0.0000002	1.48	0.403	20.00
Error	2	0.0000002	0.0000002	0.0000001			06.77
Total	8	0.0000015					100.00

C. Regression Equation:

A Regression model is developed using Statistical software MINITAB 16. This model gives the relationship between an independent/predicted variable and a response variable by fitting linear equations to observe data.

Regressions equation thus generate establishes correlations between the significant terms obtained from ANOVA analysis namely % of carbon content, normal load & sliding speed.

Volumetric wear rate = 0.0012763 - 0.000699583 (A) - 8.54734e-006 (B)

- 0.000111735 (C) Eqn ----- (1)

R-Sq = 86.84%

From Eqn (1), it is observed that the % of carbon content (A), Normal Load (B) and sliding speed (C) increases or decreases at any parametric value, it will be decreases the volumetric wear rate of the value of 0.0012763 mm^3/m.

The wear tests were conducted on pin-on-disc testing machine for dual-phase steels containing different proportions of ferrite and martensite as well as containing different percentages of carbon under different load and sliding speeds. This is done to understand the effect of carbon content in the martensite which in turn affects the ears resistance properties of the martensite phase.

Following are the findings:

1. The present study was focused on the application of taguchi technique for optimizing the process parameters on volumetric wear rate.
2. The optimal parameters for volumetric wear rate were found are A_2 (0.4% of Carbon content), B_2 (29.43 N), and C_3 (5m/s).
3. The percentage contribution of carbon content (60.00%) has the highest influence on volumetric wear rate followed by sliding speed (20.00%) and applied load (13.33%).
4. Mild wear is seen at the sliding rate of 5 m/s for all the DP steels

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