Dry Sliding Wear Behaviour of Ferrite-Martensite Dual Phase Steels

Aprameyan S
Professor & Head, Department of Mechanical Engineering,C. Byregowda Institute of Technology, Kolar, India.
Dr. U N Kempaiah
Professor, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore, India.

Abstract

In the present investigation, High Strength Low Alloy Steel (HSLA) was subjected to Intermediate Quench (IQ) heat treatment process at four different intercritical temperatures to obtain Dual Phase(DP) steels of varying percentages of ferrite-martensite microstructure The intercritical holding temperatures were 730°C, 750°C, 780°C and 810°C. The corresponding martensite volume fraction obtained were48%,56%,63%and 69%. Specimens for the wear test were prepared as per the ASTM recommended procedures and were tested for the dry sliding wear behaviour at different loading conditions ranging from 19.62N to 49.05N and at constant sliding velocity of 1.257ms^{-1}, on a Pin-on-Disc wear testing machine. The investigation reveals that amount of martensite volume fraction in the dual phase microstructure increases with increase in intercritical temperature and the wear resistance of the Dual Phase steel increases with increase in percentage volume fraction of martensite in the dual phase ferrite-martensite microstructure.

1. Introduction

Relentless quest by researchers for developing newer class of materials for the high strength-weight ratio applications in many diverse fields in the past 3-4 decades lead to the emergence of ferrite-martensite dual phase steels. Over the years dual phase steel of thicker sections has found wide range of applications as structural material in ship building, off shore structures, automobile body parts, mining and earth moving equipments to name a few. The dual phase steels exhibit unique combinations of improved strength, ductility, and toughness. Dual phase steels were developed to satisfy an increasing need, primarily in the automotive industry, for new high strength steels that permit weight reduction without sacrificing formability or dramatically increasing costs. Low carbon steels can be subjected to IQ heat treatment process to develop dual phase microstructure consisting primarily two phases namely ferrite and martensite. The amount of martensite fraction in the dual phase steels can be altered by varying the intercritical heat treatment temperature and martensite volume fraction in the microstructure increases with increase in intercritical heat treatment temperature. Martensite, being a harder phase when compared to ferrite, induces greater hardness to the dual phase steel and hence, dual phase steels with higher martensite volume fraction, are found to have scope for wear resistance applications.

2. Literature Survey

Extensive investigations have been carried out by many researchers for developing Dual Phase (DP) steels [1]-[7]. Dual phase steels are currently materials of commercial interest for the automotive industry and they have already found numerous applications including safety critical products such as side impact bars and wheel rims [8-10]. The production of machines, auto and truck body parts; vehicle chassis, engine seats, automobile rims and structural parts are a few of the applications requiring high strength to weight ratio, ductility and improved crash performance [11], [12]. Dual phase medium carbon low alloy steel grades have been successfully utilized for these applications by virtue of its peculiar combination of ferrite and martensite (~50 – 60%) in proportions different from that of conventional low carbon micro alloyed dual phase steels [13].

Rajnesh Tyagi et al.[14], developed dual phase steels with increasing volume fraction of martensite at a fixed intercritical temperature of 740°C but varying holding times. It is reported that the yield and tensile strengths have been found to increase with increasing amount of martensite whereas, percentage elongation and percentage area reduction have been found to decrease. Wear properties in dry sliding conditions have also been found to improve with increasing martensite volume fraction in dual phase steels. The unique combination of hard martensite islands embedded in soft ferrite matrix is ideally suitable for wear resistant materials. The hard martensite islands act as load bearing and provide lower real area of contact resulting in lower wear rate[15].

M. Aksoy et al.[16], have reported that the wear resistance of dual phase steel varies depending on the proportion of ferrite phase and martensite phase affects wear resistance with its hardness. They suggested that dual phase treatment might be offered as a surface treatment to provide good wear resistance for low carbon steels and cheap dual phase steels may be used as wear resistant materials instead of using expensive materials to improve the surface properties of these steels.

V. Abouei et.al. [17], reported a similar result in their work on wear behaviour of dual phase steel produced at 780°C intercritical temperature for different amount of holding time. It is reported that the wear rate of the dual phase steels decreases with increasing volume fraction of martensite, which was attributed to increasing of hardness of steels, and decreasing the probability of crack formation during delamination. Further it has been shown that plain carbon dual phase steels have a good potential for use as farm implements where strength and wear resistant become of great concern [18]. Wayne et al. [19], have shown the dependence of wear on microstructure and have concluded that the duplex microstructure of DP steel offers higher wear resistance than that observed in a steel with spheroidal carbides. It has also been indicated that the wear resistance of dual phase steels increases with the increase in volume fraction of martensite [20]-[21]. Sawa and Rigney, have found that the wear behaviour of DP steel also depends strongly on its morphology, i:e.,the shape, size, and distribution of its martensite[22].

In the present investigation, ferrite-martensite dual phase steels with varying martensite volume fraction have been produced from HSLA steels by IQ heat treatment process at four intercritical heat treatment schedules ranging from 730oC to 810oC. The volume fraction of martensite varied from 48% to 69%. The dual phase steel samples were then investigated for their wear behaviour on Pin-on Disc wear machine.

3. Experimental Procedure

HSLA steel of 0.13 wt % carbon in the form of 14mm thick hot rolled plates in quenched and tempered condition has been used as the base metal. The composition of the base metal was analysed using Optical Emission Spectrometer (model: PerkinElmer Optima 7000 DV) and Carbon & Sulphur analyser (model: Abrolins C & S Determination Apparatus (model: AI/302/84). The composition of the base metal is shown in table 1.

Specimens of 8mm diameter and 30mm length for the study of dry sliding wear behaviour of dual phase steels of different volume fraction of martensite were prepared as per ASTM standards. The specimens for the wear test were subjected to Intermediate Quench (IQ) heat treatment schedule consisting of (a) heating to austenitizing temperature of 920°C in a muffle furnace and holding at that temperature for 30 min before being quenched in iced brine solution maintained at -7°C. (b) heating the quenched specimens to different intercritical temperatures ranging from 730°C to 810°C and holding for 60 min before quenched in servo 707 oil at 25°C to obtain dual phase steels of varying volume fraction of the phase constituents namely ferrite and martensite. These Dual Phase (DP) steels have been designated as DP730, DP750, DP780 and DP810 respectively. The percentage volume fraction of martensite for different intercritical temperatures ranges from 48% - 69%. The Fe-C diagram and the heat treatment cycle adopted and as reported in a paper co-authored by the authors elsewhere [23] ,are as shown in figures 1 and 2.

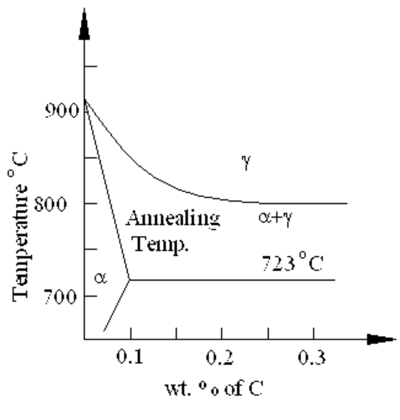


Fig.1.Equilibrium Diagram for Intercritical Annealing Heat treatment

Table 1. Chemical composition of the base metal.

Elements	C	Mn	S	P	Si	Cr	Mo	V	B	N	Fe
Wt%	0.13	1.18	0.01	0.001	0.3	0.047	0.057	0.001	0.001	0.048	Remainder

The martensite volume fraction was estimated by manual point counting method as well as automatic image analysing method.

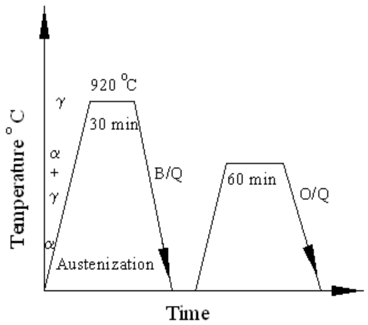


Fig. 2. Intercritical Annealing Cycle.

Figure 3 indicates the variation in ferrite-martensite volume fraction with intercritical holding temperature. The end surface of the pin specimens were first polished using emery papers of grit size ranging from 120 to 1500 and finally mirror polished on a velvet cloth with diamond paste. The edges of the samples were rounded and the samples were cleaned with acetone to remove dust and grease from the sliding surface of the pin.

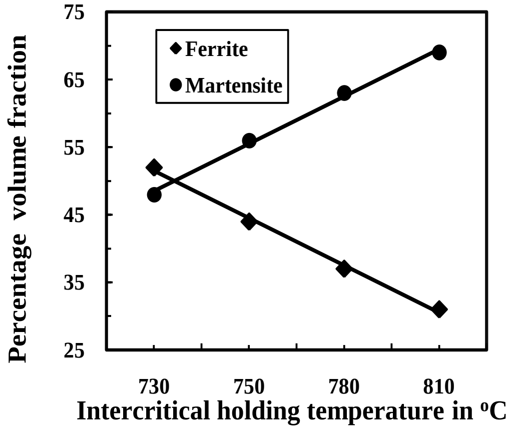


Fig.3. Variation of ferrite-martensite volume fraction with intercritical holding temperature.

The microhardness values of the IQ samples were determined using a Micro Vicker Hardness tester(Model: HWMMT-X7). The test method followed was IS 1501-2002. All specimens used for the microhardness characterization were in the polished and etched condition and measurements were carried out at 0.05kg loading conditions. The variation in the microhardness values for DP steels of varying martensite volume fraction is shown in figure 4.

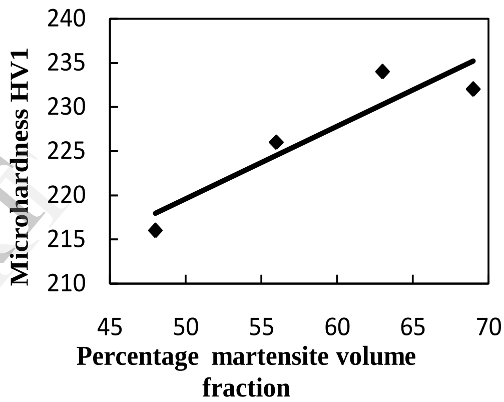


Fig. 4. Variation of microhardness of DP steels with variation in martensite volume fraction.

The optical micrographs of the samples were recorded at 1000X magnification using metallurgical microscope (model: Olympus BX 51) after suitably etching with 2% Nital. The microstructures of the specimens under investigation are shown in figure 5.

Wear behaviour of ferrite-martensite dual phase steels have been studied under laboratory conditions on a standard Pin-on- Disc wear testing machine supplied by Ducom Tribomonitors Bangalore(model: Wear and Friction Monitor TR-20LE). Applied normal loads were, 19.62N, 29.43N, 39.24N and 49.05N with fixed sliding velocity of 1.257 ms^{-1}. The counter face disc material was EN 32 Steel, with hardness of 62-65 HRC. Cumulative reduction in height of the pin

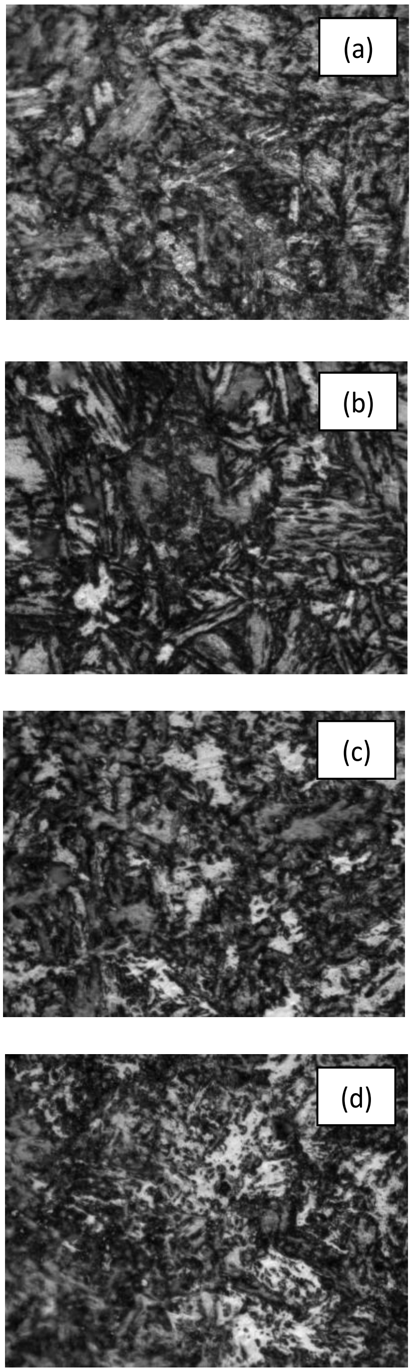


Fig. 5. Optical Micrographs of Dual Phase Steels (a) DP730, (b) DP750, (c) DP780 and (d) DP810 at 1000X .

samples were recorded after sliding distance of 753.98m. With the density of the material investigated being known, volume loss of the pin samples were determined.

4. Results and Discussion

The machined samples were first subjected to Intermediate Quench (IQ) hat treatment schedule as described earlier in the paper to obtain dual phase ferrite-martensite DP steels of varying ferrite-martensite volume fractions. The amount of ferrite phase decreases while the martesite phase increases with increase in the intercritical holding temperature. The volume fraction of martensite measured for dual phase steels DP730, DP750, DP780 and DP810 was found to be 48%, 56%, 63% and 69% at intercritical holding temperatures of 730^{o}C, 750^{o}C, 780^{o}C and 810^{o}C respectively. The optical micrographs reveal island like morphology for martensite surrounded by ferrite and the dark regions in the micrographs refer to martensite while light regions correspond to ferrite. The amount and the size of the martensite island, in the microstructure increases with increase in the intercritical holding temperatures, as revealed in figure 5. The variations of the microhardness values of dual phase steels with percentage volume fraction of martensite are shown in figure 4. These are considered as average microhardness values of the composite structure because the hardness indentations encompass sufficient ferrite and martensite regions. The increase in hardness with increasing intercritical holding time has been attributed to the increasing volume fraction of martensite, which is a strong load bearing phase in ferrite-martensite dual phase steels[14].

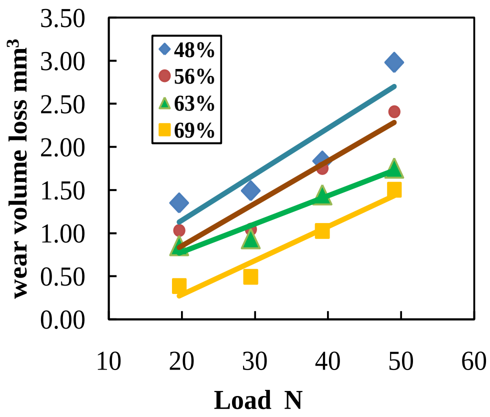


Fig.6. Plot showing variation in wear volume loss with load for different volume fraction of martensite

Dry sliding wear test were carried out for normal load values 0f 19.62N, 29.43N, 39.24N and 49.05N for sliding distances of 753.98m at constant sliding velocity of 1.257ms^{-1}. Figure 6 and figure 7 show the variation of wear volume loss and wear rate with load. The graphs indicate that the volume loss and wear rate increases with increase in normal load and they are higher for DP730 and lower for DP810 steels. The decreasing wear volume loss and wear rate of the pin specimen with increasing volume fraction of martensite is due to higher hardness imparted to the DP steels by martensite ,which results in a lower real area of contact and therefore a lower wear rate in steels containing relatively higher amounts of martensite[24].

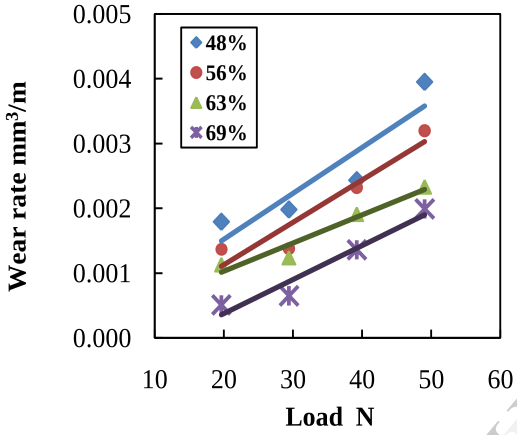
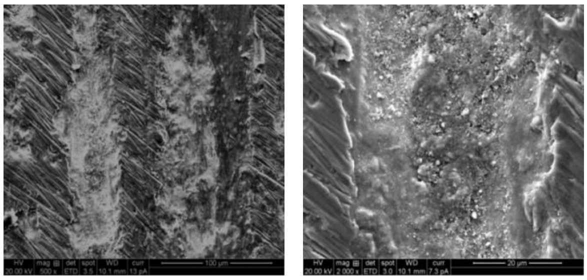
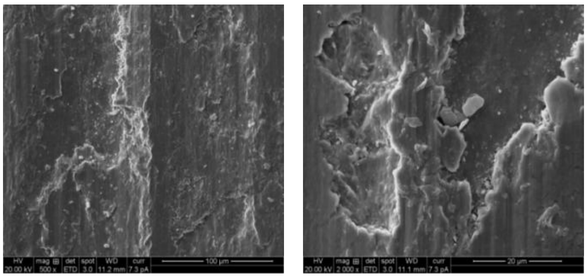


Fig.7. Plot showing variation in wear rate with load for different volume fraction of martensite.

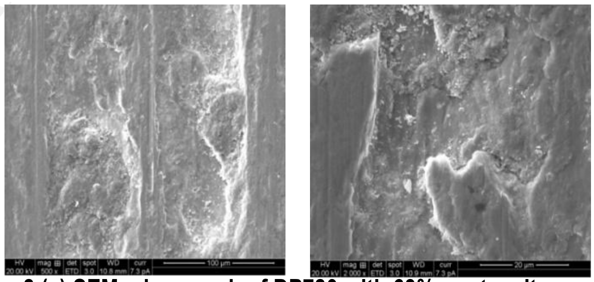
The worn surfaces of the pin samples were observed under Scanning Electron Microscope (SEM) and the SEM micrographs of the worn surface are shown in fig 8(a) – 8(d). Micrographs reveal that for DP730 and DP750 steels, the worn surfaces show deep gouge resulted from tearing of softer surface offered by the DP steels with lower martensite volume fraction. The worn surfaces for thesesteels shows craters being formed due to flaking and building up of oxide layer on the surface. The wear appears to be delamination type and the delamination mechanism involves nucleation of cracks at the interface of ferrite and martensite. Increasing the volume fraction of martensite decreases the interface of ferrite and martensite and therefore, the number of suitable places for nucleation and propagation of crack decreases [17]. This is evident from the SEM micrographs for DP780 and DP 810 steels, that reveal less severe flaking of the surface with shallow gouge that would have resulted in lower wear volume loss and wear rate.



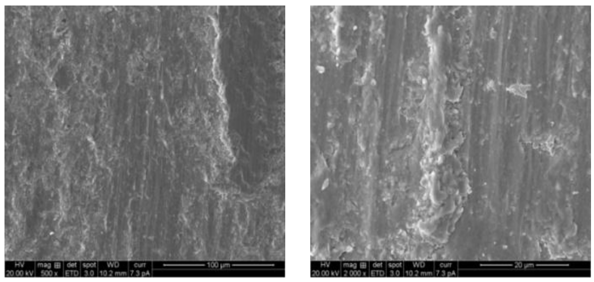
8 (a) SEM micrograph of DP730 with 48% martensite volume fraction at 500X and 2000X



8 (b) SEM micrograph of DP750 with 56% martensite volume fraction at 500X and 2000X



8 (c) SEM micrograph of DP780 with 63% martensite volume fraction at 500X and 2000X



8(d) SEM micrograph of DP810 with 69% martensite volume fraction at 500X and 2000X

5. Conclusions

The present study on the development of ferrite-martensite dual phase steels of varying martesite volume fractions and the subsequent investigation on dry sliding behaviour of these steels has lead to following conclusions.

The HSLA steels with suitable IQ heat treatment at different intercritical holding time, could be converted into ferrite-martensite dual phase steels containing varying amounts of ferrite-martensite dual phase microstructure.

The percentage volume fraction of martensite increases with increase in intercritical holding time while the ferrite volume fraction decreases.

The microhardness of the dual phase steel increases with increase in martensite volume fraction up to 63% and shows a marginal dip in its value for 69%.

The volume loss and wear rate for all the DP steels investigated increase with increase in applied normal load.

The volume loss and wear rate have found to be lesser for DP 780 and DP810 steels when compared with DP730 and DP750 steels that exhibit higher volume loss and wear rate.

Therefore, the volume loss and wear rate of dual phase steels decrease with increase in martensite volume fraction in the ferrite-martensite dual phase microstructure.

6. References

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