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Study on the Effect of Volume Fraction of Dual Phase Steel to Corrosion Behaviour and Hardness

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Abstract**—**The objective of this project is to study the *corrosion behaviour* and *hardness* based on the presence of *martensite* in *dual phase steel*. This study was conducted on six samples of dual phase steel which have different percentage of martensite. A total of 9 specimens were prepared by *intercritical annealing* process to study the effect of temperature to the formation of martensite. The low carbon steels specimens were heated for 25 minutes in a specified temperature ranging from 725^0C to 825^0C followed by rapid cooling in water. The measurement of corrosion rate was done by using extrapolation tafel method, while potentiostat was used to control and measured the current produced. This measurement is performed through a system named CMS105. The result shows that a specimen with higher percentage of *martensite* is likely to corrode faster. Hardness test for each specimen was conducted to compare its hardness with low carbon steel. The results obtained indicate that the specimen hardness is proportional to the amount of martensite in dual phase steel.

Keywords**—**dual phase steel, corrosion behaviour, hardness, intercritical annealing, martensite

I. INTRODUCTION

SINCE last decade, dual phase steel has attracted so many researches [1], [2]. Dual phase steel is a new class of high strength low alloy (HSLA) steels characterized by a microstructure consisting of dispersion of about 20% of hard martensite particle in a soft ductile ferrite matrix [3]. The effect of transformed ferrite content on mechanical properties of dual-phase steel has been studied and analyzed on the basis of observation on the austenite-to-ferrite transformation behavior during post-anneal cooling. With the increment of the transformed ferrite content, second phase particles have been finer and evenly distributed [4]. Microhardness measurement showed that transformed ferrite had always higher strength than retained ferrite. Dual phase steel have unique properties, such as continuous yielding behaviour (no yield point), low 0.2% offset yield strength (~340 MPa), high tensile strength (~690 MPa) , high work hardening rate, and unusually high uniform and total elongation[5], [6]. Although dual phase steel process good mechanical properties, further research is essential to access the true potential of dual phase steels in various applications. Investigation on the effect of corrosion behaviour to the dual phase microstructure have been done by Jha et al.[7], Thomas [8] and Zhang et al. [9]. From their studies, they found that, dual phase microstructure have a very good corrosion resistance. Sarkar et al.[10] have carried out an investigation to measure the galvanostatic corrosion behaviour of five specimens of dual phase steel (DP) steel with varying morphologies and martensite content has been assessed in comparison to a ferrite-pearlite steel in 3.5% NaCl solution. Their finding shows, the martensite content increment and higher degree structural refinement will increase the corrosion rate. Bhagavathi[11] found that , the hardness value of dual phase steel is increase 100% compare to normal steel (ferrite –pearlite) microstructure. This hardness increment of dual phase steel is attributed to the presence of harder martensite phase [12], [13]. Although a lot of research have been conducted, further investigation should be done on the of effect various morphology and different volume fraction between ferrite and martensite of dual phase steels to corrosion behavior and mechanical properties. Therefore, this study was carried out to compare the effect of different volume fraction between ferrite and martensite to corrosion behaviour and hardness. A good understanding on a dual phase steel is important before it can be considered as a replacement for any existing material.

II. EXPERIMENT

A. *Material Preparation and Heat Treatment*

Common low carbon steel has been selected in this study. The raw material was in the form of a long hot rolled rod with 20mm diameter. It was cut into 9 specimens and each specimen is 10mm long. The hardness of the specimens is 140.7Hv. The chemical composition of low carbon steel is shown is Table 1. The critical annealing temperature of the steel was estimated by using Andrew’s equation [14].The lower (A_{c1}) and the upper (A_{c2}) intercritical temperature were approximated as 723^0C and 815^0C respectively.

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TABLE I
A CHEMICAL COMPOSITION OF SPECIMEN

Element	C	Mn	P	S	Si	Ni	Cr
Wt%	0.226	0.928	0.0296	0.0359	0.219	0.0941	0.126

9 specimens were selected to study the effect of temperature to the formation of martensite. Specimens were heated in the furnace at various intercritical temperatures (Table 2) for 25 minutes and quenched in cold water in order to transform the pearlite to martensite. The first specimen was heated at under the lower intercritical temperature (A_{c1}) which is 720^0C and the temperature is increased 12^0C for the following specimens until the upper intercritical temperature is achieved.

TABLE II
TEMPERATURE SELECTED

Specimen	1	2	3	4	5	6	7	8	9
Temperature ^{0}C	720	732	744	756	768	780	792	804	816

After the intercritical annealing process, all the specimen microstructure will be observed. Before the observation, the specimens will be mounted by using the automatic compression-mounting machine, followed by grinding to produce a plane surface with minimal scratches. Next the specimens will be polished to obtain a shinning surface. Finally, in order to reveal the boundaries of the microstructures, etching process is done by using 2% Nital. Point counting method is used to determine the volume fraction of an identifiable constituent or phase from section through the microstructure. This method is done by systematic manual point count to estimate the volume fraction.

B. *Corrosion Test*

The corrosion test was done by using The CMS 105^{TM} DC corrosion measurement system which is an add-on application package to the CMS100^{TM} electrochemical measurement system. The CMS105 package uses proven electrochemical techniques to investigate corrosion problems, allowing test to predict long-term corrosion rates and extract mechanistic information from an array of experiments. The corrosion measurements are the set up by immersing the specimen with solution of 5% NaCl. The final setting was the corrosion cell kit. The DC corrosion measurement can be started by running the experimental methods, which has already set in the software of CMS100 Electrochemical Measurement System of the computer.

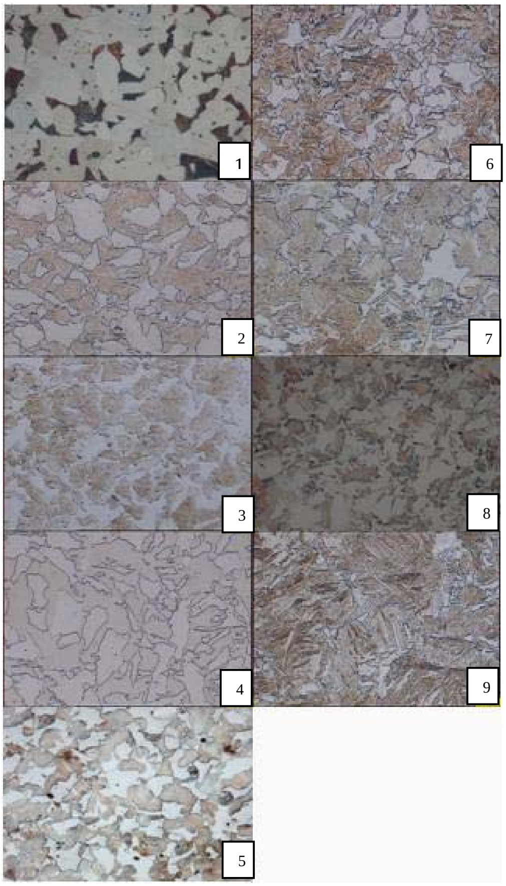
C. *Hardness Test*

The hardness of the specimens were determined using Vickers Hardness Testing Machine. The purpose of this test is to make comparison of the hardness properties between the specimen (intercritical annealing temperature between the 723°C to 815°C) with the low carbon steel. The hardness was measure at three different locations of the specimen, and then the average value were taken.

III. RESULTS AND DISCUSSION

A. *Microstructure*

Microstructure of the dual phase steel has been characterized as shown in Fig 1 to 9. The magnification of each micrograph is 500x. The micrographs are shown the different of percentage of martensite in every temperature.



Figs. 1 to 9 Microstructure of dual phase steel with different intercritical annealing temperature

Ferrite is a solid solution of carbon in body centered cubic iron, pearlite is a dual phase microstructure resulting from the transformation of austenite of eutectoid composition and consist of alering layers or lamella of α ferrite cementite.

The micrograph shows that there are three phase, ferrite (white region) pearlite (dark region) martensite (light brown area). In specimen 1, pearlite are still exist in the microstructure even after the intercritical annealing because, the temperature 720^0C is lower than lower intercritical temperature (A_{c1}). During the heating temperature, pearlite did not transformed to austenite.

The percentage volume fraction of martensite in dual phase steel is influenced by variation in the intercritical annealing temperature. The higher intercritical annealing temperature , the higher the percentage of the volume fraction of martensite in dual phase steel obtained. This is because when the intercritical annealing temperature is increase, more pearlite will be change to austenite. Austenite will then transform to

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martensite by rapid cooling. From the micrographs shown in Fig 1 to 9, the percentages of martensite obtained were between 10 % to 95% of martensite and the percentage increases with increase in temperature. Table 3 shows the details of percentage martensite formation.

TABLE III
VOLUME FRACTION OF MARTENSITE

Specimens	1	2	3	4	5	6	7	8	9
Temperature (0C)	720	732	744	756	768	780	792	804	816
Volume Fraction of Martensite (%)	0	15.45	24.5	47	58	63	74	84	93.45

B. *Corrosion test*

Electrochemical test was carried out for six different percentage of martensite. The parameters measured in this investigation were corrosion potential (E_{corr}), corrosion current (I_{corr}), polarization resistance PR, corrosion rate and the anodic and cathodic Tafel slope βa and βc.

Tafel extrapolation is an excellent mean of collecting corrosion data because it can be done quickly and requires only small specimens. The Tafel extrapolation method involves plotting the log of the current produced in an electrochemical reaction of a conducting metal in solution against a voltage applied to that metal by an electrical-potential scanning device. This method uses data obtained from cathodic or anodic polarization measurements and it is also possible to determined very low corrosion rates. This polarization tests were conducted using a computer-controlled potentiostat at a scan rate of 1mV/sec.

TABLE IV
CORROSION RATE OF DUAL PHASE STEEL

Temperature (^{0}C)	Volume Fraction of Martenite	Hardness	Corrosion Current I_{corr} (A/cm^2)	Corrosion Rate (mm/yr)
732	15.45	204.21	1.11E-05	0.129
744	24.5	280.9	1.49E-05	0.173
756	47	317.2	1.68E-05	0.195
768	58	372.4	2.19E-05	0.254
792	74	419.6	2.23E-05	0.259
815	93.45	462.6	2.25E-05	0.293

Results of corrosion polarization studies of the developed materials with respect to a standard calomel electrode are shown in Table 4. The data for corrosion potential (Ecorr) and corrosion current (Icorr) shown in Table 4 have been derived from the experimentally obtained cathodic and anodic polarization (E vs. log I) curves using Tafel's linear extrapolation method.

From the results, the difference between the highest value and the lowest value is 0.164mm/yr. The lowest corrosion rate is 0.129mm/yr which is from specimen 1 followed by specimen 2 and specimen 3 which are the corrosion rate is 0.173mm/yr and 0.195mm/yr respectively. The value of corrosion rate for specimen 4 is 0.254mm/yr, and sample 5 is 0.259mm/yr and finally the highest corrosion rate is 0.293mm/yr.

It should be noted that when the steel specimen with ferrite–martensite structure corrodes in 5% NaCl solution, the following reactions occur on the steel surface with ferrite acting as anode:

$$Fe \rightarrow Fe^{2+} + 2e^- \quad \text{(anodic)}$$

$$2H^+ + 2e^- \rightarrow H_2 \quad \text{(cathodic)}$$

It is observed from Table 4 that as a consequence to the increase in the amount of martensite brought about by using higher intercritical temperature in any heat treatment route, the amount of ferrite decreases. Such relative change in the amount of the phase constituents would lead to a change in the ratio of cathode to anode areas. These changes ration between higher martensite (cathode) to ferrite (anode) increase the corrosion rate. This occurs due to the variation in the morphology and distribution of the phase constituent. Since intercritical annealing heat treatment produces a very fine fibrous structure, it can be qualitatively said that the interfacial area between ferrite (anode) and martensite (cathode) is much more for the specimens. The current value will be increase because of the larger interfacial between ferrite and martensite.

From the present results shows in Fig 10, it is obvious that corrosion rate of dual phase steel is influenced by both volume fraction and morphology of the constituting phases. An increased amount of martensite and refinement of the structure lead to an increase in the corrosion rate of dual phase steel as measured by I_{corr} values.

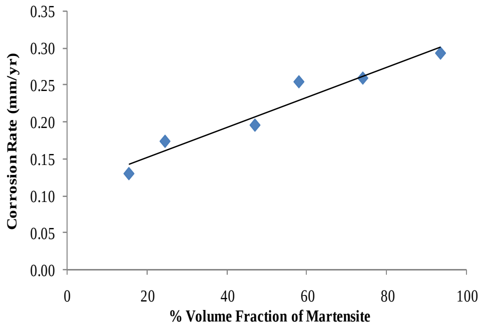

Fig. 10 Corrosion rate versus the percentage of volume fraction of martensite

C. *Hardness test*

Table V shows the hardness value of dual phase steel and low carbon steel. From the Fig 11, it shows that the hardness of the dual phase steel are increase by increasing the percentage of martensite. From the hardness test, the hardness for dual phase steels are higher than the plain low carbon steel. The dual phase steel has better hardness properties as it consists of ferrite and martensite structures. Martensite is a metastable iron phase supersaturated in carbon that is the product of a diffusionless transformation of austenite. The hardness in martensite is the result of severe lattice distortions produced by its formation, since the amount of carbon present is significantly higher than in solid solution.

TABLE V
THE HARDNESS OF DUAL PHASE STEEL

Specimen	Hardness (Hv)
Plain Low Carbon Steel	142
DP Steel (0% martensite)	156
DP Steel (15.45% martensite)	204.1
DP Steel (24.5% martensite)	280.9
DP Steel (47% martensite)	317.2
DP Steel (58% martensite)	372.4
DP Steel (63% martensite)	388.6
DP Steel (74% martensite)	419.6
DP Steel (84% martensite)	429.2
DP Steel (93.45% martensite)	462.6

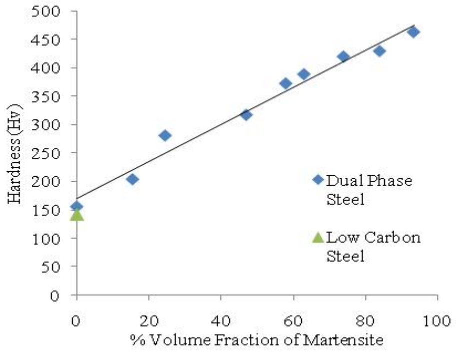

Fig 11 Hardness of dual phase steel versus the num of sample

IV. CONCLUSION

Dual phase steel can be produced by intercritical annealing temperature of the plain low carbon steel which contain ferrite and pearlite starting at 723^0C (lower intercritical temperature) for 25 minutes followed by rapid cooling. Water can be used as the medium for rapid cooling. It can be concluded from the present study that the increased in the percentage of martensite in dual phase steel will give higher corrosion rate. It shows that the percentage of martensite is proportional to the corrosion rate. The relative change in the amount of the phase constituents would lead to a change in the ratio of cathode to anode areas. These changes ration between martensite (cathode) and ferrite (anode) increase the corrosion rate. The morphology of the high percentage of martensite in dual phase steel have a fine fibrous structure and the interfacial area between ferrite (anode) and martensite (cathode) is much more for the specimens. The current flow will be increase because of the larger interfacial between ferrite and martensite. The hardness properties of dual phase steel are better than low carbon steel. The microstructure of dual phase consist of martensite thus it gives higher hardness properties.

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