The Investigation of Wear Behaviour of Dual Phase Steel DP600

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Abstract- Dual phase steels have been widely used in many applications in the automotive industry. In this study, the wear behaviour of commercially available DP600 steel with dual-phase structure are investigated. The wear rate, volume loss and friction coefficient are used to optimize wear resistance of DP600 steel with dual-phase. Abrasive and Adhesive wear tests were carried out to determine the abrasive friction coefficient of the DP600 steel.

Experimental studies show that the ferrite and martensite phases based on microstructures of the DP600 steel with dual-phase structure have an effect on tensile and wear tests. The wear resistance of DP600 steel can be controlled and optimized with wear condition (the wear rate, volume loss and friction coefficient).

Keywords Dual Phase Steel, Rolling, Flat Product, Wear, Abrasive, Adhesive.

1. Introduction

With the aim of meeting the needs and expectations of the industrial area, many new researches are made by the material engineers day by day in the steel industry. As a result of these studies, steel materials with a light, suitable strength, good deformation ability and high forming ability are foregrounded [1,2].

Dual-phase steels are produced by the critical annealing-quenching process of High Strength Low Alloy (HSLA) steels. It is a low-alloy or non-alloy high-strength steel type containing martensite phase dispersed in ferrite in microstructure. Microstructures also contain trace amounts of austenite, bainite and pearlite. Basic dual phases; Ferrite phase and martensite phase. These steels show many ideal properties when compared to HSLA steels. These; High strength, homogenous forming, percent elongation properties [1,2].

Coldren and Cornford have experimented to produce double-phase steel during ingot hot rolling. Chemical composition of test samples; 0,065% C, 1-1,2% Mn, 0.9-1% Mo, and 0.05% Al. As a result of the experiment; Samples containing martensite in high amounts showed dual-phase steel properties. Also, contrary to what is expected, they showed double-phase steel properties in samples having 70-90% polygonal ferrite, 0-25% bainitic ferrite and martensite volume above 10% of the steel they produced. The study shows that microstructures having the above-mentioned characteristics can be produced when appropriate cooling conditions are met. As a result of the experiment, there is no significant relationship between residual austenite and mechanical properties [2,3].

Hansen and Bramfitt investigated two different experiments to produce dual phase steel. Critical annealing heat treatment and hot rolling. The chemical composition of the test sample; 0,04-0,11C, 0,80-1,2Mn, 0,51-1,45Si, 0,05-0,65Cr, 0,27-0,62Mo. The Dual-phase steels produced shows similar tensile properties except yield strengths.The yield strength of hot rolled steels is higherThis is caused by the presence of spherical bainite, which forms the third phase, except polygonal ferrite and martensite, which are found in the microstructure. They stated that the coiling temperature should be below 610 ° C in order to produce martensite without pearlite formation [2,4].

In this study; Abrasive and adhesive wear behaviours of dual phase DP600 steel produced for industrial purposes were investigated. In addition, the yield stress, tensile stress and elongation properties of selected specimens of different orientations of DP600 Steel (Orientation) were examined.

2. Experimental Studies

2.1. Material

In the experimental work, DP600 dual-phase steel with a thickness of 4.5 mm produced by Hot Rolling was selected. The chemical composition of steel is given in Table 1.

Table 1. Chemical composition of the sample (%Wt)

Chemical composition (%Weight)							
%C	**%Mn**	**%Si**	**%P**	**%S**	**%Al**	**%V**	**%Ti**
0,079	0,82	0,23	0,039	0,0013	0,031	0,001	0,002
%Nb	**%Mo**	**%Ca**	**%N**	**%Cu**	**%Ni**	**%Cr**	**%Ti/N**
0,000	0,002	0,0011	0,0067	0,02	0,04	0,66	0,3

2.2. Rolling

Production of DP600 steel with dual phase structure used as test samples were carried out by Hot Rolling method. The production line is given in Fig.2.1. Dual-phase steel production in the Hot Rolling process is more economical than other production methods [2,3].

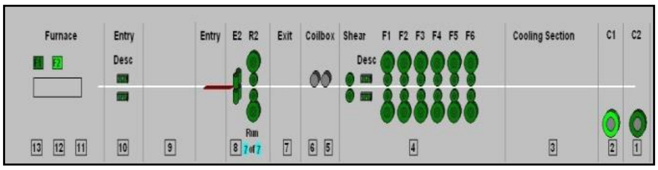

Fig. 1. Hot Rolling process

Production of flat rolled products by hot rolling is carried out as a result of applications at different stations in Figure 2.1. It is annealed to hot shaping temperature in slab. After the annealing process, the slab enters the reaction with oxygen. The oxide layer formed in this reaction is called descaling. Pressurized water is sprayed onto the slab to break the resulting oxide layer. The slab, which is cleaned from the oxide layer on the surface, is first sent to the coarse rolling process and then to the coil box to prevent temperature loss. The slab is subjected to strip rolling according to the order sizes. The slab is then cooled down continuously in the shower tables controlled by the automation system to create the desired microstructure. The strip is then coiler at the appropriate temperature [5].

The rate of cooling of material during rolling is too slow to bring ordinary carbon steels to normal dual-phase steel. At slow cooling rates after rolling, suitable alloying elements should be used to form an ideal dual-phase steel structure. In the production of dual-phase steel by the hot rolling method, the formation of the structure is difficult to follow. CCT diagrams are used for this [2,3].

The recommended alloying elements are Mn, Cr, Ni and Mo. If quenching is carried out after hot rolling, double-phase steel structure is obtained with less alloy addition [2,3].

2.3. Tensile Test

To make the tensile test, the drawing sample is prepared according to the standards from the material. In this study, test specimens were prepared according to TS 138 EN 100008 standards and experiments were carried out. The selection direction of samples is given in Fig. 2.2. Sheet metal materials exhibit different mechanical properties in different directions (isotropic and anisotropic) The samples are angularly removed from the plate. (R_0, R_{45}, R_{90}) Angular samples are prepared and necessary calculations are made [6].

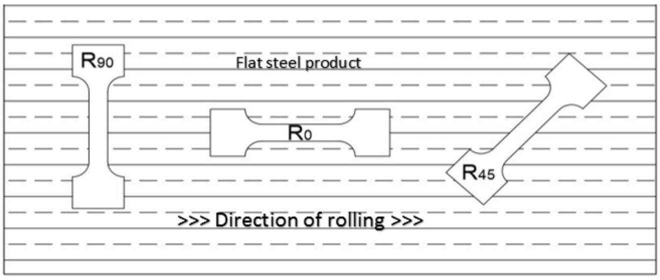

Fig. 2. Tensile test sample selection

2.4. Wear Test

Load on the sample is recorded during wear test in order to get data for calculation of friction coefficient. Eq. (1) was used for defining friction coefficient.

$$\textit{The coefficient of friction is, } \mu = \left(\frac{F}{P}\right) \quad (1)$$

Where F is the frictional force measured by the load cell and P is the normal load on the specimen [7].

The volume loss was calculated from the weight loss according to the following Eq. (2).

$$\textit{Volume Loss (m m}^3\textit{)} = \left(\frac{WeightLoss(g)}{Density\left(\frac{g}{mm^3}\right)}\right) \times 1000 \quad (2)$$

The wear tests were conducted five times for every sample. The wear rate was calculated from the following Eq. (3) [7]:

$$\text{Wear Rate } (mm^3/m) = \left(\frac{VolumeLoss(mm^3)}{SlidingDistance(m)} \right) \times 1000 \quad (3)$$

Abrasive and adhesive wear tests were carried out on the TURKYUS Pin-On-Disc. The weights and densities during the test were measured on the RADWAG electronic scale [7].

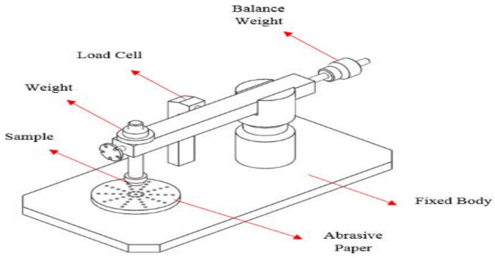

Fig. 3. Pin-On-Disk Wear Device

2.4.1. Abrasive Wear Test

Experiments have been carried out on a pin on disk abrasive wear device designed according to ASTM G99-05 as standard. The wear tester used in the wear tests is given in Figure 5. The surfaces to be abraded of all samples were sanded with 220 mesh SiC abrasive before testing to obtain the same surface quality. The wear tests were carried out at a speed of 3.16 m / s with 5, 10 and 15 N loads. 220 mesh SiC was used as the abrasive disc. Experimental times were determined as 95,190 and 285 meters. The specimens were moved perpendicular to the abrasive disc surface. The weight loss of the samples was also measured with an electronic balance of ± 0.001 g precision. Furthermore, in order to determine the friction coefficient, the frictional forces were measured with the load sensor mounted on the device and the friction coefficients were determined. Before and after the wear test, the samples were cleaned with ethyl alcohol and dried. All samples were subjected to wear test twice as shown in Table 2 and weight loss, volume losses, friction coefficients and wear rates were calculated using the formulas (1,2,3) indicated by the averages of these values [7].

Table 2. Abrasive test parameters

Sample Numbers	Sliding Distance (m/s)	Applied Load (N)	Sliding Distance (m)
DP-600	3,16	5	95
DP-600	3,16	5	190
DP-600	3,16	5	285
DP-600	3,16	10	95
DP-600	3,16	10	190
DP-600	3,16	10	285
DP-600	3,16	15	95
DP-600	3,16	15	190
DP-600	3,16	15	285

2.4.2. Adhesive Wear Test

Load Experiments have been carried out on a pin on disk abrasive wear device designed according to ASTM G99-05 as standard. The wear tester used in the wear tests is given in Figure 5. The surfaces to be abraded of all samples were sanded with 220 mesh SiC abrasive before testing to obtain the same surface quality. The wear tests were carried out at a speed of 3.16 m / s with 5, 10 and 15 N loads. In the experiment; AISI 52100 Bearing Steel material is used as abrasive. AISI 52100 bearing steel has 60 HRC hardness. Experimental times were determined as 95,190 and 285 meters. The specimens were moved perpendicular to the abrasive disc surface. The weight loss of the samples was also measured with an electronic balance of ± 0.001 g precision. Furthermore, in order to determine the friction coefficient, the frictional forces were measured with the load sensor mounted on the device and the friction coefficients were determined. Before and after the wear test, the samples were cleaned with ethyl alcohol and dried. All samples were subjected to wear test twice as shown in Table 3 and weight loss, volume losses, friction coefficients and wear rates were calculated using the formulas (1,2,3) indicated by the averages of these values [7].

Table 3. Adhesive test parameters.

Sample Numbers	Sliding Distance (m/s)	Applied Load (N)	Wear Distance (m)
DP-600	3,16	30	475
DP-600	3,16	30	575
DP-600	3,16	30	665
DP-600	3,16	40	475
DP-600	3,16	40	575
DP-600	3,16	40	665
DP-600	3,16	55	475
DP-600	3,16	55	575
DP-600	3,16	55	665

3. Experimental Results

3.1. Tensile Test Results

The results of three different tensile tests of the two-phase DP600 steel specimen taken in three different directions are given in Table 4.

Table 4. Tensile Test Results

Sample	DP600 R_0	DP600 R_{45}	DP600 R_{90}
Thickness (mm)	4,19	4,16	4,20
Width (mm)	25,37	25,13	25,19
Yield Strength (MPa)	347	359	341
Tensile Strength (MPa)	579	575	572
Elongation (%)	% 34	% 31	% 32

Tensile test results show that there are very similarities in the yield, tensile break results of three differently prepared (R0, R45, R90) samples. The microstructure formed in the sample produced by hot rolling shows the same behaviour in all the sections as isotropic regardless of direction.

Tensile testing of flat steel products produced by hot rolling; It is related to deformation rates, annealing, supply and winding temperatures [8].

The most important parameters determining the yield and tensile strengths in the double-phase steels are the proportions of the ferrite and martensite phases present in the microstructures. The equivalent strength of low-alloy steels, which are used equivalently for dual-phase steels, exhibit approximately the same behaviour as the yield and draw characteristics.

3.2. Wear Test Results

To characterize the wearing behavior of the DP600 Steel; Volume loss, wear rate and coefficient of friction were evaluated.

3.2.1. Volume Loss of Abrasive Sample

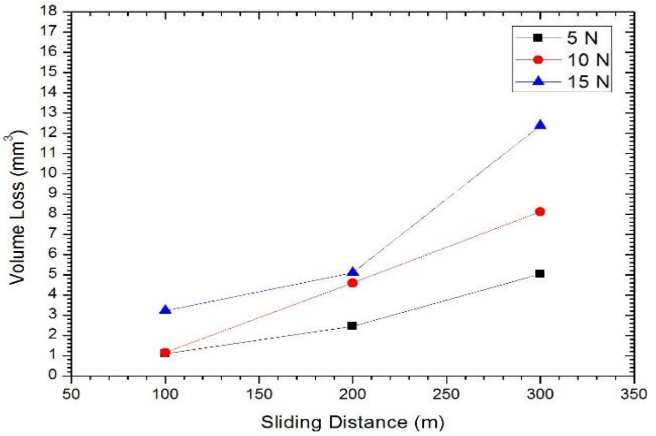

Fig. 4. Volume Loss of Abrasive samples

Volume loss of the abrasive wear test of DP600 Steel under different loads (5N, 10N, 15N) are given in Fig.3.1. The volume loss resulting from the increase in load also increased significantly in the Fig. 6. It can be seen clearly that abrasive wear tests have higher volume loss rates than adhesive wear tests due to abrasives. 5N, 10N and 15N test specimens have similar volume losses up to 200 m. In the range of 200-300 m there is no similarity in volume losses of the samples. The result shows the good correlation of literature study [9].

3.2.2. Volume Loss of Adhesive Sample

In The Fig.3.2 shows the volume loss adhesive wear test of DP600 Steel under different loads (30N, 40N, 55N) Figure 7 shows that volume loss during the test increases significantly at the end of the load increase Similarly, the increase in sliding distance has led to an increase in volume loss. 40N, 55N test specimens show similarities in volume losses throughout the test period. However, it can be seen that the weight loss profile of 30N test sample is less than the other samples. Our test sample of 55N and 40N showed a noticeable difference from the other sample at 500m, since the force applied by the abrasive was higher. Adhesive wear tests have less volume losses than abrasive wear tests due to abrasive.

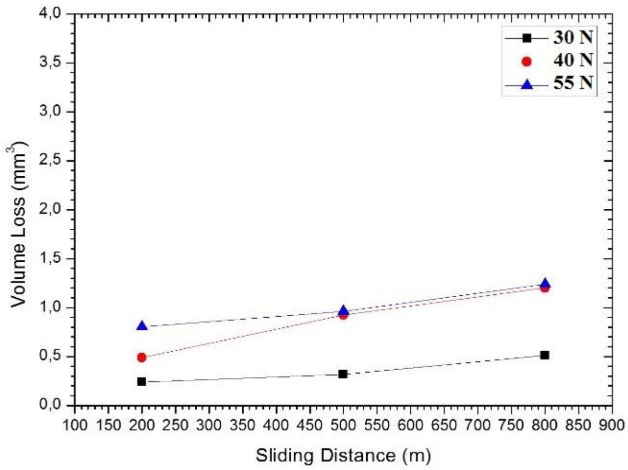

Fig. 5. Volume Loss of Adhesive samples

The volume of adhesive sample in Fig. 6 show good correlation within the literature [9].

3.2.3. Wear Rate of Abrasive Sample

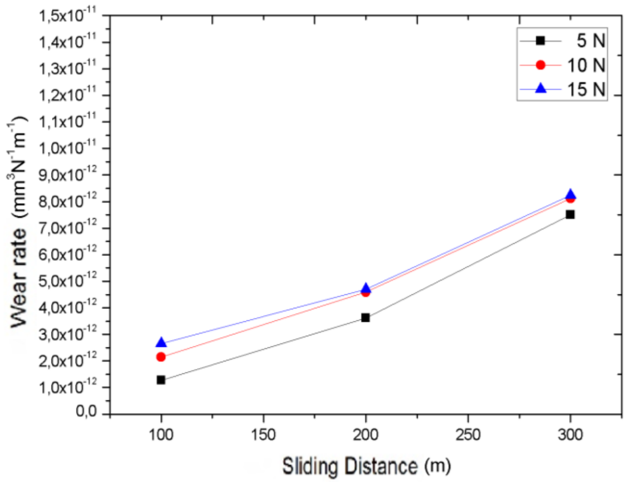

Fig. 6. Wear rate of Abrasive Samples

In the characterization of wear behaviour of steel, the volume losses are not enough alone. In order to determine the effect of sliding distance on wear behaviour, wear rate data should be evaluated.

Fig 6 exhibits abrasive wear test wear rates of the DP600 Steel under different loads (5N, 10N, 15N). 10N and 15N samples showed a similar wear rate at the 300 m sliding distance. In other words, the high sliding distance does not have a significant effect on the 10N and 15N samples. 5N, 10N and 15N samples showed higher wear rates than the adhesive wear test. This is due to the use of 220 mesh SiC discs which are used as abrasive [7].

3.2.4. *Wear Rate of Adhesive Sample*

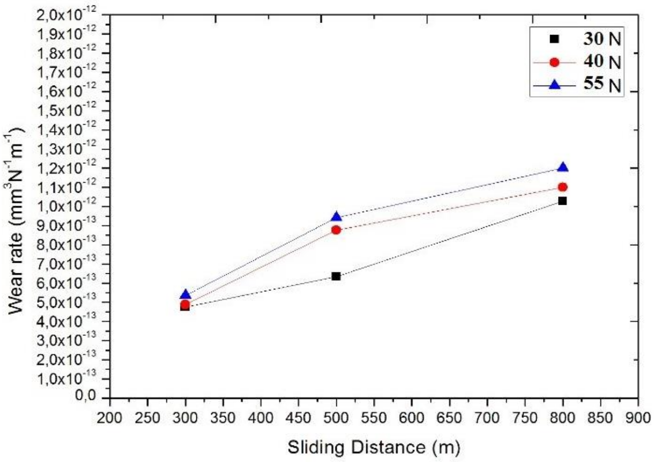

Fig. 7. Wear rate of Adhesive Samples

Wear test were carried out on the graph with different loads (30N, 40N, 55N). Fig. 8 illustrates the of wear rates of adhesive samples. It can be seen that the wear rates obtained as a result of the adhesive wear tests are lower than the abrasive wear rates. This result; Is an abrasive disk type used in adhesive wear tests. 40N and 55N samples exhibit similar wear rates between 300-500 m sliding distances. 35N test sample showed a proportional increase between 300-500 m. Showed a remarkable increase in the range of 500-800 m.

3.2.5. *The Friction Coefficient of Abrasive Sample*

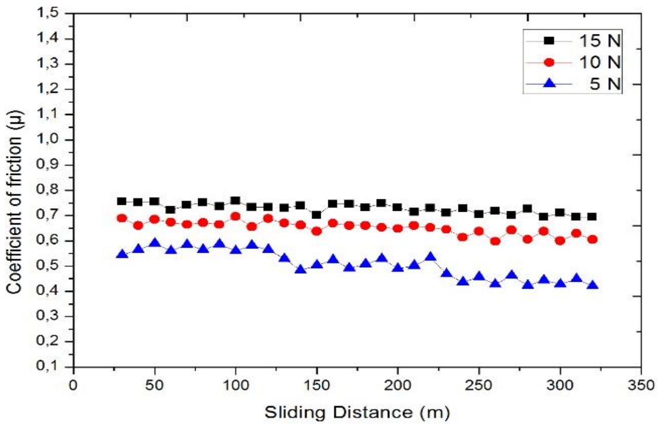

Fig. 8. Friction Coefficient of Abrasive Samples

The most important parameter used in studying the wear behaviour of metals is the friction coefficient. The coefficient of friction is used to characterize how the metals exhibit resistance during wear.

It can be related the coefficient of friction to the force of breaking a piece from a material. If it is easy to break off the material surface, the friction coefficient decreases. If the applied force increases, it should be easier to break the piece. Tests were carried out on the graph with different loads (5N, 10N, 15N). As a result of the abrasive wear test of the DP600 Steel, the friction coefficient was plotted depending on the sliding distance. In Figure 9 it has been observed that the friction coefficient decreases considerably with increasing force. This result is parallel to the studies in the literature. The highest coefficient of friction was obtained at ~ 0.8 to 5N. The lowest coefficient is seen in the ~ 0.4 to 15N sample.

3.2.6. *The Friction Coefficient of Adhesive Sample*

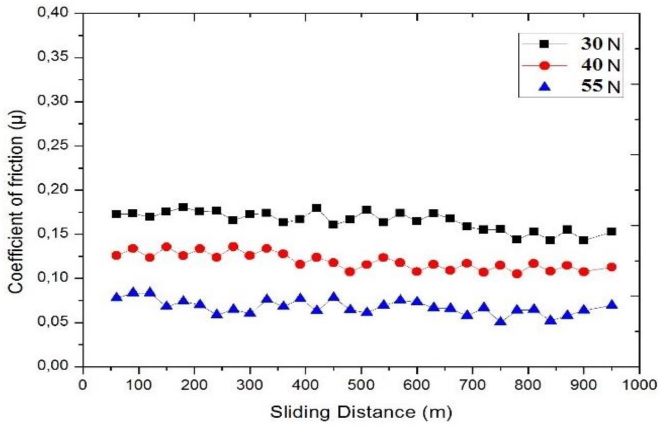

Fig. 9. Friction Coefficient of Adhesive Samples

The friction coefficient of adhesive samples is given in Fig. 9. It can be clearly understood that the friction coefficient is affected by sliding distance. Although the loads on the adhesive wear test are higher than those on the abrasive wear test, there is a significant reduction in their resistance. This is because; The disc used as an abrasive has a metallic structure. All of the samples are beginning to test with a significant increase before 50 mm sliding distance. A decrease in the coefficient of friction is seen with increasing force.

4. Conclusions

In this study; The mechanical properties of commercially available dual phase DP600 steel; Tensile and yield strengths, abrasive, adhesive wear behaviors were investigated. The results obtained are given below.

- Tensile tests were carried out by extracting tensile samples in different rolling directions of the flat test specimen produced after rolling. Tensile strength, tensile strength and breaking elongation of the specimens selected depending on the direction of orientation were determined at the end of the tensile test.
- All samples (isotropic) showed the same behavior regardless of the direction of the sample used as a result of tensile tests.
- As a result of the wear test, volume loss, wear rate and friction coefficients were determined under the slip distance and different loads. In the results of wear obtained; The volume losses and wear rates found in the

abrasive wear differ from the results of the adhesive wear.

- The highest abrasive rates as a result of abrasive wear tests; High sliding distance distance and 15 N load.
- The highest Adhesive rates as a result of abrasive wear tests; High sliding distance distance and 55 N load.

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