

Enhancement Wear Resistance of Carbon Dual Phase Steel by Cryogenic Treatment

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Abstract

Dual phase steels containing three different amounts of martensite 21, 37 and 87 Vol. Pct. have been made from carbon steels containing 0.12, 0.33 and 0.43 wt. pct. Carbon respectively. Intercritical annealing treatment at 760 °C was employed, followed by quenching in Brine. Cryogenic treatment was carried out using liquid nitrogen. Dry sliding wear tests have been conducted on Dual phase (DP) steels before and after cryogenic treatment, using a pin-on disk machine under load 25 N and at a constant sliding velocity 1.74 m/s, for 10 min. at room temperature. Wear properties have been found to improve with the increase in martensite volume fraction in dual phase steels, also, it was observed that, after cryogenic treatment the wear resistance of dual phase steel has improved.

Key words: wear, cryogenic treatment, dual phase steel

1-Introduction

Dual phase steels have found continued relevance in the automobile industries because of its unique high strength to weight ratio, formability, energy savings and crash energy management [1]. This has made them suitable for the production of car body parts, wheel rims, and a good number of structural parts. The dual phase steels consist of a ferrite (soft phase) and martensite (hard phase) composite structure, which is responsible for its unique mechanical properties. Initially, dual phase steels were technically defined as steels with microstructure consisting of 30% martensite with the balance ferrite; but as a result of its amazing combination of mechanical properties, there has also been interest in the development of dual phase steels with between 50 – 60% martensite derived by the utilization of steels of medium carbon composition. Dual phase steels with 50 – 60% martensite have been touted to have the potentials for good combination of high strength, toughness, ductility and fatigue strength – extending the use of dual phase steels for more structural applications [2].

Recent studies have 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 [3]. However, the tribology of dual phase steels has not yet been explored extensively, and only a few studies have been reported.

Wayne and Rice 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 spheroid carbides. It has also been indicated that the wear resistance of dual phase steels increases with the increase in volume fraction of martensite [4].

Sawa and Rigney have found that the wear behavior of DP steel also depends strongly on its morphology, *i.e.*, the shape, size, and distribution of its martensite [5].

The work reported is part of a study carried out on DP steels containing different martensite volume fraction and examine its effect on wear behavior of these steels. Cryogenic quenching treatments have been accepted and adopted in commercial practice as an effective method for completing martensitic transformation in alloyed and casehardened steels [6].

Noted for improving wear resistance, the cryogenic treatments, usually involving cooling within the temperature range of from -120 °C to -195 °C; replace popular dry ice and mechanical refrigeration treatments applied before a single or multiple tempering steps. However, reported wear resistance improvements vary between a few and a few hundred percent, and conflicting results are presented for the change in impact resistance of treated steels [7]. The inconsistencies in reported data may be, at least partly, explained by a new effect of cryogenic aging observed to take place in the background of retained austenite transformation. Meng observed precipitation of fine carbides instead of the usual carbides following -180 °C cryogenic treatments and noted improvements in both wear resistance and toughness [8]. Lal concluded that cryogenic treatments are most effective if applied soon after quenching, and that the length of cryogenic

soaking is more important than the temperature of cryogenic medium [9]. Huang identified highly dispersed, nanosized Fe₂C carbides in HSS cutting tools treated and, in contrast to the earlier work, found a linear proportionality between the cryogenic quenching temperatures and wear rates [10].

2-Materials and Methods

2.1 Materials

The steels grades used in this work were selected from standard types of carbon steel, with different carbon content ranging from low to medium. This helps to understand the effect of carbon content and cryogenic treatment on the properties of dual phase steel. The tested steels, has chemical compositions shown in table 1, designated (C12D, C32D and C42D), according to the German standards specifications (DIN).

Table 1: Chemical composition of three steel grades

Steels Elements%	C12D	C32D	C42D
C	0.12	0.33	0.43
Si	0.25	0.276	0.209
Mn	0.58	0.527	0.673
P	0.012	0.023	0.018
S	0.035	0.045	0.010
Cr	0.087	0.142	0.132
Mo	0.015	0.016	0.017
Ni	0.073	0.057	0.070
Cu	0.174	0.011	0.118

2.2 Heat Treatments

The heat treatment included normalizing, intercritical annealing and tempering treatment as shown in table 2. Intercritical annealing carried out at (760 °C), and the holding time was (30 min), followed by quenching in Brine solution (10% NaCl) to obtain (DP) steel. Tempering was carried at (200 °C) for one hour, and was employed after cryogenic treatment.

Table 2: The details of the employed heat treatments cycles.

steel	Heat treatment	Temperature (°C)	Holding time (min)	Cooling medium
C12D	N	900	30	Air
	IA	760	30	Brine
	T	200	60	air
C32D	N	860	30	Air
	IA	760	30	Brine
	T	200	60	water
C42D	N	850	30	Air
	IA	760	30	Brine
	T	200	60	Air

2.3 Cryogenic Treatment

Liquid nitrogen was used as cooling media to carry out the cryogenic treatment. The specimens were encased in paraffin wax to act as insulator as shown in fig (1). This enables gradual change in the temperature of the specimen to prevent any thermal shock that may occur when loaded into liquid nitrogen container, thus causing undesirable deformation or cracking. When cryogenic treatment temperature (-196 °C) is reached, the specimens then held at this temperature for a period of 24 hours, the setting is shown in fig.(2), after that specimens were removed and left to warm at room temperature. The cryogenic treatment of the specimens was done in a chamber which is fully covered with multilayer super insulation and is filled by liquid nitrogen.

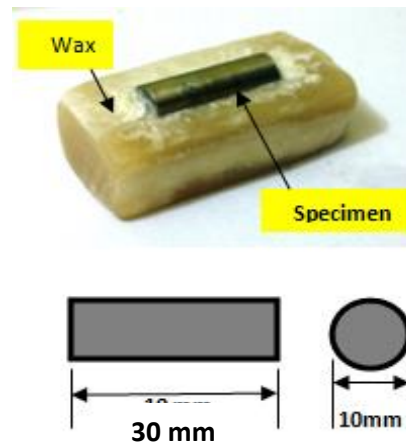


Figure 1: a- the wear specimen showing wax insulation partially removed. b- Dimensions of the specimen

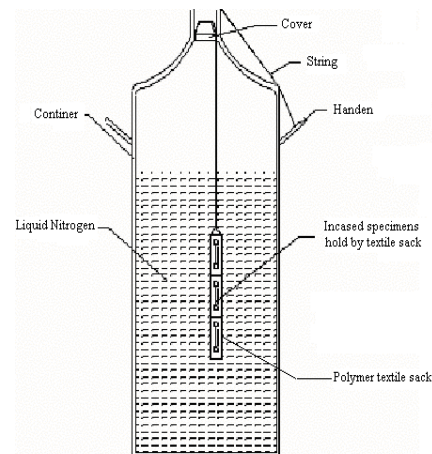


Figure 2: schematic presentation of the cryogenic treatment setup

2.4 Wear Test

Pin-On-Disc wear test machine was used in this research, in University of Technology in the Department of Materials Engineering. In this testing the specimens were testing under load (25 N), at constant linear sliding velocity (VS = 1.74 m/s) in dry condition at a room temperature of ~25°C, and the time used was (10 min). Before testing, the disc was cleaned with silicon carbide papers. The specimens were prepared according to ASTM (G99-05) standard with dimensions (10 mm) diameter and (30 mm) length was used as static pin.

2.4.1 Volume Wear Rate

The weight lost method was used in present work. In which the specimens were weighted before and after testing, the volume wear rate (Wrv) was calculated using formula (1) [11].

$$Wrv = \Delta w / 2\pi r n t \rho \quad \dots (1)$$

Where:

Wrv = Volume wear rate in cm³/mm.

Δw = Weight before test – weight after test

π = Constant ratio = 3.14

r = radius of disc in mm=60 mm

n = Disc rotation number in rpm =277.4 r.p.m.

t = time in minute =10 min

ρ = density of steel in gm/cm³,

Where the density for:

C12D = 7.85 gm/cm³

C32D = 7.88 gm/cm³

C42D = 7.60 gm/cm³

$2\pi r n t$ = sliding slip

3- Results and Discussion

3.1 Wear Resistance

The wear test was carried out under load of (25 N), with linear sliding velocity (VS=1.74 m/s) for a time (t= 10 min), the volume wear rate (Wrv cm³/mm) and the percentage improvement in wear resistance were calculated and the results are presented in table 3 and in figures (3, 4, 5 and 6)

Table 3: Wear test results for steel (C12D, C32D& C42D) after different treatment and percentage in wear reduction

Type of treatment	C12D			C32D			C42D		
	Wrv (cm ³ /mm)	Increase or decrease % Comparison		Wrv (cm ³ /mm)	Increase or decrease % Comparison		Wrv (cm ³ /mm)	Increase or decrease % Comparison	
		With (NT)	with (DP)		with (NT)	with (DP)		with (NT)	with DP
NT	37.3E-10	-----	-----	22.8E-10	-----	-----	4.52E-10	-----	-----
N+CT+T	16.6E-10	+124.6%	-----	12.7E-10	+79.5%	-----	3.52E-10	+28.4%	-----
DP	8.37E-10	+345.6%	-----	6.94E-10	+228.5%	-----	2.89E-10	+56.4%	-----
DP+CT	4.61E-10	+709.1%	+81.5%	2.64E-10	+763.6%	+162.8%	2.07E-10	+118.3%	+39.6%
DP+CT+T	7.15E-10	+421.6%	-17%	2.92E-10	+680.8%	+137.6%	2.51E-10	+80%	+15.1%

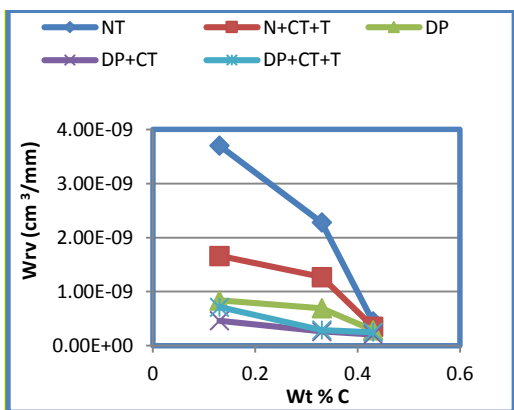


Figure 3: Effect of cryogenic treatment on the volume wears rate of dual phase steel of different carbon content

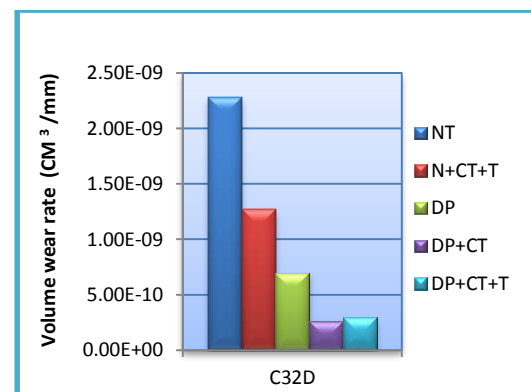


Figure 4: Histogram showing effect of heat treatment on volume wear rate for (C12D) steel

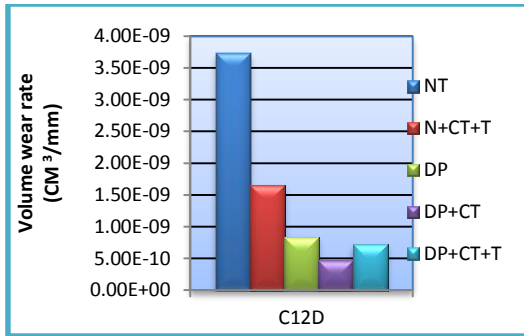


Figure 5: Histogram showing effect of heat treatment on volume wear rate for (C32D) steel.

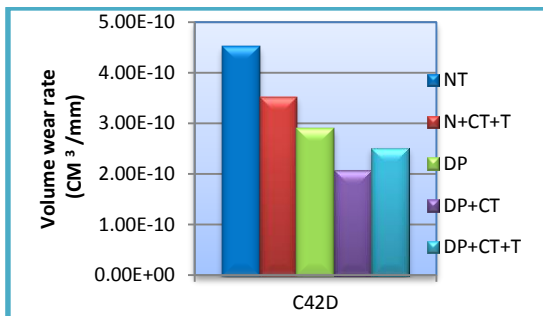


Figure6: Histogram showing effect of heat treatment on volume wear rate for (C42D) steel.

The wear test results for (C12D) as presented in table 3 clearly shows that volume wear rate of dual phase steel is lower than that of normalized steel by **(28.93E-10 cm³/mm)**, which means a reduction in the volume wear rate by **(345.6%)**. When dual phase steel subjected to cryogenic treatment (DP+CT), the wear rate was further reduced to **(4.61E-10 cm³/mm)**, i.e. a reduction in wear rate by **(709.1%)**, a gain over that of (DP) by **(81.5%)**. Tempering at 200 °C after cryogenic treatment increases the wear rate to **(7.15E-10 cm³/mm)**, and the improvement in wear resistance over that of (DP) becoming only by **(17%)**. As for normalized steel, cryogenic treatment also reduced the wear rate down to **(16.6E-10 cm³/mm)**, and the improvement in wear reduction was **(124.6%)**.

For (C32D) steel, the volume wear rate of dual phase steel is lower than normalized steel by **(15.86E-10 cm³/mm)**, or an improvement of **(228.5%)**, this is further improved after cryogenic treatment (DP+CT) to **(763.6%)** an improvement of **(162.8%)** over that of (DP) steel. Tempering at 200 °C reduces these improvement to **(680.8%)** compared to normalizing and to **(137.6%)** compared to (DP). Cryogenic treatment of normalized (C32D) steel reduces the volume wear rate by **(10.1E-10 cm³/mm)** or an improvement of **(79.5%)** in wear resistance.

For (C42D) steel, the volume wear rate of dual phase steel is lower than normalized steel by **(1.63E-10 cm³/mm)** or an improvement of **(56.4%)**. The wear rate of dual phase steel decreased after cryogenic to **(2.07E-10 cm³/mm)**, which means an improvement of **(118.3%)**, but (cryogenic + tempering) treatment reduce the improvement to **(80 %)**, while wear resistance of normalized steel improved after (cryogenic +tempering) by **(28.4%)**.

From the above, it can be concluded that, for the three grades of steel (C12D, C32D & C42D), the wear resistance of dual phase steel is always higher than normalized steel, this is a direct result of hard martensite formation in the microstructure of dual phase steel, and it will be improved as the volume fraction of martensite increased. The observed trend is in agreement with the observation of Wayne and Rice [4], they have shown the dependence of wear on microstructure and have concluded that the duplex microstructure of dual phase steel offers higher wear resistance than that observed in steel with spherical carbides. Also, it was observed that, after cryogenic treatment the wear resistance of dual phase steel has improved, this may attributed to the transformation of retained austenite to martensite in the microstructure of dual phase steel, and the precipitation of fine (η) carbides within the martensite.

The effect of cryogenic treatment on wear resistance reported by Professor D. N. Collins at the University of Dublin, he commented "In addition to the well-known effect of transforming retained austenite to martensite, with the consequent increase in hardness, deep cryogenic treatment, has an effect on martensite. It causes crystallographic and microstructural changes which, on reheating, result in the precipitation of a finer distribution of carbides in the tempered microstructure, with consequent increases in both toughness and wear resistance." [12]

The wear resistance of dual phase steel is increased with increasing the volume fraction of martensite, this reported by Tyagi et al [13], also Sawa and Rigney have found that the wear behavior of dual phase steel also depends strongly on its morphology, i.e., the shape, size, and distribution of its martensite within the matrix [5].

The effect of carbon content on the response of the investigated steel grades to cryogenic treatments, concerning wear resistance, are presented in figure 3 and the histogram figures (4, 5 & 6) for (C12D) ,(C32D) and (C42D) respectively .It can be seen that steel (C42D) has the lowest responses, since Martensite represent (78%) as shown in figure 7(a) of the microstructure for this steel due to its higher carbon content, whereas the martensite contents of (C12D) and (C32D) steel are approximately

(21%) and (37%) respectively as shown in figures 7 (b and c). This means that structural changes in the ferrite phase, is primarily responsible for the high response of (DP) for these two steel to cryogenic treatment, since Ferrite represents (79%) and (63%) of their structure. Figure 10 is the microstructure of dual phase C12D steel after cryogenic treatment showing structural changes, in which fine precipitation inside ferrite phase are clearly visible.

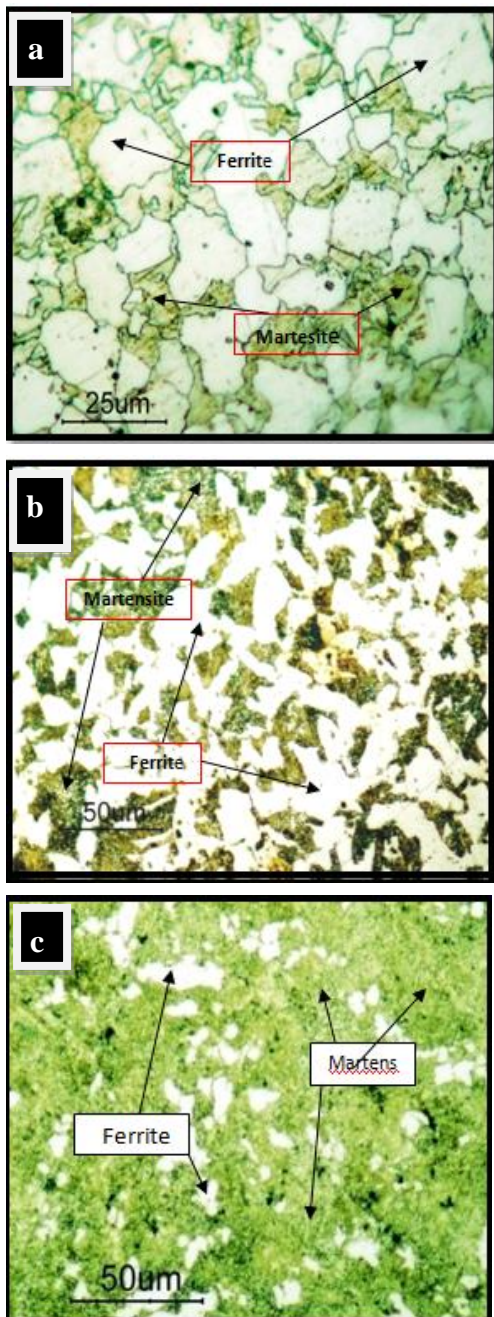


Figure 7: Microstructure of dual phase for, (a) C12D steel, (b) C32D and (c) C42D

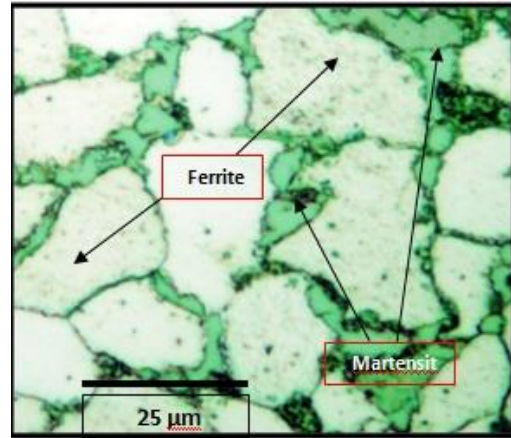


Figure10 Microstructure of dual phase C12D steel after cryogenic treatment showing fine precipitate in the ferrite.

5- Conclusions

1. Dual phase treatment improves wear resistance by **345.6%**, **228.5%** and **(56.4%)** for (C12D, C32D and C42D) steel respectively. This can be further improved by cryogenic treatment to **(709.1%)**, **(763.6%)** and **(118.3%)**, which is indicating good response of (DP) steel to cryogenic treatment.
2. The response of carbon steels to cryogenic treatment largely influenced by the carbon content and the heat treatment prior to cryogenic treatment. Lower carbon steels (C12D) and (C32D) generally has better response than (C42D) of higher carbon content.
3. Higher response of lower carbon steels to cryogenic treatment may attribute to microstructure changes within the ferrite phase.

5- References

[1] Ahmad E, Manzoor T and Hussain. Thermomechanical processing in the intercritical region and tensile properties of dual phase steel. *Materials Science and Engineering*, (Lausanne) 508(1-2):259-265, 2009.

[2] Bag A, Ray KK and Dwarakadasa ES. Influence of martensite content and morphology on tensile and impact properties of high - martensite dual-phase steels. *Metallurgical and Materials Transactions A* (Warrendale), 30 (5):1193-1202. 1991.

[3] A.K. Jha, B.K. Prasad, O.P. Modi, S. Das and A.H. Yegneswaran: *Wear*, 254, 120. 2003.

[4] S.F. Wayne and S.L.Rice: *Wear*, 85- 93. 1983.

[5] M. Sawa and D.A. Rigney: *Wear*, 1987, 119, 369.

[6] D.L. Milam, *Case-hardened stainless Steel bearing component and process*, U.S. Patent 5, 851, 313, Dec.22, 1998

- [7] G.R. Bourne et al., Effects of Cryogenic Treatment on wear Resistance of AISI D2 Tool Steel, STLE –Annual Meeting 2003, Tribology Laboratory, and Univ.ofFlorida, <http://nersp.nerdc.ifl.edu/~wsawyer/presentations/cryoSTLE2003.swf>, last accessed: 2/11/2005.
- [8] F. Meng et al., Role of Eta-carbide Precipitations in the Wear Resistance Improvements of Fe-12Cr-Mo- V-1.4C Tool Steel Cryogenic Treatment, ISIJ International, Vol. 34 (1994), No. 2, pp. 205-210.
- [9] D.M. Lal, Cryogenic treatment to Augment wear resistance of tool and die Steels, Cryogenics 41(2001) 149-155.
- [10] M.C. Huang et al., Study on Cryogenic Phase Change and Wear Characteristics of High Speed Steel, *Acta Metallurgica Sinica (English Letters)*, Vol. 16, No. 6, pp, 524-530 December 2003.
- [11] Archard, J.F., Hirst, W., “The Wear of Metals under Unlubricated Conditions. ”, proceedings of the Royal Society, pp: 397-410, (1990).

- [12] Cryotreatment-State of the Art, an update ”, T. Holm, AGA Internal Report. (1997),
- [13] R. Tyagi, S.K. Nath and S. Ray: Metall. Mater. Trans. A, 33 A, 3479, 2002.

Abbreviation table

Abbreviation	The Meaning
DP	Dual Phase
NT	Normalizing treatment
N+CT+T	Normalized +cryogenic + tempering
DP+CT	Dual Phase + cryogenic treatment
DP+CT+T	Dual Phase+ Cryogenic + Tempering treatment
IA	Intercritical Annealing treatment
T	Tempering treatment
F	Ferrite
M	Martensite

تحسين مقاومة البلي للصلب الكربوني ثنائي الطور بالمعاملة الزمهريرية

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الخلاصة:

صلب ثنائي الطور من الصلب الكربوني وبنسب حجمية مختلفة من المارتنسايت (21, 37 و 87 بالمئة), تم تحضيره من انواع الصلب ذات نسب كربون (0.12, 0.33 و 0.43 بالمئة) وعلى التوالي, باستخدام المعاملة الحرارية الوسطية والبالغة 750م, اعقب ذلك عملية اخماد في محلول ملحي. بالنسبة الى المعاملة الزمهريرية فقد اجريت باستخدام النتروجين السائل. اجري فحص البلي الجاف على العينات قبل وبعد المعاملة الزمهريرية وباستخدام طريقة الدبوس على القرص الدوار, تحت حمل مقدارة 25 نيوتن لمدة عشرة دقائق وسرعة انزلاقية ثابتة بمقدار 1.7 م/ثا, في درجة حرارة الغرفة. وقد وجد ان مقاومة البلي للصلب ثنائي الطور تتحسن مع زيادة نسبة المارتنسايت فيه, كذلك لوحظ ان مقاومة البلي قد تحسنت بعد المعاملة الزمهريرية.

الكلمات الرئيسية: البلي, المعاملة الزمهريرية, صلب ثنائي الطور.