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Evolution of Martensite volume fraction on Behavior of Dual Phase Steel

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Abstract

Dual-phase (DP) steels are a subset of high-strength, low-alloy steels that exhibit a unique balance of strength and ductility due to their dual microstructure of ferrite and martensite. This study investigates the effects of varying martensite volume fractions on the mechanical properties of DP steel by preparing samples with martensite contents from 20% to 50%, achieved through intercritical annealing at temperatures between Ac1 and Ac3, followed by quenching in ice-brine. The mechanical properties of these samples were analyzed using optical microscopy, hardness tests, and impact toughness measurements. Results reveal that increasing the martensite volume fraction enhances both hardness and impact toughness, indicating that adjusting heat treatment parameters can optimize DP steels for strength-critical applications. This study provides insight into the microstructural factors influencing DP steel properties and highlights effective processing routes for tailoring material performance.

Keywords: Dual-Phase Steel, Microstructure, Heat treatment, Mechanical properties.

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دراسة تأثير نسبة حجم المارتنسيت على سلوك الفولاذ ثنائي الطور

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1- المركز الليبي التقني العالي للتدريب و الإنتاج – طرابلس – ليبيا

2- الجامعة المفتوحة – ليبيا

الملخص

الفولاذ ثنائي الطور (DP) هو نوع من الفولاذ عالي القوة ومنخفض السبائك الفولاذية، يتميز بتوازن فريد بين القوة والمرونة بفضل بنيته الدقيقة المزدوجة المكونة من الفريت والمارتنسيت. تتناول هذه الدراسة تأثيرات اختلاف نسب حجم المارتنسيت على الخصائص الميكانيكية للفولاذ ثنائي الطور من خلال تحضير واختبار عينات تحتوي على محتوى من المارتنسيت بنسب تتراوح بين 20% إلى 50%، والتي تم تحقيقها عن طريق عملية التلدين بين الحرج في درجات حرارة تتراوح بين Ac1 وAc3، تلاها عملية التبريد في محلول ملحي بالجليد. تم تحليل الخصائص الميكانيكية لهذه العينات بواسطة المجهر الضوئي واختبارات الصلابة وقياسات صلابة التأثير. تظهر النتائج أن زيادة نسبة حجم المارتنسيت تؤدي إلى تعزيز كل من الصلابة وصلابة التأثير، مما يدل على أن تعديل معاملات المعالجة الحرارية يمكن أن يحسن الفولاذ ثنائي الطور للاستخدامات الحرجة من حيث القوة. تقدم هذه الدراسة رؤى هامة حول العوامل الهيكلية الدقيقة التي تؤثر على خصائص الفولاذ ثنائي الطور وتبرز أساليب المعالجة الفعالة لتخصيص أداء المواد.

الكلمات المفتاحية: الفولاذ ثنائي الطور، التركيب المجهري، المعالجة الحرارية، الخواص الميكانيكية.

Introduction

In recent years, the demand for engineering materials with specific properties has increased. High toughness, low weight, and low cost are particularly needed in modern industries.[1] Such steel materials play an important role in air craft and car industries. The family of advanced high strength steels (AHSS) includes dual phase steels (DP) [2]. They are a novel family of alloy steels with low strength that are mostly composed of a ferrite matrix with a second hard phase of bainite or martensite [3]. Due to their excellent weldability, ease of processing, and high strength and ductility, DP steels are frequently used in the automotive industry, especially in passenger vehicles [4]. Heat treatment in the ferrite austenite phase field, followed by quenching, produces dual phase steel that changes from austenite to martensite, as seen in Figure 1 [5].

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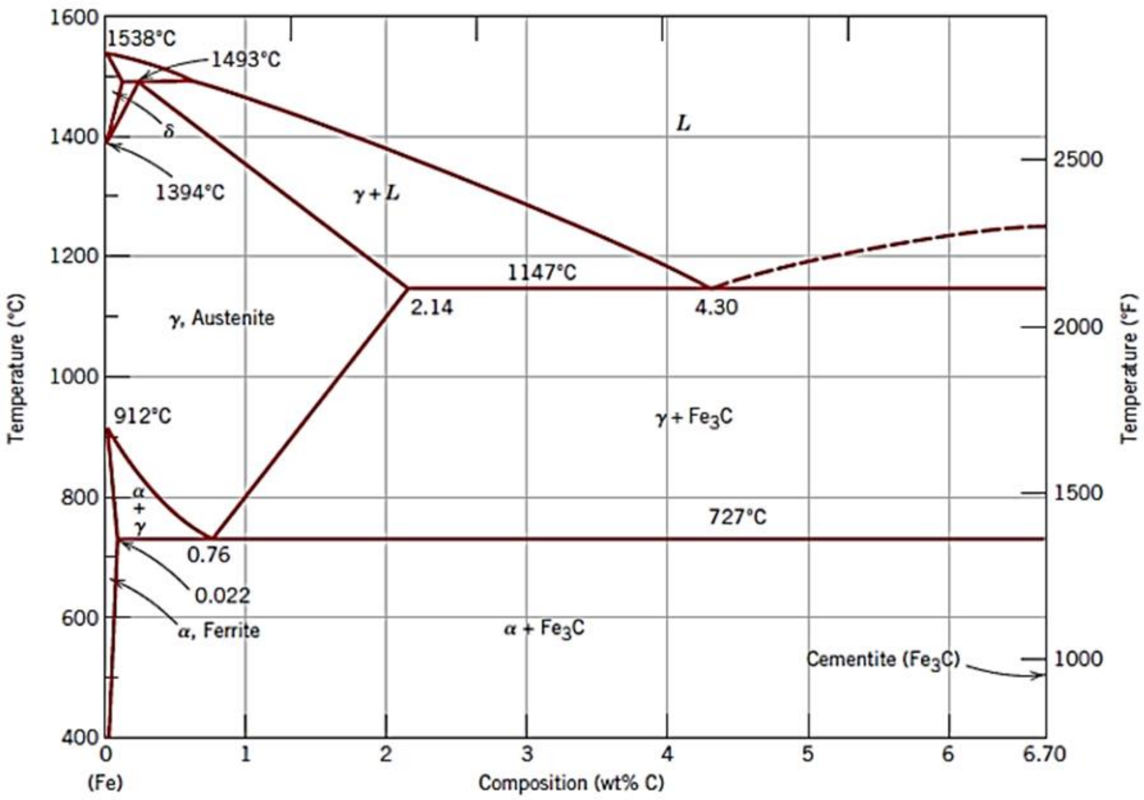

Figure.1, Phase Diagram of iron -carbon equilibrium [5].

Additionally, due to There are ferrite and martensite phases in the microstructure of dual phase steels. Consequently, the steel's ductility and formability are preserved while its strength is greatly increased.[6].

The intercritical annealing temperature in the ferrite plus austenite region will also be influenced by the proportion of martensite in the ferrite-martensite steel. Additionally, when the volume proportion of martensite grows, the dual phase material's strength increases.[7].

Quantification of Phase Volume Fraction with ASTM E562's Systematic Point Count Method, In order to statistically estimate the volume percentage of an identifiable ingredient or phase from sections through the microstructure using a point grid, this test technique explains a methodical manual point counting procedure that involves choosing an appropriate array [8].

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Material and Methodology

Material

The chemical composition of Dual Phase Steel, which was used as a base material in this study, is given in Table1.

Table 1. The chemical composition of Dual Phase Steel

C	Cr	Mn	Si	P	S	Ni	Mo
0.08742	0.07257	0.55438	0.16847	0.00768	0.00872	0.08828	0.05239

The chemical analyses were conducted using Spark emission spectrometer.

Samples Preparation:

Five Samples for the study were prepared at the center of research and technology according to standard for heat treatment, impact test, microstructural and hardiness test.

The raw material was cut in to Five sample according to ASTM E23 Standard [7], Charpy V notch impact samples as shown in Figure 2.

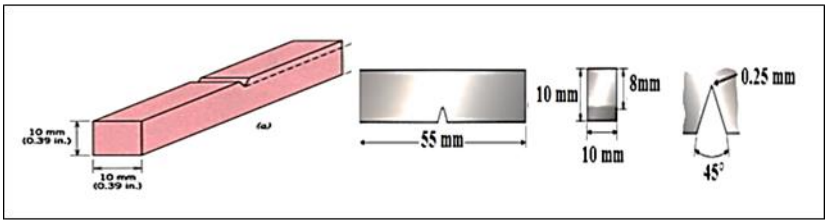

Figure 2. Impact test sample dimension.

Heat treatment:

To investigate the relationship between the volume faction, impact test and hardness test of dual phase steel. The five specimens were heated in the furnace to 1000 °C for 60 minutes, and then air-cooled for 30 minutes. The first sample was used as a base material, after that various intercritical temperatures for 30 minutes, and then cooled in air for 30 minutes, then quenched quickly in a cooled salty water solution bath in order to transform the pearlite to martensite for the rest of samples. as shown in the table2 below

Table 2, The steps for heat treatment for the samples.

Sample	2,3	4,5
Temperature (°C)	735	810
Time (min)	30	30

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Hardness Test

This test is to make comparison of the hardness properties between the heated specimens and the Dual Phase Steel. Hardness was measured using a Brinell hardness tester. The final hardness values are the average of three readings.

Charpy Test

The Charpy impact test was used to measure the fracture toughness of the steel. The test is conducted in normal room temperature using the impact testing machine (MFLD- 680) with a range of capacity 0- 300 Joules.

Metallography Examination

Sample preparation of metallography examination, metallographic samples were ground by the abrasion of the specimen surface against water lubricated abrasive wheels (silicon carbide papers changing from “120 to 1200 girt emery paper”).

After grinding, the polishing process was done by the use of the rotary disk with diamond paste. Polishing should yield a scratch free specimen surface. Then, the etching operation was done with the 2% nital solution (2%nitric acid solution in 98% ethylalcohol). Microstructural examination was carried out using OLY MPAS Microscope as shown in Figure. 3.

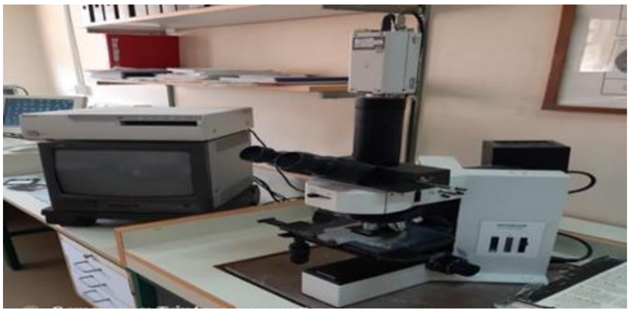

Figure.3, Oly Maps Microscope.

Volume fraction of martensite

The systemic Point Count Method is the suggested technique utilized in this investigation to determine the volume fraction. This technique involves selecting an appropriate array of points, placing it over the specimen, counting points that fall on the chosen phase, repeating with a new array, and continuing until the desired accuracy is achieved. In this work, we opt to use an 81-point grid (9 x 9) for the whole range of volume fractions. A test grid is a transparent sheet made up of a specific number of evenly spaced points generated by the intersection of very thin lines (square array). Make sure the magnification is set as high as necessary to resolve the microstructure clearly without creating.

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The number of test points that fall within the phase or constituent of interest is counted and divided by the total number of grid points, producing a point fraction—typically given as a percentage—for that field. A test grid with a regular array of test points is superimposed over the image. The volume percent of the constituent points in the test grid can be estimated from the average point fraction for n measured fields.

$$P_P\,(i) = \left(\frac{Pi}{P_T}\right) X\,100 \qquad (1)$$

where, P_P is the percentage of grid points in the field-observed constituent.

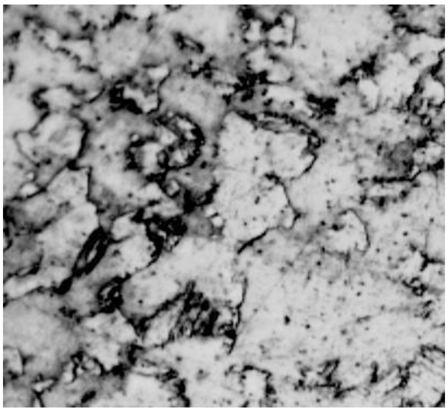
P_T is the test grid's total amount of points.

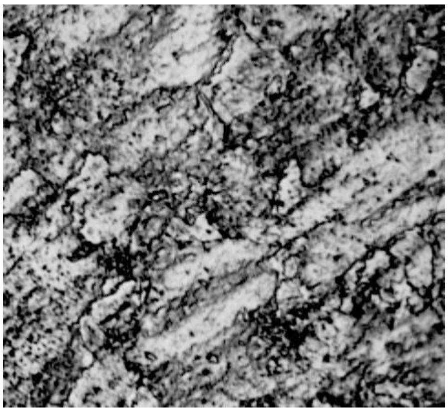
Pi is the field's point count.

i is the number of fields counted [9].

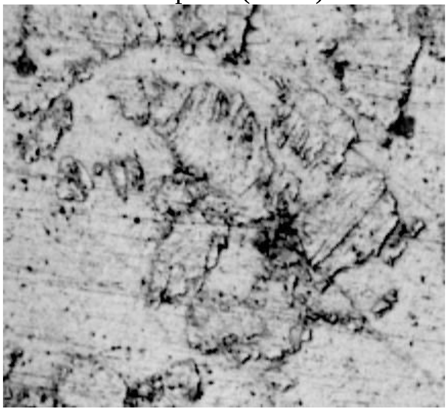
Results and Discussion

Figure 4 shows the microstructure of all specimens. Generally, ferrite and martensite are present in varying percentages across specimen microstructures.


Sample 1(100X)


Sample 2 (100X)


Sample 3 (100X)


Sample 4(100X)

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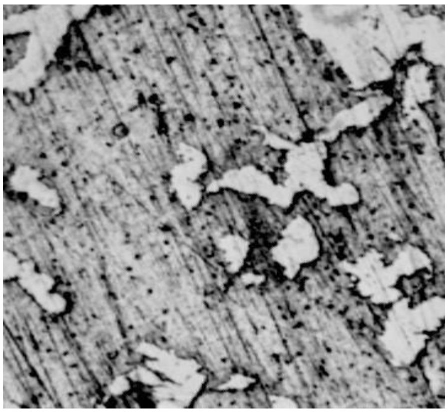

Sample 5(100X)

Figure 4. Microstructure for Dual phase steel.

Lis et al. (2005) demonstrated that low-carbon steel could achieve a dual-phase ferritic-martensitic structure through controlled rolling or intercritical annealing, provided that pearlite formation is suppressed [10]. Elements such as Cr and Mo aid this transformation by promoting martensite and inhibiting pearlite. This study confirms that heat treatments within the austenite-ferrite phase fields can effectively produce DP steel microstructures with adjustable martensite content, aligning with Lis et al.'s findings. By using intercritical annealing to achieve stable ferritic-martensitic structures, this research supports and builds on the principle that precise heat treatment optimally stabilizes DP phase composition.

The mechanical properties of dual-phase steel depend on the chemical composition, carbon content, and volume fraction percentage. The recorded of the hardness test, impact test and volume fraction for the 5 heated samples are shown in the Table 3.

Table 3: show result of the mechanical properties of the samples were used in this work

Sample	1	2	3	4	5
Hardness Test	158	180	186	232	202
Impact Test	10	20	23	52	34
Volume fraction	32.088875	40.11125	40.118	27.467	24.959

The result shows that as the temperature increases the strength and the hardness increases as well.

During the heat treatment and annealing process, the ferrite grans and martensite were formed which has a direct relation with the volume fraction value.
Previous work by Shahverdi et al. (2021) have shown a direct relationship between higher martensite volume fractions and improvements in hardness and yield strength in DP steels [11]. The findings of the current study are consistent with this pattern, demonstrating that increased martensite fractions result in elevated hardness and impact toughness values, reflecting the strengthened properties of DP steel. For instance, this study observed that

samples with higher martensite percentages (e.g., up to 50%) achieved significantly greater hardness and impact resistance, supporting the notion that martensite presence enhances the steel's overall mechanical robustness.

This research also highlights that increasing intercritical annealing temperatures leads to a higher martensite fraction and reduced ferrite content. This trend is consistent with findings by Pritchard and Trowsdale (2002), which report that higher annealing temperatures shift the ferrite-martensite balance towards martensite, thereby enhancing hardness [7]. However, this shift can reduce ductility, reflecting a potential trade-off between strength and flexibility in DP steels. Such consistency in results underscores the importance of temperature control in tailoring DP steel properties to specific application needs.

Conclusion

This work focused on examining the behavior of dual-phase (DP) steel with varying martensite volume fractions ranging from 20% to 50%, achieved through intercritical annealing and rapid quenching. Hardness and impact tests were conducted to analyze the effects of these heat treatments on DP steel's microstructure and mechanical properties. Key findings include:

- Heat treatment processing directly impacts the microstructure and mechanical properties of DP steel. Adjusting intercritical temperatures and cooling rates effectively controls the balance between ferrite and martensite, allowing for the precise tuning of steel properties.
- The rapid cooling process facilitates the transformation of austenite to martensite, resulting in lower ferrite content and higher martensite fractions. This transformation is crucial for achieving desirable mechanical characteristics, such as increased hardness and improved impact resistance.
- The results indicate that the best combination of hardness and impact toughness occurs within a martensite volume fraction range of 32%–40%, offering a favorable balance between strength and toughness.

This study underscores the importance of controlling heat treatment parameters, particularly intercritical annealing temperatures and cooling rates, to tailor DP steel for applications requiring specific mechanical strengths, such as those in the automotive and aerospace industries. By demonstrating how systematic adjustments to these parameters allow for a refined balance of toughness and hardness, the research expands the field's understanding of DP steel optimization. This study's findings provide a comprehensive dataset and valuable insights into the effects of microstructural manipulation on DP steel, contributing to both existing literature and practical applications. The demonstrated fine-tuning of martensite volume in DP steels offers a novel approach to enhancing both hardness and impact resistance, paving the way for advanced engineering applications.

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In conclusion, this research extends the knowledge of heat treatment effects on DP steels by providing clear evidence that incremental adjustments in martensite volume via intercritical annealing and quenching can enhance mechanical performance. The study thus contributes a robust dataset that validates established principles while offering unique insights into mechanical tuning, positioning DP steels as a versatile material for high-performance applications.

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