International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-2240; ISSN(E): 2319-2259
Vol. 3, Issue 2, Mar 2014, 37-44

International Academy of Science, Engineering and Technology
IASET Connecting Researchers; Nurturing Innovations

THERMO-MECHANICAL PROCESSING OF CARBIDE FREE STEELS

MASOUD. I. M[1], JAWDAT A. AL-JARRAH[2], A. I. Z. FARAHAT[3] & ABU MANSOUR T[4]

[1]Department of Chemical and Material Engineering, Faculty of Engineering, Northern Border University, Arar, KSA

[1]On leave from Industrial Engineering Department, Faculty of Engineering, Fayom University, Al Fayoum, Egypt

[2,4]Department of Mechanical Engineering, Faculty of Engineering, Northern Border University, Arar, KSA

[3]Head, Department of Plastic Deformation, Central Metallurgical Research and Development Institute, Helwan, Egypt

ABSTRACT

Given their high energy absorption capacity and fatigue strength, hot formed Dual Phase (DP) Steels are particularly well suited for automotive structural and safety parts such as longitudinal beams, cross members and reinforcements. An ultrafine grained microstructure in DP steels was produced by use of large strain hot deformation and subsequent intercritical annealing. The suitable intercritical annealing parameters have been worked out by performing dilatometer tests. The final microstructure consists of fine martensite islands embedded in ferrite matrix. Microstructure evolution during intercritical annealing was investigated by means of scanning optical and electron microscopy (SEM). The study reveals that increasing the Al content from 0.89 to 1.92 mass% is highly beneficial for the formation of martensite.

KEYWORDS: Thermo, Mechanical Process, Free Carbide Steel, Al and Silicon Additions, Post Cooling Rates

INTRODUCTION

Dual Phase steels are high tensile strength steels. DP steels (Dual Phase steels) consist of 5-30% martensite “islets” in a ferrite matrix plus a few percents of bainite and retained austenite. They are used mainly in the automobile industry due its technical characteristics. Si and/Aluminum Bainitic steel is very promising class of steel, because it exhibits carbides free matrix or cementite particles [1, 2]. The cementite particles of bainitic steel deteriorate the mechanical properties where they work as a source of crack and voids nucleation. In the novel bainitic structures, the cementite precipitates can be avoided by addition of Silicon and/Aluminum [3]. Bainitic steel of free carbide matrix has excellent combination of high strength with good ductility and low cost [4, 5]. Automotive industry can use them especially for under-body suspension. The mechanical properties of carbide-free bainitic steels were found higher than those of high strength steels containing thin bainite and retained austenite. The microstructure of free carbide bainitic steel can be generated by quenching from the intercritical zone (between Ac1 and Ac3) to a certain temperature (400°C) followed by a simple isothermal holding treatment.

The strength of these steels is attributed to fine microstructure (relative fineness of bainite lathes) and high dislocation densities, whereas ductility was attributed to the film of retained austenite present in between the bainitic lathes [6-8]. The addition of silicon can prevent the detrimental effect of carbides by delaying their precipitation [9-11] and enhances the matrix to both crack initiation and propagation [12, 13]. Bainitic steel containing high carbon has good amounts of austenite, which has high carbon content and become more stable retained austenite [9].

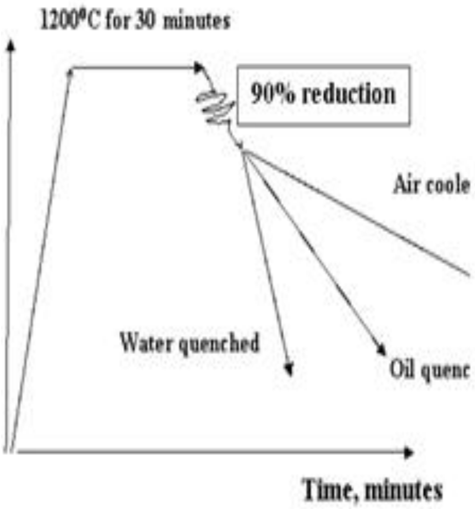
EXPERIMENTAL WORK

Casting 100kg of steel with different alloying element in open air induction furnace was carried out. The yield metal was made in Y-block shapes of 40mm thickness. The chemical composition is listed in **Table 1**.

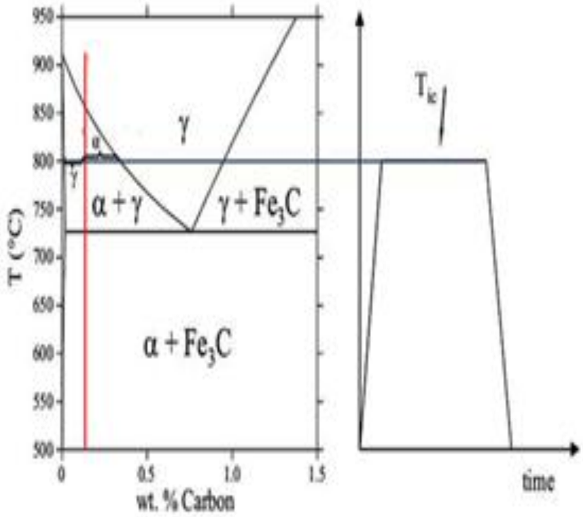
Table 1: Chemical Composition of Alloy Steel 1 and 2, wt%

Alloy	C	Si	Mn	P	S	Cr	Al	Cu
1	0.468	1.99	1.53	0.0404	0.0169	0.863	0.893	0.127
2	0.393	1.78	1.47	0.0386	0.0155	0.938	1.920	0.128

Machining and cutting preparation for hot forging process was carried out. Dilatation curve was measured to detect the different transformation temperature such as AC1, AC3, Bs, Bf and martensite transformation. Thermo-mechanical process was carried out at 1200°C as shown in **Figure 1**. A cross-section area reduction of 95% was done using hot forging. Post different cooling rates were applied after hot forging to study the different micro-structure. Microstructure was observed using optical and SEM microscope. Tensile and hardness tests were carried out.



(a)



(b)

Figure 1: (a) Thermo-Mechanical Process of Free-Carbide Steel,
(b) Intercritical Annealing Process for Dual Phase Steel

RESULTS AND DISCUSSIONS

Dilatation Behavior

Figure 2 shows the dilatation behavior of alloy 1 and 2. It is apparent that, the materials exhibits degradation at 1135 and 1125°C for alloy 1 and alloy 2 respectively. It is clear that the transformation temperatures Ac1 and Ac3 little bit shifted up due to increasing the aluminum content. To explore the bainite transformation temperature, the first derivative curve was conducted as seen in **Figure 3** for both alloys 1 and 2. It is also obvious that bainite transformation zone is approximately identical.

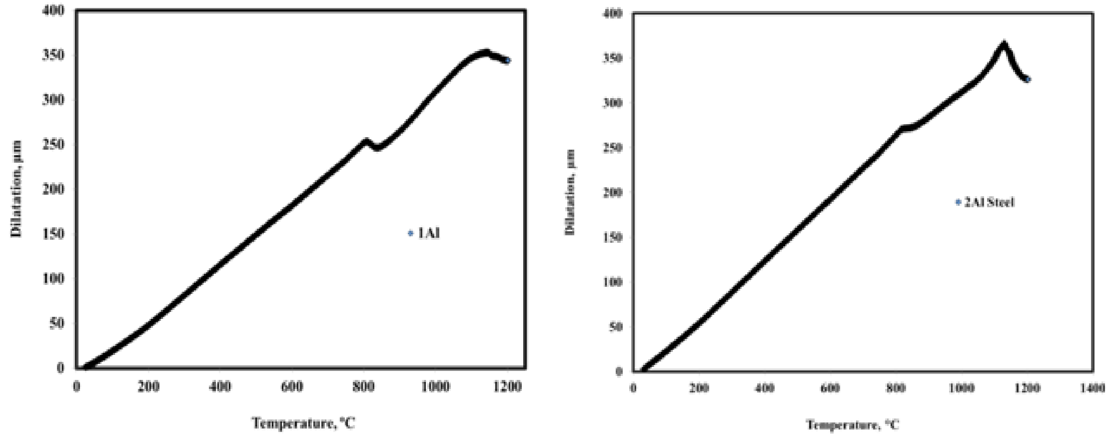


Figure 2: Total Dilatation Behavior of Alloy 1 and Alloy 2

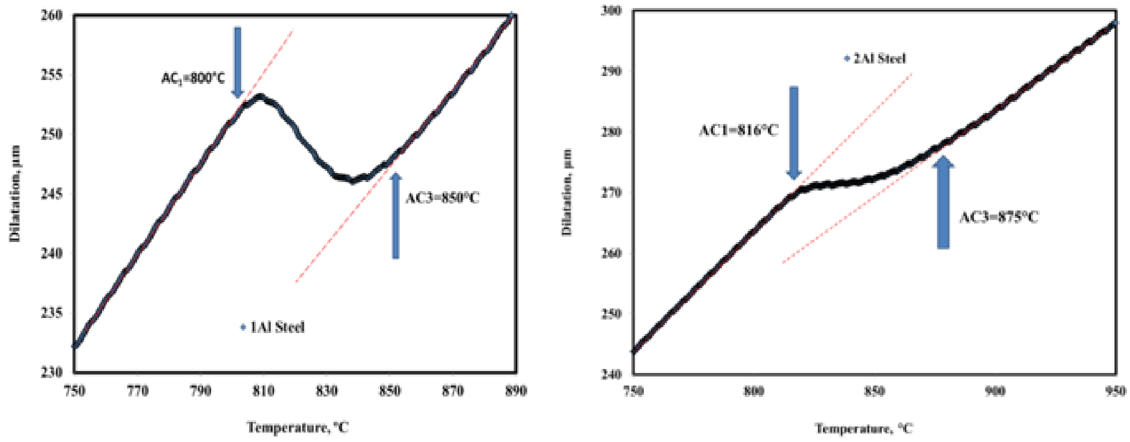
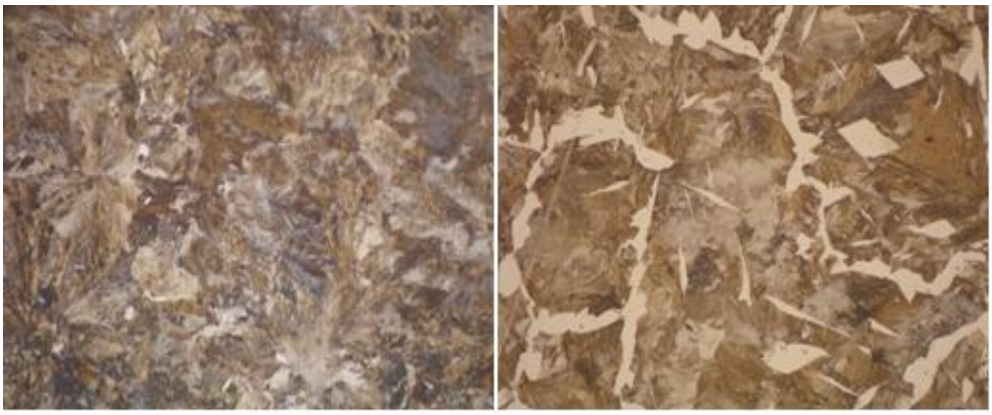


Figure 3: Critical Transformation Temperature AC1 and AC3

Microstructure of as Cast Dual Phase Steel

Optical micrograph for alloy 1 and 2 is shown in **Figure 4**. Microstructure of as cast steel alloy 2 reveals remarkable difference compared with that for alloy 1. The main difference between alloy steel 1 and 2 is that steel 2 contains 2% Aluminum compared with 1% Aluminum of steel 1. **Figure 4 (a)** of alloy 1 consists of ferrite-pearlite and very few amount of ferrite on the grain boundary. While alloy 2 consists of ferrite-pearlite and a lot of ferrite on the grain boundaries as shown in **Figure 4 (b)**.

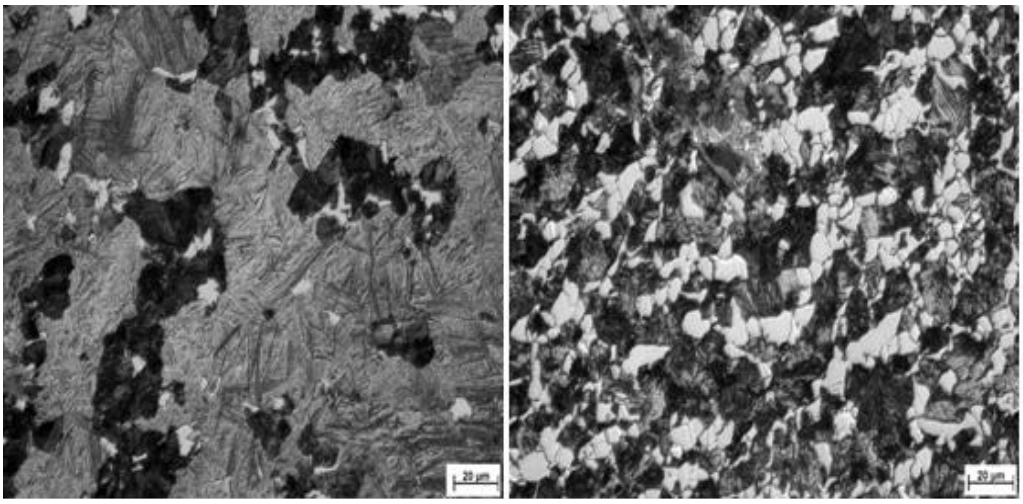


(a) **(b)**

Figure 4: Microstructure of as Cast Steel (a) Alloy 1 (b) Alloy 2, X100

Microstructure of Hot Forged Dual Phase Steel

Steels 1 and 2 were hot forged at temperature of about 1200°C followed by air cooling. Microstructure of these steels is shown in **Figure 5.** Alloy 1 shows matrix of bainite with pearlite and traces of ferrite, on the other hand steel Alloy 2 reveals ferrite-pearlite matrix. This increase of ferrite in Alloy 2 is due to the higher amount of Aluminum content which acts as ferrite forming element.



(a) (b)

Figure 5: Microstructure of Hot Forged Air Cooled Steel, (a) Alloy 1 (b) Alloy 2, X100

Tensile Strength

The tensile behavior of both alloys 1 and 2 is presented in **Figure 6** and the work-hardening coefficient (n) is presented in **Figure 7**. It is clear that the maximum tensile strength is 1063MPa for alloy 1 and the maximum tensile strength for alloy 2 is 944MPa. The work-hardening coefficient is about 0.25 for alloy 1 and 0.23 for alloy 2 due to Aluminum increasing. Also it is found that the ductility increases with increasing the aluminum content which encourages the ferrite phase.

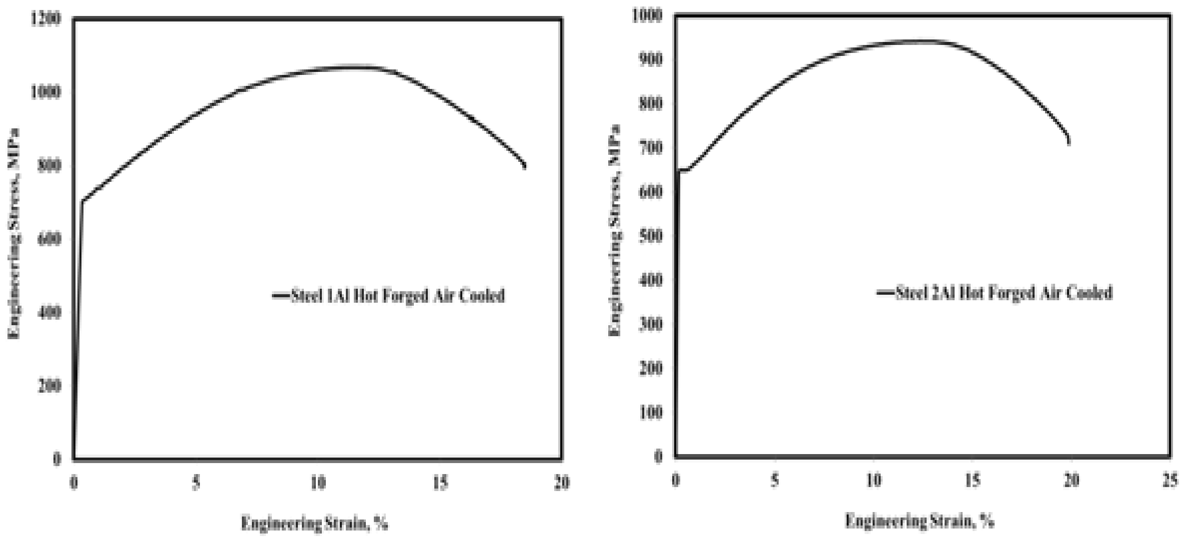


Figure 6: Engineering Stress-Strain Curve for Alloy 1 and Alloy 2 after Hot Forging

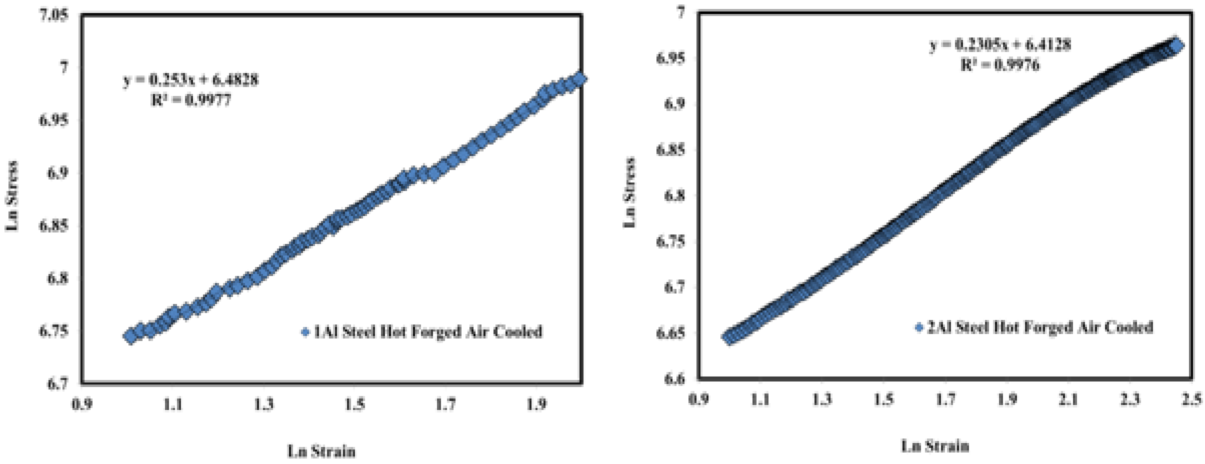
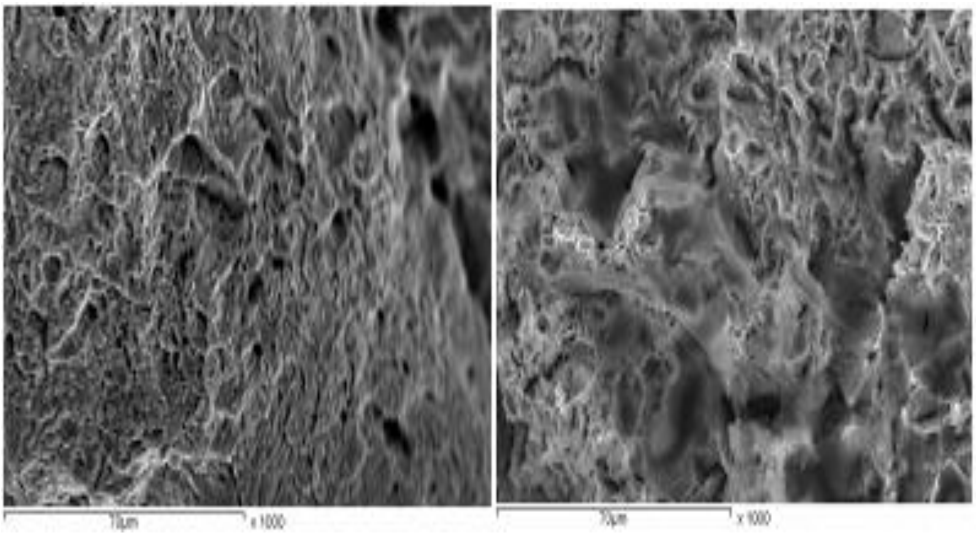


Figure 7: Work-Hardening Coefficient of Both Alloys 1 and 2

Fracture Surface of Steel Alloys 1&2

Figure 8 (a) is Fractography of hot forged air cooled steel Alloy 1 which shows dimple fracture which means ductile fracture.



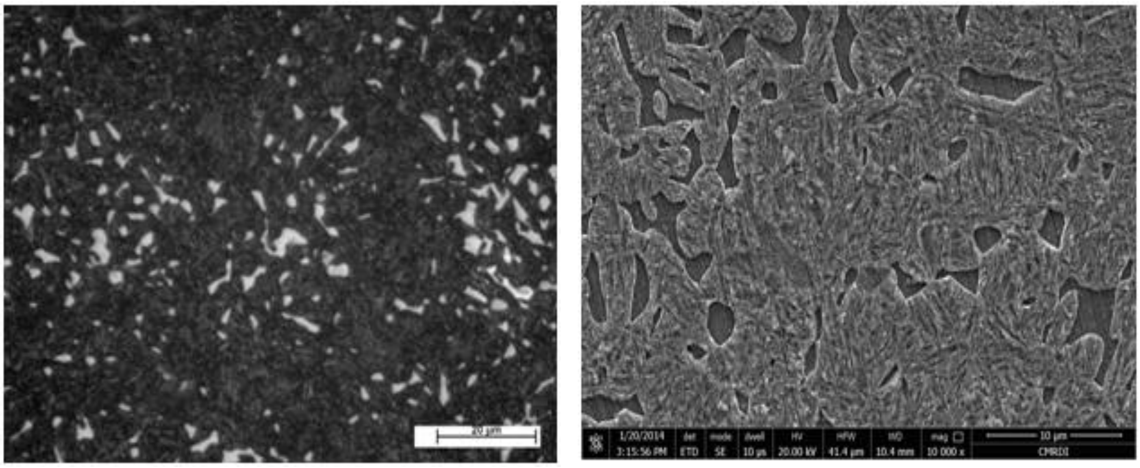
(a) **(b)**

Figure 8: (a) Fractography of Hot Forged Air Cooled Alloy 1 (b) Fractography of Hot Forged air Cooled Alloy 2

On the other hand, Fractography of hot forged air cooled steel Alloy 2 in **Figure 8(b)** shows partially dimple fracture which means ductile-brittle fracture.

Dual Phase Treatment

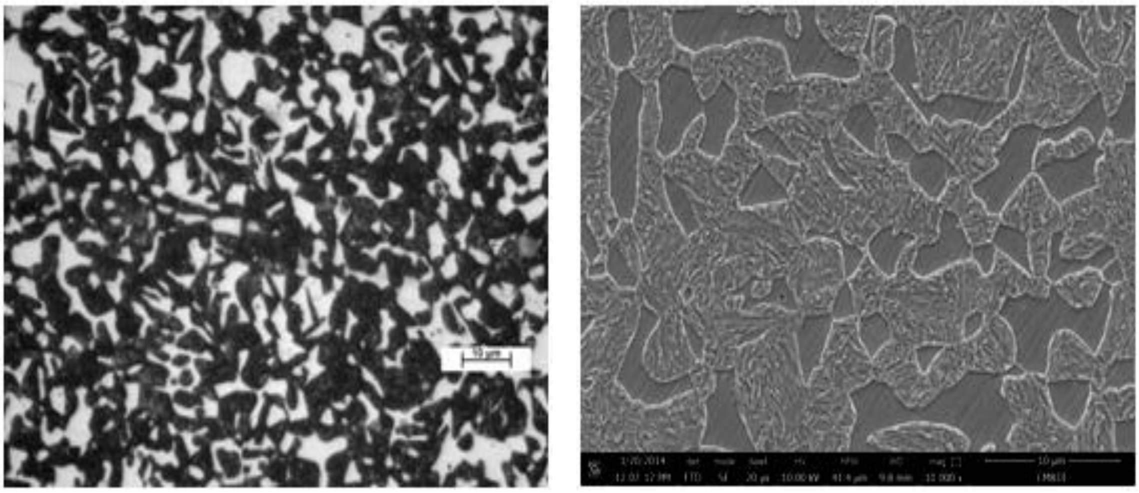
The microstructure of Alloy 1 shows the different constituents after heating in the intercritical zone at 825°C for 25min and water quenching. It seems clear that the microstructure consists of Ferrite and bainite (**see Figure 9**).



a) Optical Microstructure **b) SEM Micrograph**

Figure 9: Alloy 1 Hot Forged Air Cooled + Heating upto 825°C for 25min, then Water Quenched

The microstructure of Alloy 2 shows different constituents after heating in the intercritical zone at 845°C for 25min and water quenching. It seems clear that the microstructure consists of Ferrite and bainite (**see Figure 10**). The amount of ferrite increases due to increasing of Al content.



a) Optical Microstructure **b) SEM Micrograph**

Figure 10: Alloy 2 Hot Forged Air Cooled + Heating upto 845°C for 25min, then Water Quenched

Mechanical Properties

The tensile strength decreases with increasing Al content except for alloy 1 where it suffers from the non-metallic inclusions as shown in **Figure 11**. It is noticed that the intercritical temperature increases from 825 to 850°C by increasing Al content from about 1 to 2% (alloy 1 and 2 respectively). After annealing at 850°C, steel alloy 2 of 2%Al reveals higher tensile strength compared with that of alloy1 (1%Al). On the other hand, tensile strength shows slight increase with increasing Aluminum content as shown in **Figure 11**.

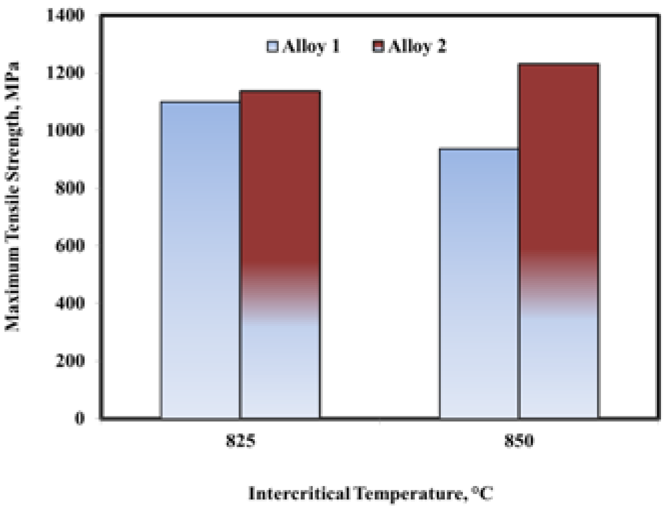


Figure 11: Effect of Intercritical Annealing Temperature on the Tensile Strength

CONCLUSIONS

The results of this work can be summarized as

- The transformation temperatures Ac1 and Ac3 little bit shifted up due to increasing the aluminum content.
- Steel microstructure remarkably affected by the aluminum content.
- Hot forged steel at temperature of about 1200°C followed by air cooling shows matrix of bainite with pearlite and traces of ferrite for low aluminum content steel, on the other hand reveals ferrite-pearlite matrix with higher amount of Aluminum content.
- Tensile strength decreases with increasing aluminum content due to ferrite formation.
- The study reveals that increasing the Al content from 0.89 to 1.92 mass% is highly beneficial for the formation of martensite.

ACKNOWLEDGEMENTS

Author would like to express their sincere gratitude and thanks to deanship of research in Northern Border University for their supporting and help.

REFERENCES

1. Mohammad Reza Akbarpour, A. Ekrami: Effect of ferrite volume fraction on work hardening behavior of high bainite dual phase (DP) steels, Materials Science and Engineering A 477 (2008) 306–310.
2. Fukuoka Kazuaki TOMITA Kunikazu SHIRAGA Tetsuo, Examination of Surface Hardening Processfor Dual Phase Steel and Improvement of Gear Properties, JFE Technical Report No. 15 (May 2010).
3. J. Adamczyk, A. Grajcar, Heat treatment and mechanical properties of low-carbon steel with dual-phase microstructure, Journal of Achievements in Materials and Manufacturing Engineering, Volume 22, Issue 1, May 2007.

4. Ranbir Singh Jamwal, Microstructural Origins of Variability in The Tensile Ductility of Dual Phase Steels, Master thesis , Georgia Institute of Technology, May 2011.
5. Anand Prakash Modi, Effects of microstructure and experimental parameters on high stress abrasive wear behaviour of a 0.19wt% C dual phase steel, Tribology International 40 (2007) 490–497.
6. Jinbo Qua, Wael Dabboussi, Farid Hassani, James Nemesb, Steve Yue, Effect of microstructure on the dynamic deformation behavior of dual phase steel, Materials Science and Engineering A 479 (2008) 93–104.
7. Xuan Liang, Jun Li, YingHong Peng, Effect of water quench process on mechanical properties of cold rolled dual phase steel microalloyed with niobium, Materials Letters 62 (2008) 327–329.
8. Kyong Su Park, Kyung-Tae Park, Duk Lak Lee, Chong Soo Lee, Effect of heat treatment path on the cold formability of drawn dual-phase steels, Materials Science and Engineering A 449–451 (2007) 1135–1138.
9. Fatih Hayat, Huseyin Uzun, Effect of Heat Treatment on Microstructure Mechanical Properties and Fracture Behaviour of Ship and Dual Phase, Journal of Iron and Steel Research, International. 2011, 18(8): 65-72.
10. R. Khondker a, A. Mertens b, J.R. McDermidb, Effect of annealing atmosphere on the galvanizing behavior of a dual-phase steel, Materials Science and Engineering A 463 (2007) 157–165.
11. Aydin Huseyin, Kazdal Zeytin Havva, Kubilay Ceylan, Effect of Intercritical Annealing Parameters on Dual Phase Behavior of Commercial Low-Alloyed Steels, Journal of Iron and Steel Research , International. 2010. 17(4): 73-78.
12. Mohammad Reza Akbarpour, A. Ekrami, Effect of temperature on flow and work hardening behavior of high bainite dual phase (HBDP) steels, Materials Science and Engineering A 475 (2008) 293–298.
13. E. Ahmad, T. Manzoor, N. Hussain, N.K. Qazi, Effect of thermomechanical processing on hardenability and tensile fracture of dual-phase steel, Materials and Design 29 (2008) 450–457.