April 2013

FINE GRAINED DUAL PHASE STEEL BY THERMO MECHANICAL PROCESSING

NEERAJ AGARWAL

Department of Metallurgical and Materials Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India, neerajagrawal88@yahoo.com

G.P. CHAUDHARI

Department of Metallurgical and Materials Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India, chaudfmt@iitr.ernet.in

Follow this and additional works at: <https://www.interscience.in/ijarme>

Part of the [Aerospace Engineering Commons](#), and the [Mechanical Engineering Commons](#)

Recommended Citation

AGARWAL, NEERAJ and CHAUDHARI, G.P. (2013) "FINE GRAINED DUAL PHASE STEEL BY THERMO MECHANICAL PROCESSING," *International Journal of Applied Research in Mechanical Engineering*: Vol. 2: Iss. 4, Article 3.

DOI: 10.47893/IJARME.2013.1092

Available at: <https://www.interscience.in/ijarme/vol2/iss4/3>

This Article is brought to you for free and open access by the Interscience Journals at Interscience Research Network. It has been accepted for inclusion in International Journal of Applied Research in Mechanical Engineering by an authorized editor of Interscience Research Network. For more information, please contact sritampatnaik@gmail.com.

FINE GRAINED DUAL PHASE STEEL BY THERMO MECHANICAL PROCESSING

NEERAJAGARWAL¹, G.P.CHAUDHARI², S.K. NATH³

^{1,2,3}Department of Metallurgical and Materials Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

E-mail: neerajagrawal88@yahoo.com, chaudhmt@iitr.ernet.in

Abstract- The effect of thermo mechanical processing (TMP) on the mechanical properties of HSLA steel was investigated. TMP was conducted using a laboratory open die forging machine. Multiaxial forging (MAF) and intercritical annealing methods were used. TMP is designed to obtain ultrafine grained (UFG) steels. MAF is performed on prismatic shaped samples up to nine strain forging steps to produce ultra-fine grained (UFG) ferrite-pearlite steel with higher strength as compared to as received steel. Fine grained (FG) ferrite-martensite dual phases (DP) steel was fabricated by using combined effect of warm MAF and intercritical annealing. The tensile strength of FG-DP steels was much higher than that of the coarse-grained (CG) counterpart, and the uniform elongations were significantly enhanced. This steel exhibited the superior combination of higher strength and more rapid strain hardening compared to those of CG-DP steel was explained in terms of their specific microstructural features.

Keywords- Thermo mechanical processing, Multi axial forging, ultrafine grained, coarse grained, severe plastic deformation, Dual phase.

I. INTRODUCTION

Thermo mechanical Processing (TMP) involves both thermal and mechanical Process that defines product shape, microstructure and properties. By understanding the metallurgical refinement occurring during TMP, the microstructure of the steel can be modified for the benefit of the final product properties and application [1]. Addition of micro-alloy (carbide, nitride or carbo-nitride forming elements) such as Nb, V, Ti in structural steel and strip steel grades, the materials are known as High Strength Low Alloy (HSLA) steel [1-2]. HSLA steels containing additions of Nb, Mo, V, and Ti exhibit superior strength at elevated temperatures when compared to plain carbon steels. Nb, Ti provides grain refinement and forms NbC, TiC, TiN precipitates that give extra strength [2-3]. DP steels are widely used in automobile component such as car body panels, wheels, bumpers etc. [4]. The demand to produce automobiles which fulfill the requirements like, passenger safety, vehicle performance and fuel efficiency, has become the biggest challenge faced by the steel industry. In response the steel industry has developed advanced high strength steels (AHSS) including (DP), transformation induced plasticity (TRIP) and martensitic steels (MART) [2, 4]. These steels are characterized by improved formability and crash worthiness compared to conventional steel grades, such as pearlitic steels [2, 5]. Currently, AHSS steels are extensively used in the auto industry and the problem is that the weight percentage of AHSS steel will increase to 35% by 2015, whereas mild steel will decrease to 29% (in 2011) in bodies and closures of light vehicles [2, 5]. The increased use of the AHSS in the automotive industry are due to the

reduction of the car weight resulting from the use of high strength thinner steel, reducing the fuel consumption, Increased passenger safety by an improved crash worthiness [2, 6]. DP steel consists of a hard phase, typically martensite dispersed in a soft ferrite matrix obtained by intercritical annealing [6-7]. Martensite is a supersaturated solid solution of carbon in ferrite with body-centered tetragonal (bct) crystal structure. DP steels have attractive mechanical properties like low yield ratio, high ultimate tensile strength, high initial work hardening rate, good uniform elongation for a given ultimate tensile strength (UTS) and they also have good crash worthiness [4-8].

The severe plastic deformation (SPD) techniques allows for the grain size of metallic materials to be easily refined to the submicron level, to form the so-called UFG materials [9-10]. UFG materials are defined as materials in the bulk form having fully homogeneous and equiaxed microstructure with average grain sizes less than 1 μm and with a majority of the grain boundaries having high angle of misorientations [9]. UFG materials are quite attractive due to their ultrahigh strength, which is more than twice that of their coarse grained counterparts [9-10]. Industrially, DP steels are fabricated by two processing routes: either intercritical annealing of cold-rolled steels or hot-rolling followed by fast cooling [8]. The cold-rolled ferrite pearlite microstructure is heated to the intercritical temperature range where both ferrite and austenite coexist. The austenite formed is then rapidly cooled to room temperature to transform into martensite [8, 10]. The hot-rolling process takes place in the austenitic region [8]. The hot-rolled steel is subsequently cooled into the ferrite-austenite

temperaturerange where desired fraction of ferrite is formed. This is followed by an accelerated coolingstep such that the remaining austenite transforms to martensite.

In this work, HSLA steel is treated in order to obtain various microstructures and mechanical properties. Treatment involved severe plastic deformations by multi-axial forging followed by intercritical annealingto obtainFG ferrite–martensite DP steels. Then, tensile and hardness properties were compared to those of a coarse grained DP steel prepared by the identical intercritical annealing with and without warm MAF.

II. EXPERIMENTAL PROCEDURES

The HSLA low carbon steel used in the present Experiment are procured in the form of plates of thickness 20 mm manufactured by Steel Authority of India Limited (SAIL). The chemical composition is listed in Table I. Dimensions of the steel specimens used for warm MAF were in the ratio 1.5:1.22:1.0.

The as-received plates of thickness 20 mm were machined into prismatic shaped samples of size 30 mm×24.4 mm×20 mm. Forging was performed at a strain rate of about 10 s^{-1} using a friction screw forging press of 10^6 N capacity. Samples were heated in a muffle furnace at 500°C and after a furnace holding time of 50 minutes they were alternately forged, with loading direction changed through 90° (i.e. X-Y, Y-Z, Z-X) as shown in Fig.1. The samples were quickly cooled in water after each MAF strain step. Forging strain of $\varepsilon = -0.4$ was applied to the longest side at each MAF strain step. In addition, grain refinement and the corresponding strength increases and become almost saturated by an accumulated strain of almost -3.6 . Assuming volume conservation and material isotropy, this procedure enables the initial dimensional ratio to be maintained at the end of each pass. Graphite powder was used for lubrication of flat die surfaces during open die forging. At large strains, use of graphite lubrication causes relatively homogeneous deformation. After each strain step a small bulgedvolume was Grind off to get enough flatness so that the specimen could be stably positioned under theforging press for applying subsequent forging

Strain step. Up to 9 strain steps were performed in this work. Before and After 6 and 9warm MAF pass from forge sample test coupons are made of size 25 mm×12 mm×1 mm (length ×width× thickness) with the help of diamond cutter that test coupons are used for making of FG DP steel in vertical tubular furnace with Intercritical annealing of 745°C for 2min followed by water quenching. Test coupons are intercritically annealed in the heating zone of tubular furnace with the help of wire for required time and then wire is cut so that test coupons will quench rapidly in water at base of tubular furnace.

Figure 1. Schematic diagram showing the principle of MAF. Longest side converts into shortest side after each forging step.

For optical microscopy, Leica DMI 5000M microscope was used. The grain size of deformed ferrite, pearlite and martensite were measured by linear average intercept method. Hardness Tests were performed using a FIE-VM50 PC Vickers hardness tester by employing 10 kg load with dwell time of 15s. At least six hardness readings were taken and the average is reported along with standard deviation. For tensile test Tinius Olsen H25 K-S tensile testing machine was used. Room temperature tensile tests were performed at constant cross head speed of 0.5 mm/min on small size samples with 13 mm gauge length and total length of 24 mm. The width and thickness were 3 mm and 1 mm, respectively.

III. RESULTS AND DISCUSSIONS

A. MICROSTRUCTURE

Table I. Chemical composition of the steel obtained by spark emission spectroscopy (Values in wt %)

Elements	C	Mn	Si	P	S	Nb	Ti	V	Fe
wt %	0.13	1.52	0.28	0.028	0.009	0.05	0.052	0.004	Balance

Microstructure of metals, affected by various processing conditions, is revealed by metallography. In the present work, microstructural evolution after different MAF strain steps was studied using opticalmicroscopy. The microstructure characteristics of DP steels are primarily determined by not only the intercritical annealing conditions but also at the starting microstructure before intercritical annealing. Before intercritical annealing optical microstructures of HSLAsteel before and after Warm MAF are shown in Fig. 2. The microstructure before Warm MAF is consisted of approximately 20 vol % pearlite (dark patches) indicated by arrow with the remainder ferrite (white) as shown in Fig. 2a. After warm MAF, pearlite colonies were deformed and become into smaller ones with very irregular shapes indicated by arrow in Fig. 2b&c. Macroscopically, this resulted in a decrease of inter-pearlite colony spacing. After six warm MAF strain steps pearlite is broken into cementite and fine ferrite is observed in Fig. 2b. After nine MAF strain steps more fine substructures are seen with the ferrite and pearlite is fragmented and dispersed in the ferrite matrix and appears to be as carbide particle as shown in Fig. 2c. The grain size of deformed ferrite was found to be $1.23 \mu\text{m}$ after nine MAF forging steps as compared to as-received steel of $3.1256 \mu\text{m}$. similar results have been reported,

during the refinement of grain structure in plain low carbon steel under multiaxial compression [9, 11]. After intercritical annealing, the microstructure changed into two phase region in which one is hard martensite and other is soft ferrite. Martensite is formed from pearlite due to rapid quenching. Microstructures of CG-DP and FG-DP steels are shown in Fig. 3. As similar to conventional DP steels prepared by intercritical annealing, the two main types of martensite morphology were observed in CG-DP steel Fig. 3(a): (i) intercritical annealing, martensite residing at the former pearlite colonies and (ii) large volumes of martensite transformed from austenite which was formed by pearlite decomposition. By contrast, under the identical intercritical annealing conditions, the microstructure of FG-DP steel (Figs. 3(b, c)) consisted of equiaxed FG ferrite and uniformly distributed feathery martensite indicated by arrow. Due to fine ferrite and feathery martensite FG-DP have higher mechanical properties as martensite give higher strength and hardness and fine ferrite give higher crash worthiness. In addition, the martensite sites were not confined to the former pearlite colonies or irregular martensite networks were seen along the ferrite boundaries which are due to the manganese segregation rather than pearlite decomposition [4, 12].

Figure 2. Optical micrographs of HSLA steel before and after warm MAF (a) before warm MAF (b) after 6 warm MAF steps and (c) after 9 warm MAF steps.

Figure 3. Optical micrographs of Dual phase steel before and after warm MAF at 745o C × 2 min. (a) DP before warm MAF

(b) DP after 6 warm MAF steps and (c) DP after 9 warm MAF steps.

Variation of Vickers hardness with the processing condition of HSLA steel is shown in Table II. Hardness increases with increase in the number of MAF strain steps and DP treatment. As compared to the as-received HSLA steel, the hardness increased by about 37% after six MAF strain steps and further increased by only about 5.5% between six and nine MAF strain steps specimens. After intercritical annealing of as received steel hardness increased to 320 VHN of CG-DP, i.e. there is an increase of about 70.2 % as compared to the as-received steel. The increase of about 3% is observed for 9 warm MAF DP specimens as compared to 9 warm MAF specimens. Fig. 4 showing the Engineering stress-Engineering strain curves for HSLA CG- DP and FG-DP after 9 MAF strain steps. FG-DP has high strength as compared to CG-DP due fine grained ferrite and feathery martensite. It is clear that the

Table II. Shows the variation of hardness value of different thermo mechanically processed steels

HSLA steel Processing conditions	Hardness, VHN
As-received steel specimens	185±2.139
After 6 warm MAF strain steps specimens	255±2.252
After 9 warm MAF strain steps specimens	269±2.351
As-received HSLA DP specimens	318±5.105
After 6 warm MAF DP specimens	342±4.065
After 9 warm MAF DP specimens	350±5.023

tensile strength also follows the same pattern as the hardness. This proved that FG-DP have higher strength and comparable hardness as compared to CG-DP. The increase in tensile strength of FG-DP steel after 9 MAF strain steps (1169 MPa) is 27 % as compared to CG-DP HSLA steel (924 MPa). Similar observations have been result in the mechanical properties of dual phase steel by inter critical annealing [6, 12].

Figure 4. Showing the Engineering stress-Engineering strain curves for HSLA CG-DP and FG-DP after 9 MAF strain steps.

IV. CONCLUSIONS

1. Ultimate tensile strength reaches maximum value of (1169 MPa).

2. Ultrafine grained ferrite-pearlite steels were fabricated by warm MAF with a strain of 0.4 at 500°C.
3. Fine grained ferrite-martensite DP steels were fabricated by subsequent inter critical annealing of 745°C for 2 min followed by water quenching. Under these processing conditions, the microstructure of DP steels consisted of FG ferrite with uniformly distributed feathery martensite.
4. The strength and hardness of FG-DP steels was much higher than that of their coarse-grained counterpart due to FG ferrite and larger martensite volume fraction.
5. Tensile test confirm the formation of DP steel because the yield point is absent.

REFERENCES

- [1] D. Nakhaie, P.H. Benhangi, M. Mazinani, F. Fazeli, M.R.G. Ferdowsi, "Thermo mechanical Processing of a Nb-Micro alloyed Steel in a Controlled-Forging Treatment," *Advanced Materials Research*, vol. 409, pp. 835-840, Nov. 2012.
- [2] P. Tsipouridis, E. Werner, C. Krempaszky, E. Tragl, "Mechanical Properties of Dual-Phase steel," *Steel Res. International*, vol. 77, pp. 654-667, June 2006.
- [3] R. Soto, W. Saikaly, X. Bano, "Precipitates in Dual-Phase steel micro alloyed With Titanium and Their Effect on Mechanical Properties," *Acta Materialia*, vol. 47, pp. 3475-3481, June 1999.
- [4] L. Gao, Y.M. Zhou, J.L. Liu, X.D. Shen, Z.M. Ren, "Effect of water quenching process on the microstructure and magnetic property of cold rolled dual phase steel," *Journal of Magnetism and Magnetic Materials*, vol. 322, pp. 929-933, Nov. 2010.
- [5] R. Song, D. Ponge, D. Raabe, "Processing microstructure and mechanical properties of ultrafine grained bcc steels," *Materials Science and Engineering A*, vol. 441, pp. 1-17, Aug. 2006.
- [6] P. Deb and M. C. Chaturvedi, "Influence of thermo mechanical treatment on the structure-property relationship of a microalloyed dual-phase high strength, low alloy steel," *Materials Science and Engineering*, vol. 78, pp. 7-13, Oct. 1986.
- [7] J.F. Caseiro, J.A. Oliveira, A. Andrade-Campos, "Thermo mechanical modeling strategies for multiphase steels," *International Journal of Mechanical Sciences*, vol. 53, pp. 720-733, June 2011.
- [8] H. Azizi-Alizmini, M. Militzer, W.J. Poole, "Formation of Ultrafine Grained Dual Phase Steels through Rapid Heating," *ISIJ International*, vol. 51, pp. 958-964, Mar. 2011.
- [9] A.K. Padap, G.P. Chaudhari, S.K. Nath, V. Pancholi, "Ultrafine-grained steel fabricated using warm multiaxial forging: Microstructure and mechanical properties," *Materials Science and Engineering A*, vol. 527, pp. 110-117, Aug. 2009.
- [10] K. T. Park, S.Y. Han, "Ultrafine grained dual phase steel fabricated by equal channel angular pressing and subsequent intercritical annealing," *Scripta Materialia*, vol. 51, pp. 909-913, June 2004.
- [11] D.H. Shin, K.T. Park, "Ultrafine grained steels processed by equal channel angular pressing," *Materials Science and Engineering A*, vol. 410, pp. 299-302, Feb. 2005.
- [12] Y. Son, Y.K. Lee, "Ultrafine grained dual phase steel fabricated by equal channel angular pressing and microstructure and mechanical properties," *Acta Materialia*, vol. 53, pp. 3125-3134, Feb. 2005.