Effect of Intercritical Annealing on the Mechanical Behaviour of Steels- A Review

Mandeep Singh[1]

[1]Department of Mechanical Engineering, Lovely Professional University.

Abstract - Intercritical Heat treatment (IHT) of materials has shown significant effect on their various properties. Improvement in the various properties like increase in wear resistance, reduced residual stresses, increase in hardness, increase in tensile strength, ductility improvement, fatigue resistance, toughness imparted by formation of ferrite & martensite dual phase structure. Different approaches have been applied for heat treatment to study the effect on different types of steel and other materials. In recent years, researchers have tried to evaluate the process to optimize the parameters. This paper brings out the comprehensive analysis of the strategies followed in IHT and their significant effects on properties of materials. The final part of the paper discusses the effect of Intercritical Heat Treatment (IHT) on mechanical behaviour, micro structural changes and corrosion behaviour of different steels.

Keywords: - *Dual Phase Steel, Intercritical Annealing, Hardness, Microstructure*

I. INTRODUCTION

Steel is the most significant material used in manufacturing industry in various forms. The various forms of steel are low carbon steel, medium carbon steel, high carbon steel. In service, mostly steels are subjected to extremely high and fluctuating loads. The material must withstand those loads for long times without breaking and without undergoing excessive wear or deformation. For a steel at a given hardness, wear resistance may vary widely depending on the heat treatment used and wear mechanism involved in the process. Among steels with widely differing compositions but identical hardness, wear resistance may vary under identical wear conditions.

The important factors taking into account by the automotive industry in a manufacturing process of modern cars are: the high ratio of material strength to its density, reduced fuel consumption, safety improvement and limitation of the harmful exhaust gases. It can be achieved by an optimization of well known materials and using new groups of materials with the good formability. The growing significance have metallic materials with a high value of strain hardening exponent and absorbing the large amount of the energy under conditions of high strain rate. The micro alloyed structural steels are an example of materials fulfilling requirements of the automotive industry. Their application together with suitable metallurgical technologies enables to manufacture products with the fine-grained structure of deformed undercooled austenite [18, 19, 20].

A variety of produced vehicles decides about the necessity of manufacturing weldable plates and sheets, characterized by the various tensile strength, formability and work hardening depending on the structure. In the modern automotive industry the hot-rolled plates of micro alloyed steels are often used. They are manufactured in integrated lines connecting the continuous casting, rolling and accelerated cooling from a finishing rolling temperature. Depending on the specific application and localization of an element in the structure of a vehicle different steels are selected. They are characterized by the various ratio of strength to ductility and ability to energy absorbing during crash events [21,22]. Heat treatment is one of the most promising methods to enhance performance of the materials. The concept of metal working at a temperature below lower critical temperature& above upper critical temperature is not new it varies according to the need. Depending upon the application of the temperature it may be classified as:-

1. Hardening.
2. Annealing.
3. Normalising.
4. Tempering.

But now a day’s Intercritical Annealing of the low carbon alloy steel or HSLA steel is used which gives promising results in the field of engineering & manufacturing. In this treatment the steel is heated between lower critical temperature & upper critical temperature depending upon the material then it quenched directly in the water such that the soft austenite get converted into martensite.

The aim of this review is to summarize the most significant findings till now in Intercritical Annealing of steel by considering various parameters, methods, metallurgical changes, and results to better understand the process to improve it further for maximum utilization of the same.

II. Fundamental of Intercritical Annealing Heat Treatment Process:-

Intercritical Annealing is a heat treatment process in which the material is heated between the lower critical temperature (Ac_1) & upper critical temperature (Ac_3) to obtain partial austenitization, followed by either slow cooling or holding at a temperature below the lower critical temperature[1,2,3]. The Ac_1 & Ac_3 is determined with the help of Andrew equation based on the chemical composition of material. During Intercritical annealing the ferrite & pearlite structure transform to dual phase structure of ferrite & martensite. Martensite produced in the dual structure depends on the heating temperature, soaking period, and cooling medium. More the martensite volume fraction less the carbon content [4,5]

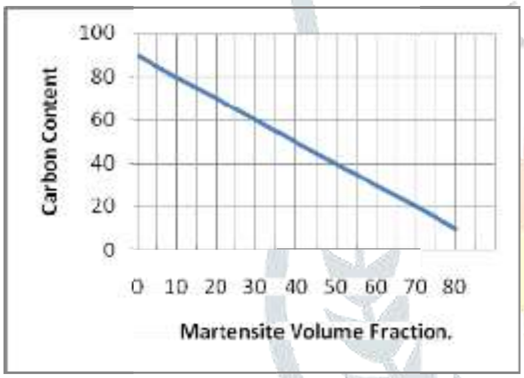


Fig.- 1

Figure 1 shows the linear relationship between the carbon % & martensite volume fraction. As the volume fraction of martensite increases the local carbon content decreases. Also higher the annealing temperature selected in this zone, the more austenite forms and transforms to martensite, but the less Carbon content in this Martensite. The mechanical properties achieved by IHT are functions of the annealing temperature. So the tensile strength increases with rising of the annealing temperature (because the martensite content in the structure is increasing), with slight decrease of elongation.

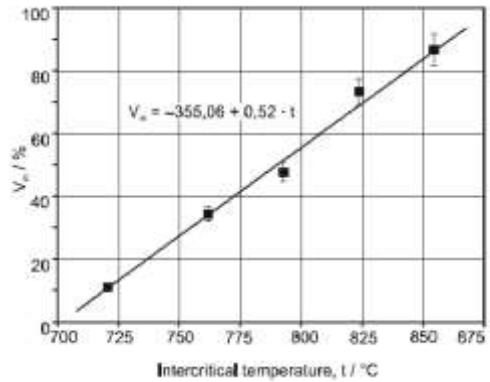
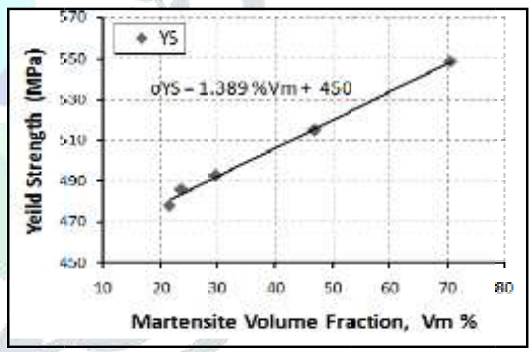


Fig.- 2

Fig. 2 shows the martensite volume fraction with increasing temperature.

III. Effect of Intercritical Heat Treatment on the mechanical properties of steel:-

Majid Pouranvari [4] studied the effect of intercritical heat treatment on low carbon alloy steel & concluded that as the temperature is increased the volume fraction of martensite also increases which leads to better ductility properties in the steel, on the other hand the tensile strength of the dual phase steel also increases but the percentage of the carbon content in the martensite phase decreases.



Also the uniform elongation & total elongation increases upto 50% of the V_m after that it start decreasing. The yield strength makes a linear relation with increasing martensite volume fraction as shown in fig.

S. K. Akay, M. Yazici, A. Avinc [5] while describing a comparative study of hardness characteristics , micro structural changes and the electrical resistivity of low carbon steel at different intercritical temperature such that at 780^0 C , 825^0 C & 870^0 C concluded that heat treatment at high critical temperature improves the hardness & the electrical resistivity of the steel that are attributed to that there was a larger amount of γ-retained austenite forms compared to that of α′-martensite in DPS microstructure & the deformation of the crystal structure respectively.

K.A. Bello, S.B. Hassan, M. Abdulwahab,U. Shehu, L.E. Umoru, A. Oyetunji, I.Y. Suleiman [6] while studying the effect of intercritical heat treatment on low carbon alloy steel concluded that the two factors plays a major role in achieving better hardness & impact toughness behaviour of steel -The holding time during heat treatment & the holding temperature. As the holding time increases the martensite volume fraction increases as well as the impact toughness behaviour of steel this is due finer ferrite –martensite microstructure and carbide precipitate-free ferrites in the HMDP steel specimens, also the hardness of the specimens increases due increase in martensite volume fraction.

T. Dalalli Isfahani, A. Shafyei and H. Sharifi [17] while comparing the mechanical properties and ductile brittle transition temperature during step quenching & direct quenching concluded that tensile properties of dual phase steel improves while step quenching but impact toughness show improvement during direct quenching due to uniform distribution of small spherical, network martensite resulting in a more uniform distribution of dislocations. The (*YS / TS*) ratio for the step quenched specimen, direct quenched specimen and the initial steel is 0.54, 0.55 and 0.676 respectively.

S.Zahid, P.P. Hector, A. Salam & J.Ahmad [13] while searching the optimum method for obtaining maximum hardness of steel & selecting desired heat treatment process for phase steel conclude that the specimen heated at 790^0 C & 800^0 C exhibit higher hardness as compared to austenized steel as well as oil quenched steel. Also the tensile strength also improves at different intercritical temperature & water quenched but the toughness does not show remarkable improvement.

V.Abouei [15] studied that as we increase the holding time of the specimen during inter critical annealing the volume fraction of the martensite increases which leads to the increase in the hardness. The hardness of the specimen increase linerally. Dry sliding wear tests have been conducted on DP steels using a pin-on-disk machine under different normal loads of 61.3, 68.5, 75.7 and 82.6 N and at a constant sliding speed of 1.20 m/s. The wear rate of the specimen found to be decreases as the volume of martensite increases & decreasing the probability of cracks formation during delamination.As the martensite fraction decreases the pro of crack formation also increases which leads to high wear rate.

A. García-Junceda, F.G. Caballero, C. Capdevila, C. García de Andrés [16] while studying the effect of different inter critical temperature on the amount of local carbon content in austenite (PEELS Analysis) of dual phase steel concluded that there is inhomogeneous distribution of carbon content in austenite regions. As the austenite volume fraction grew, the average carbon content in austenite decreased and the carbon distribution became more homogeneous. There is increased number of austenite region with lower carbon content as compared to higher carbon content.

P.O. Offor, M.Eng; B.A. Ezekoye, Ph.D.and V.A. Ezekoye [9] while investigating the effects of various intercritical temperatures and holding times on hardness properties of 0.14wt% C steel concluded that hardness properties increased with increase in intercritical normalizing temperature and hardness properties increased with increase in holding time.

K V Sudhakar , and E S Dwarakadasa [12] while studying fatigue crack growth in dual martensite steel under different intercritical annealing temperature concluded that tougher martensite growth forms as the temperature increases & fatigue crack growth decreases & significantly increase in the yield strength , ultimate tensile strength of micro alloyed steel

Mohammad Ismail Esah Hamzah , Goh Chun Guan and Ihsan Abd Rahman [14] while evaluating the corrosion performance on the concrete embedded dual phase steel concluded that corrosion resistance is better as compared to conventional steel.by the Tafel extrapolation method range. Better Corrosion resistance of dual phase steel due to no carbides formation & trapped carbon in martensite structure.

M. R. Akbarpour, F. Nematzadeh, S. E. Hasemi Amiri, H. Rezaii [10] while studying the effect of long duration intercritical heat treatment on the mechanical properties of AISI 4340 steel concluded that the holding time is the promising factor for the improvement of the ductility & work hardening. The yield strength increases with ferrite volume fraction but ultimate tensile strength increases as the volume fraction of the ferrite rises above 55%.

K.A. Bello, S.B. Hassan and O. Aponbiede[11] while studying the effect of austenitising conditions on the microstructures and mechanical properties of martensitic steel with dual matrix structure. Intermediate quenching treatment results in substantial improvements in the general mechanical properties of developed MDP steels.

Yuki Toji, Katsumi Nakajima, Takako Yamashita, Kaneharu Okuda, Hiroshi Matsuda, Kohei Hasegawa and Yasushi Tanaka[8] while investigating the effect of intercritical annealing time on γ→α Transformation during cooling in cold-rolled dual phase steels while concluded that α→γ transformation during intercritical annealing & subsequent γ→α transformation during cooling.

R. Nadlene , H. Esah, S. Norliana, M.A. Mohd Irwan [7] while studying the effect of volume fraction of dual phase steel to corrosion behaviour and hardness concluded that corrosion rate is proportional to the formation of volume fraction of the martensite in the specimen, such that the corrosion rate increases as the percentage of martensite increases due to higher inter critical temperature due large inter facial area between the martensite & ferrite boundaries which leads to increased current flow. The hardness of the specimen increases as the temperature increases as the pearlite transform into austenite which alternately transform into martensite on quenching in water.

IV. DISCUSSION:-

The study of the previous work shows that the intercritical annealing of the steel is the primary heat treatment by which we can obtain dual phase structure of ferrite – martensite. Some researchers concluded that the mechanical properties like hardness, tensile strength, ductility, corrosion resistance & wear resistance show remarkable improvement. Few of the researchers worked on the holding time during intercritical annealing while studying they conclude that the ductility & hardness increases but the notch impact toughness & strength decreases due to more martensite formation. Some researchers concluded that the microstructure of the IHT steel consists of ferrite- martensite phase different in proportions depending upon the temperature higher the temperature more will be the martensite & less will be the ferrite as well as the local carbon content. Some researchers said that the corrosion resistance increases due to large interfacial area between the ferrite & martensite boundaries.

REFERENCES:-

[1]. G. Krauss, Principles of Heat Treatment of Steel, p.240-246, Ed. M. A. Grossmann and E.C. Bain, Pub. ASM, Ohio, 1980.

[2]. G. R. Speich, Physical Metallurgy of Dual-Phase Steels, p. 4-10 in Fundamentals of Dual-Phase Steels, Conf. Proc. The Metal. Soc. of AIME 1981, Ed. R.A. Kot and B.L. Bramfitt, Warrendale, Pa. 1981.

[3]. Pierre Messien, Jean-Claude Herman, Tony Gréday, "Phase Transformation and microstructures of intercritically annealed Dual- Phase Steels", p. 161 in Fundamentals of Dual- Phase Steels, Conf. Proc. The Metal. Soc. of

[4]. Majid Pouranvari, "Tensile strength and ductility of ferrite-martensite dual phase steels", Association of Metallurgical Engineers of Serbia, Vol 16 (3) 2010 p. 187-194.

[5]. S. K. Akay, M. Yazici, A. Avinc, "The effect of heat treatments on physical properties of a low Carbon steel", The Publishing House Proceedings of The Romanian Academy, Series A, Volume 10, Number 1/2009, pp. 000–000.

[6]. K.A. Bello, S.B. Hassan, M. Abdulwahab, U. Shehu, L.E. Umoru, A. Oyetunji, I.Y.Suleiman, "Effect Of ferrite-martensite microstructural evolution on hardness and impact toughness behaviour of high martensite dual phase steel", Australian Journal of Basic and Applied Sciences, 1(4): 407-414, 2007.

[7]. R. Nadlene , H. Esah, S. Norliana, M.A. Mohd Irwan, "Study on the effect of volume fraction of dual phase steel to corrosion behaviour and hardness", World Academy of Science, Engineering and Technology 74 2011.

[8]. O Yuki Toji, Katsumi Nakajima, Takako Yamashita, Kaneharu Okuda, Hiroshi Matsuda, Kohei Hasegawa and Yasushi Tanaka, "Effect of Intercritical Annealing Time on γ→α Transformation during Cooling in Cold-rolled Dual Phase Steels", 155th ISIJ Meeting Steel Research Laboratory, JFE Steel Corporation

[9]. P.O. Offor, M.Eng; V.A. Ezekoye, Ph.D., and B.A. Ezekoye, Ph.D., "Influence of heat treatment on the mechanical properties of 0.13Wt%C structural steel", The Pacific Journal of Science and Technology, Volume 11.Number
2. November 2010 (Fall).

[10]. M. R. Akbarpour, F. Nematzadeh, S. E. Hasemi Amiri, H. Rezaii, **"**Effect of Long duration intercritical heat treatment on the mechanical properties of AISI 4340 steel", Materials Science-Poland, Vol. 28, No. 2, 2010.

[11]. K.A. Bello, S.B. Hassan and O. Aponbiede, "Effects of Austenitising Conditions on the Microstructures and Mechanical Properties of Martensitic Steel with Dual Matrix Structure", Journal Of Minerals & Materials Characterization & Engineering, Vol. 11, No.1, pp.69-83, 2011.

[12]. K V Sudhakar and E S Dwarakadasa, "A study on fatigue crack growth in dual phase martensitic steel in air environment", Bull. Mater. Sci., Vol.

23, No. 3, June 2000, pp. 193–199. © Indian Academy of Sciences.

[13]. S.Zahid, P.P. Hector, A. Salam & J.Ahmad, "Effect of different phase proportions of martensite on the mechanical properties of a dual phase steel", Journal of Scientific Research Volume XXXIX No. 2, December, 2009.

[14]. Mohammad Ismail Esah Hamzah , Goh Chun Guan and Ihsan Abd Rahman, "Corrosion Performance of Dual-Phase Steel Embedded in Concrete", The Arabian Journal for Science and Engineering, Volume 35, Number 2B.

[15]. V.Abouei, H.Saghafian, Sh.Kheirandish and Kh.Ranjbar, "A Study on the Wear Behaviour of Dual Phase Steels", J. Mater. Sci. Technol., Vol.23 No.1, 2007.

[16]. A. García-Junceda, F.G. Caballero, C. Capdevila, C. García de Andrés, "Determination of local Carbon content in austenite during intercritical annealing of dual phase steels by Peels Analysis", Materalia Research Group, Department of Physical Metallurgy, Centro Nacional de Investigaciones Metalúrgicas (CENIM), Consejo Superior de Investigaciones Científicas (CSIC), Avda. Gregorio del Amo, 8, 28040 Madrid, Spain.

[17]. T. Dalalli Isfahani, A. Shafyei and H. Sharifi, "Comparison of the mechanical properties and ductile brittle transition temperature during step quenching & direct quenching".

[18]. T. Gladman, The Physical Metallurgy of Microalloyed Steels, University Press Cambridge, Cambridge, 1997.

[19]. J. Adamczyk, Engineering of Metallic Materials, The Silesian University of Technology Publishers, Gliwice, 2004, (in Polish).

[20]. A.J. DeArdo, "Modern thermomechanical processing of microalloyed steel: A physical metallurgy perspective", Proceedings of the International Conference "Microalloying'95", Pittsburgh, 1995,15-33.

[21]. W. Bleck, Cold-rolled, high-strength sheet steels for auto applications, JOM 48 (1996) 26–30.

[22]. R. Alderdice, E.A. Campbell, Process plant implications of ULSAB and high strength autobody steels, Ironmaking and Steelmaking 25 (1998) 435–442.