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LITERATURE REVIEW ON THE EFFECT OF PROCESSING ON THE MECHANICAL AND METALLURGICAL PROPERTIES OF LOW CARBON STEELS

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ABSTRACT

In this paper the effect of the mechanical/thermo mechanical processing on the mechanical and metallurgical properties of low carbon steels, viz, Cold Reduced low carbon Steel (CRS) and Themo Mechanically Treated (TMT) steel are discussed. These steels are widely used in automobile, railways, naval architecture, petroleum industry, etc, applications with exposure to extreme temperature conditions and subjected to stress and exposed to corrosive environment [1]. The most commonly used type of steel are low carbon steel, High Strength Low Alloy Steel (HSLA), Cold Rolled Steel and Hot Rolled steel (HRS). The mechanical properties like ductility, strength and metallurgical properties like microstructure, grain size, etc, influence the properties of the rolled steels. In this paper an effort is made to study the research reported in literature, on the innovations in processing of low carbon steel through grain refinement and heat treatment to produce steel possessing good mechanical and metallurgical properties.

Keywords: low carbon steel, cold rolled steel, hot rolled steel, ultra fine grain low carbon steel, microstructure, work hardening, soaking time, mechanical properties.

INTRODUCTION

The steels generally used in the automobile, railways and construction industries are as given below:

1. Cold Formed Steels.
2. Carbon Steels.
3. Alloy Steels.
4. Free Cutting Steels.
5. Spring Steels.
6. Rust resisting and Stainless Steels.

Among these steels the cold formed steel having 0.06 to 0.15 percent of carbon, ie, the Cold reduced low carbon steel sheets and strips are mostly used in the manufacture of automobile parts and body shell, since the CRS possesses good formability and produces components of good surface finish. The cold reduced low carbon steel, conforming to IS 513:2008 comprises of four grades namely, CR1, CR2, CR3, CR4 and CR5. The CR1 is the commercial grade, CR2 is used for drawing applications and the CR3, CR4 and

CR5 grades are used for deep drawing applications. In spite of its application in industries, the work reported in literature is meager [2]. The low carbon steel after cold rolling process is subjected to increase in hardness due to the work hardening effect of the cold rolling process.

Hence it is not suitable for further processing to manufacturing of automobile components by forming process. Therefore it is subjected to reduction of hardness by annealing, carried out mostly by excluding oxygen from the annealing furnace at a temperature of 680 °C for 24 hours, in order to prevent the surface of the steel losing its bright appearance. The annealing heat causes the steel coils to buckle and distort. Therefore these annealed coils are de-coiled and rolled in temper mill with special textured work rolls [3].

The properties influencing the forming/rolling of low carbon steel and CRS is its ductility. The ductility/formability of steel is dependent

on crystal structure, grain size, and temperature during rolling and heat treatment; type of heat treatment and the alloying elements present in the steel.

Generally the presence of FCC crystal structure is preferable for achieving good ductility.

The cold rolling yields elongated or distorted grains, more than in the hot rolling process and hence the cold rolling results in loss of ductility. The cold reduced low carbon steels can be rolled with ease due to its low carbon content which is available to interfere with the slip planes.

During the cold rolling of cold reduced low carbon steel enormous pressure is applied through the rolling mills, which causes the distortion of the crystals and thus the presence of large grains that permit heavy drawing/rolling [4].

Studies on Ultra-Fine Grained

The Ultra-Fine Grain (UFG) steel having mean grain size smaller than 1 µm are widely studied due to its high strength, super plasticity, low ductility to brittle transition temperature [5, 6,7].

The investigators have invented a novel thermo mechanical processing technique to achieve Ultra-Fine Grain (UFG) in carbon steels, called as marten site process. This process does not require Severe Plastic Deformation (SPD), which needs large amount of plastic load and machinery. In this process initially the martensite micro structured low carbon steel is cold rolled and undergoes reduction and annealing to evolve multi-phased ultra-fine ferrite grains with carbides precipitated uniformly and tempered martensite existing partially [8,9,10].

T. S. Wang, *et al* prepared a high strength Ultra-Fine Grained (UFG) low carbon steel from annealing of cold-rolled martensite-ferrite dual-phase structure.

The UFG microstructure was engineered to have a microstructure comprising of fully recrystallized ferrite grains having sub micron and micron grains, along with dispersal of nano scale carbides [11].

Studies on microstructural growth, texture and orientation

Alan J. Heckler and W.G.Granzow conducted crystallite orientation distribution analysis on cold rolled and recrystallization textures in low carbon steels. In this investigation 60 percent reduced cold rolled low carbon steels were studied and found that during early stages of recrystallization the fibre textures decreased and after the complete recrystallization and grain growth there was increase in the fiber texture of the grains, which is desirable since it is useful in drawing/rolling of low-carbon steel [12]. Z. Larouk, H. Bouhalais, studied the nucleation and growth kinetics of low carbon steel, their activation energy and the grain size after complete recrystallization. The grain refinement of the ferrite grains after the complete recrystallization yields good mechanical properties. It was observed that the activation energy for primary recrystallization is higher for highly deformed low carbon steel wires [13]. R. L. Every and M. Hatherly, investigated the presence and effect of preferred orientations in hot-rolled, cold-rolled (70% reduction) and annealed low-carbon steels (capped and aluminium-killed grades). The presence of oriented nucleations during the early stages of recrystallization occurring in highly strained lattice regions, influence and decide the orientation and texture developed in the final processed steel [14]. Seshadri Seetharaman, discussed in his book, the inherent property of HSLA steel to inhibit the recrystallisation. This virtue is utilised in controlling the rolling process of HSLA steel making and thus achieve heavily deformed/misoriented austenite grains. The phase transformation further yields a fine ferrite grain size and good mechanical properties [15].

Studies on soaking time

The cold drawing of low carbon steel lends to increase in strength, reduction in ductility and increase in hardness due to work hardening/strain hardening. During cold working the dislocations in the structure start to move and cause further formation of new dislocations leading to a deformed structure having anisotropy of mechanical properties.

The annealing of the cold drawn low carbon steel alters the microstructure and improves the ductility. Nurudeen Adekunle Raji and Oluleke Olugbemiga Oluwole conducted annealing experiments at 900°C, to study the effect of soaking time during the annealing process, on the mechanical properties of cold-drawn low carbon steel. Initially between 10 minutes to 30 minutes soaking time the stress relief occurs. Later between 30 minutes and 40 minutes soaking time, the recrystallization and formation of new austenitic-nucleating grains initiates [16]. The microstructure is shown in Figure-1.

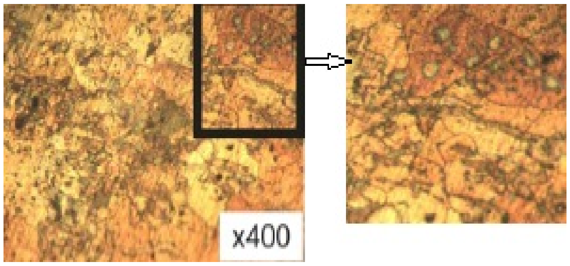

Figure-1. Microstructure of cold drawn low carbon steel showing formation of new austenitic – nucleating grains [16].

The complete austenitization of the grains where in the carbon goes into the solid solution occurred during 40 minutes and 60 minutes soaking time. These metallurgical changes influence the mechanical properties and are evident in the observation wherein till 60 minutes of soaking time the tensile strength, impact strength, showed a decreasing trend and after 60 minutes these mechanical properties started to increase. Similarly the ductility reduced till 40 minutes and increased till 60 minutes of soaking time.

Chiaki Ouchi, studied the development of quenching processes in the hot rolling of HSLA steel plates by the use of Thermo-Mechanical Processing (TMP) and Direct Quenching (DQ) Processes. I. Schindler, *et al*, investigated the influence of cold rolling and annealing on mechanical properties of HSLA steel.

They observed that the grain size obtained from the previous cold reduction process and the following annealing process parameters greatly influence properties of HSLA strips, as the annealing temperature increases the strength reduces[17].

Studies on formability/drawing

Salunkhe Ujwala Sunil and K.Baba Pai carried out Erichsen cupping experiment to study the formability of low carbon steel sheets of CR1, CR2, CR3 and CR4 grades of Cold Reduced Close Annealed Steel (CRCA) conforming to IS 513:2008 standards. The investigators observed that the CR4 grade low carbon steel by virtue of having bigger size grains, associated with low grain boundary area and hence have less grains density. This aids the CR4 steel to have less carbon percentage and which further compliments to making the steel to be softer, ductile in nature and less stress during rolling. Hence the study indicates that CR4 grade of cold drawn low carbon steel has superior formability compared to the other three grades of steel [18]. N.A.Raji and O.O.Oluwole, studied the manufacturing of nails from coils of low carbon steel through cold drawing process. The investigators studied the effect of cold drawing on the mechanical properties of low carbon steel used in the manufacturing of nails. The microstructural investigations revealed the grains elongate in the direction of cold drawing deformation and increases with increasing degree of deformation. The misorientation of grain increases with severe plastic deformation, which contributes to the anisotropic nature in the mechanical properties of the low carbon steel [19]. C.Capdevila, C.Garcia-Mateo, F.G.Caballero and C.Garcia de Andres developed a neural network model to represent the optimization by compromising between ultimate tensile strength and elongation of low carbon steel sheets. In this model around 21 parameters like chemical composition, thermochemical processes, etc. were considered for various forming operation [20]. Amitkumar R Shelar, *et al*, used experimental and Finite Element Analysis (FEA) to optimize and minimize the damage involved in sheet metal forming. The investigators optimized the sheet metal process to produce sheet metal without wrinkle defects [21].

Studies on coating

Conventionally uncoated /coated steel plates are cold reduced using a cold reduction mill. The cold reduction process increases the strength, hardness and stiffness of the steel plate, but also reduces the ductility and thus making it unsuitable for further forming process. The investigators have found a novel method for producing ductile coated products with metallic coatings of chromium, copper, nickel, etc. In this invention the cold reduction is followed with annealing performed at 722.8 °C, which is the critical temperature of steel having carbon above 0.025 percent. Here the body-centered cubic structured ferrite microstructure changes to face-centered cubic austenite, which favours further workability of the cold reduced low carbon steel [22].

Studies on welding

The welding related studies have revealed that possibility of occurring large thermal stresses in dissimilar metal weld joints due to difference in thermal expansion during temperature fluctuations [23]. Kluech et al. has highlighted that the metallurgical changes including carbon transformation and carbon precipitation at the grain boundaries caused due to thermal stresses [24, 25]. Besides lot of studies have been done regarding effect of hardness changes on mechanical properties of the dissimilar weld joints [26]. The welding between dissimilar metals, viz, between DSS/CRS yielded good quality joints as shown in Figure-2.

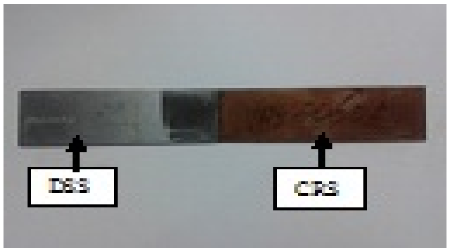

Figure-2. DSS/CRS tensile specimen [27].

Ultimate tensile strength (299Mpa) is high compared to yield strength (217Mpa) and breaking load (9KN). This indicates that the mechanical properties of DSS/CRS weld metal joint are able to meet functional requirement of the application. Similarly the hardness shows decreasing trend from weld metal to CRS Base Metal (BM) through CRS Heat Affected Zone (HAZ). This indicates that hardness in weld metal i.e. Fusion Zone is high when compared to CRS HAZ and CRS BM. DSS/CRS weld metal joint hardness survey results revealed that strength of the Fusion Zone (FZ), DSS Base Metal (BM) and DSS Heat Affected Zone (HAZ) is high when compared to CRS HAZ and CRS BM area [27] Figure-3.

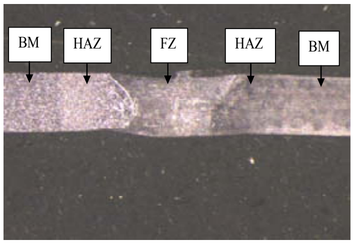

Figure-3. Macro structure DSS/CRS at magnification: 10x [27].

The Macro analysis of the dissimilar welded joint specimen revealed complete weld fusion as shown in Figure-3. M. Sadeghian, M. Shamanian and A. Shafyei investigated the effect of heat input on microstructure and mechanical properties of dissimilar welding between Super Duplex Stainless Steel (SDSS) and High Strength Low Alloy steel (HSLA) using Gas Tungsten Arc Welding (GTAW). They observed that an increase in the heat input used in the GTAW process caused a decrease in the percentage of ferrite. The impact tests revealed that the specimen with low heat input exhibited brittle fracture [28]. D. Devakumar, D. B.Jabaraj, V. K. Bupesh Raja, investigation the microstructural and mechanical properties of similar and dissimilar metal welded between Duplex Stainless Steel (DSS)/Duplex Stainless Steel (DSS) and Duplex Stainless Steel (DSS)/Corten-A steel (HSLA Steel). These welded joints were fabricated by Gas Tungsten Arc Welding (GTAW) process and yielded good quality weldments [29]. Robert A. Weber, Bruce R. Somers, and Eric J. Kaufmann, studied the application and disadvantages of using low carbon age hardenable steels, ie., High Strength Low Alloy Steel (HSLA) in Construction industry. They observed that the Post Weld Heat Treatment (PWHT) should be avoided because HSLA is prone to reheat cracking [30]. A.K. Lakshminarayanan, V.E. Annamalai, K. Elangovan, investigated the Friction Stir Welding (FSW) of low carbon steel used in automobile industry. They observed that dwell time, rotational speed and plunge depth influenced the joint properties. Also they optimized the FSW process parameters to achieve maximum lap shear tensile strength by utilizing optimization techniques, viz, numerical and graphical techniques [31].

CONCLUSIONS

The low carbon Steels have good potential to be a cheap and effective raw material for making whole body shell and the various parts of automobiles, due to the virtue of their ease of formability. Most of the investigators have studied the process parameters like soaking time, annealing temperature to reduce the cold work induced anisotropy in the mechanical and metallurgical properties of CRS, HSLA and HRS Steels. It is obvious from the literature that these steels can be engineered to produce favorable microstructure, grain size and grain orientation, to achieve good formability and good surface finish.

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