

Age Hardening in COR-Ten Steel



Vandana Sharma, J. K. Sharma, Suresh Kumar, Sanjay Panwar

Abstract. Weathering steels developed under the name COR-TEN steels, established themselves as a promising material to meet the demand for atmospheric corrosion resistance and eliminate the need for painting. COR-TEN steel is resistant to corrosive effect of weather such as rain, snow, ice, fog, etc. A coating of dark brown oxidation is developed over the metal surface, when it comes in contact with the environment thereby inhibiting the deeper penetration and negating the need for painting and reducing the rust-prevention cost over the years. Thus the steel is allowed to rust which forms a protective layer and slows down the rate of corrosion. The present study emphasizes the age hardening behavior of COR-TEN steel. The steel was subjected to solution treatment at 1000°C following accelerated cooling with water, oil and air. The oil quenched steel was then subjected to aging treatment at 400°C and 500°C for various times ranging from 5 min to 1500 min followed by water quenching. In order to ascertain the response to aging hardness measurement were conducted by employing a load of 20 Kgf. Metallographic examinations were also conducted to study the resulting structural transformations in various stages of investigations.

Keywords; Structural Steels, Weathering Steels, Atmospheric Corrosion, COR-TEN Steel.

I. INTRODUCTION

Atmospheric corrosion has been a major concern for any steel structure when exposed to atmosphere and/or severe weather conditions. This dilemma necessitates the use of steel with anti-corrosive properties and result in the development of a special class of steel called weathering steel. These weather resistant steels exhibit better anti-corrosive properties than other structural steels for many applications. Michigan began the application of weathering steels in bridges in the mid-sixties of twentieth century. These steels were primarily produced from naturally occurring iron ores, which develop a 'self-protective' oxide layer when exposed to the environments [1-3]. Gradually these steels, produced under a variety of trade names, established themselves as promising materials for various architectural and structural applications [4-6].

The potential advantages of these steels is the development of the dense self-protective oxide layer that virtually eliminate the need for the periodic maintenance painting that can add considerable expense to the cost of the structure during its lifetime.

Weathering steels (WS), are a class of High-Strength Low-Alloy (HSLA) steels, with carbon content less than 0.2 wt. % with Cu, Cr, Ni, P, Si and Mn as alloying addition to a total of no more than 3-5 wt.% [7]. The enhanced corrosion resistance of WS in relation to mild steel or plain carbon steel (CS) is due to the formation of a compact and well-adhering corrosion product layer known as patina in low aggressive atmospheres.

Buck observed that steel sheets with 0.07% Cu manufactured by US Steel and exposed in three environments of different corrosivities (rural, industrial and marine) showed a 1.5-2% greater atmospheric corrosion resistance than CS [5]. Later hereported that the improvement achieved with Cu concentrations in excess of 0.25% was insignificant; noting that 0.15% Cu provided similar results to 0.25% Cu in most cases [6]. Once the capacity of copper steel became known, further research led to the development of WS and thus to High-Strength Low-Alloy (HSLA) steels [8].

In 1920's US Steel produced a new family of HSLA steels intended primarily for the railway industry. Finally, in 1933 US Steel launched the first commercial WS under the brand name USS Cor-Ten steel, a name which reflects the two properties that differentiate it from CS, i.e., its corrosion resistance (Cor); and from a copper steel, i.e., its superior mechanical properties (tensile strength, Ten). This product was claimed to provide a 30% improvement on the mechanical properties of conventional CS, thus reducing the necessary thickness and accordingly the weight of steel to be used for a given set of mechanical requirements [9]. Several attempts have been made to improve the mechanical properties of HSLA steels by the addition of the alloying elements, special heat treatments as well as thermomechanical treatments along with the suitable modifications in production methods. The resistance to the plastic deformation of metals may be increased by three general methods namely cold working, solid solution hardening or by precipitation hardening. Mechanical properties and corrosion resistance could be significantly improved through deformation and aging. The optimum corrosion resistance can be attained by the dissolution of all the precipitates and homogeneous distribution of alloying elements in the solid solution [10]. The resulting mechanical properties of many of the high-strength alloys depend on the use of one or more of these induced effects. Precipitation strengthening is the preferred mechanism for the strengthening of high-strength alloys.

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Strengthening particles form at low temperature in austenite and α - γ interface during transformation and in ferrite during cooling. Also, it is established that dislocation-precipitate interaction leads to the evolution of an optimum combination of mechanical properties. Accordingly, present investigation was aimed at studying the combined effect of dislocations and precipitates on the aging behavior of the COR-TEN steel.

II. MATERIAL AND METHODS

The COR-TEN steel plate, with chemical composition (wt%) 0.12C, 0.25-0.75Si, 0.2-0.5Mn, 0.01-0.2P, 0.03S, 0.5-1.25Cr, 0.25-0.55Cu, 0.65Ni; was used for its response to precipitation strengthening. The steel was subjected to solution treatment at 1000°C for 180 minutes followed by oil quenching (OQ), water quenching (WQ) and air cooling (AC). The small pieces from the oil quenched material were subjected to aging treatment at 400°C and 500°C for various times ranging from 5 to 1500 minutes followed by water quenching. Hardness measurements were conducted on a VM-50 Vickers Hardness Testing Machine by employing a load of 20Kgf. Each specimen was subjected to at least five indentations and averaged. Extensive optical microscopic examinations were conducted for the study of micro structural changes resulting from various thermal treatments.

III. RESULTS AND DISCUSSION

A. Hardness

The steel in as-received (AR) condition exhibits a hardness value of 170 HV₂₀. Solution treatments at 1000°C followed by cooling in various media results in variation in hardness (Fig.1). It has been observed that the hardness increases with increasing cooling rate as manifested by the column diagram, quenching in water results in maximum hardness (270 HV₂₀). However, intermediate cooling rate (i.e. oil quenching) results in approximately the same hardness as in AR condition.

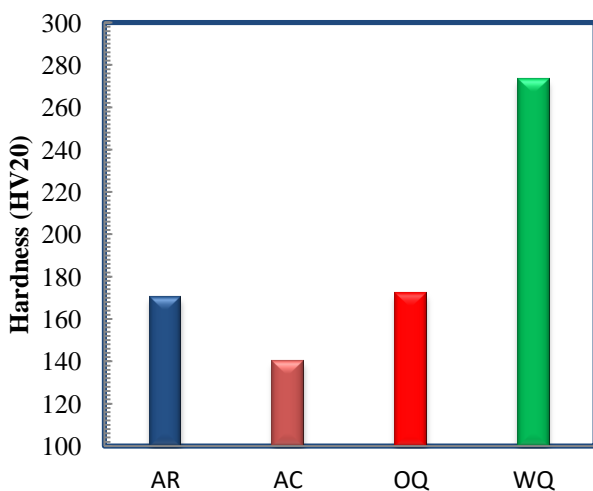


Fig.1. Hardness of COR-TEN steel in various conditions.

Fig.2 shows the variation of hardness with aging time 400°C and 500°C. As seen in Fig.2, aging initially increases the hardness after 5 min for 400°C and 500°C. It is also observed that COR-TEN steel exhibit a complex aging behavior as is evident by multiple aging peaks in aging

curve for both the temperatures. It is also observed that 400°C results in maximum response to age hardening. Fig.2 shows that the hardness decreases with successive aging and increases as the aging progresses. It is also seen that 500°C results in poor hardening as compared to that for 400°C. Moreover, the aging at lower temperature accelerated the process of aging as manifested by duration for second peak after 600 min for 400°C as against the second peak for 500°C after 1200 minutes. Prolonged aging results in drastic fall in the hardness values.

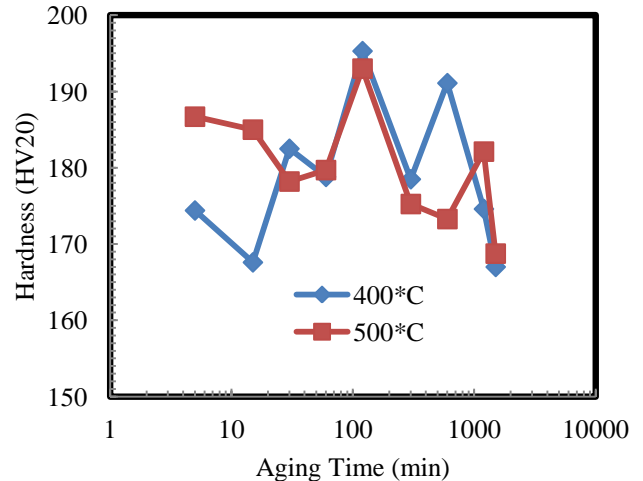


Fig.2. Hardness of COR-TEN steel as a function of aging time.

B. Optical Microscopy

The COR-TEN steel primarily consisted of a ferrite-pearlite microstructure. Solution treatment in general causes the dissolution of pearlite colonies. Figs. 3-4 illustrate the structural transformation of a COR-TEN as a result of austenitization at 1000°C followed by cooling in air, and oil respectively. It is seen that air cooling results in evolution of coaxial ferrite grains. However, oil quenching causes the refinement of grains together with the formation of coarse precipitate particles within and along the grain boundaries. On the contrary, quenching in water resulted in homogeneous mixture of ferrite and pearlite and dissolution of grains.

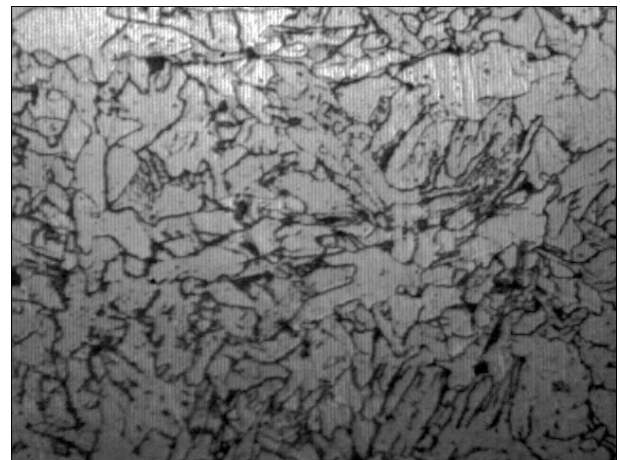


Fig.3. Optical Micrographs of COR-TEN steel in air cooled condition after solution treatment at 1000°C for 180 minutes.

Fig.5 shows the optical micrographs of COR-TEN steel after 120 minutes of aging at 400°C. Aging, in general, is accompanied by the recovery and recrystallization process. It is seen that aging initially causes recrystallization, which is manifested by the existence of fine grains of ferrite and pearlite together with a few coarse precipitate particles along the boundaries.

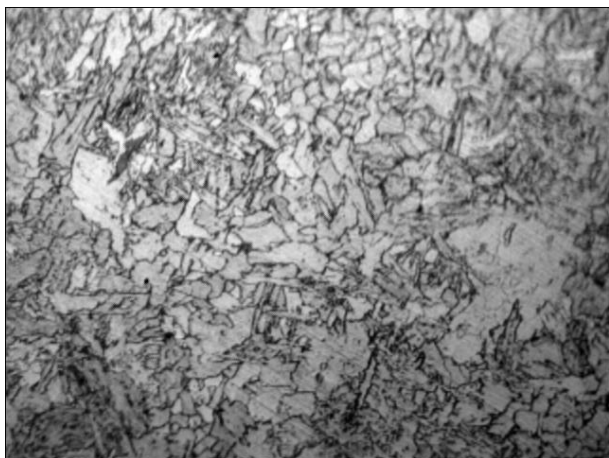


Fig.4. Optical Micrographs of COR-TEN steel in Oil quenched condition after solution treatment at 1000°C for 180 minutes.

As aging progresses, formation of fresh precipitate particles within the ferrite grains took place and their density was increased after 30 minutes. Subsequent aging for 120 minutes (Fig. 5) results in the enhanced concentration of fine precipitate particles within the ferrite matrix.

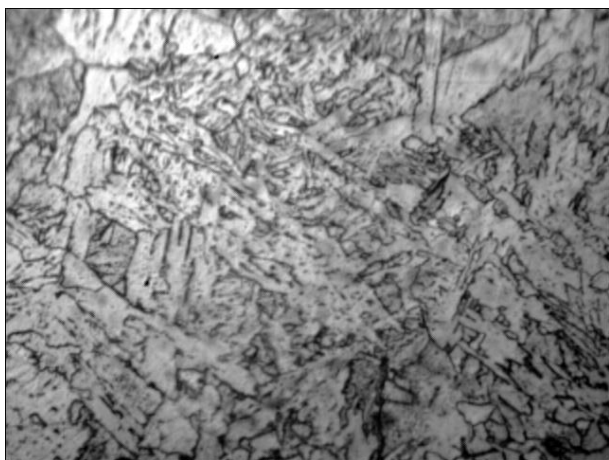


Fig.5. Optical Micrographs of COR-TEN steel after aging at 400°C for 120 minutes followed by water quenching.

However, prolonged aging for 600 minutes and 1500 minutes again causes the dissolution of pre-existing precipitates and fresh nucleation of a few coarse precipitate particles. Similar observations were made for aging at 500°C (Fig. 6).

IV. DISCUSSION

Steels can be hardened by quenching from an elevated temperature [11-13]. The hardness of quenched alloy increased with time. This represents that age-hardening is the only hardening method for hardening of alloys. The fundamental reason of age hardening of high strength alloys is the decreasing solid solubility with increasing

temperature[14]. At high temperatures, the alloy exists as a homogenous solid solution. If after such solution treatment the alloy is rapidly cooled to room temperature by quenching into water or any other fluid, the separation of θ -phase is suppressed and an unstable supersaturated solid solution is produced.

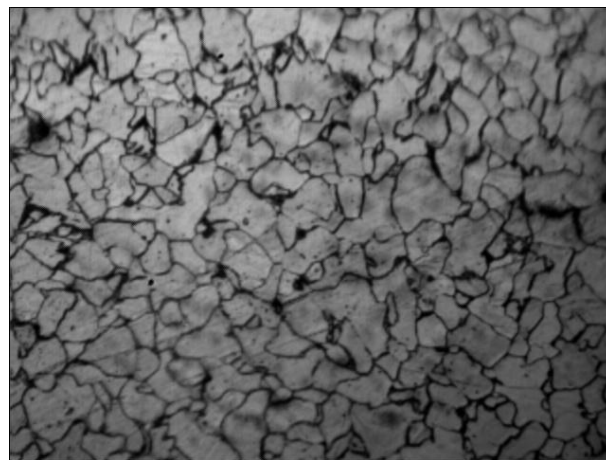


Fig.6. Optical Micrographs of COR-TEN steel after aging at 500°C for 600 minutes followed by water quenching.

The hardening is a result of the precipitation of the second phase particles, when the quenched material is aged for a sufficient time, and the precipitates were of the form of a fine submicroscopic dispersion. In general, the precipitation hardening is also accompanied with the nucleation and growth of precipitating particles. Usually nucleation takes place in the region where there is atomic disarray namely around the grain boundaries, dislocation or around inclusions [15]. These regions are associated with high free energy per atom which renders them unstable during the transformation. Accordingly, the simultaneous existence of fine and coarse precipitates along the grain boundaries resulted invariance of hardness after various stages of aging.

Precipitation strengthening in an alloy, in general, depends on the solubility of the precipitating phase at an elevated temperature [15]. Aging is the preferred mode of precipitation hardening in HSLA/COR-TEN steels. The variation in hardening after various stages of aging are attributed to the recovery and recrystallization processes, which primarily cause the coalescence and growth of grains. It is also attributed to nucleation and growth of the precipitate particles as the aging progresses. Accordingly, the dip and rise in the hardness curve as a function of aging time were obtained grains [16-19].

V. CONCLUSION

Aging treatments at 400°C resulted in better response to age hardening effects in this steel. The hardness initially decreases with aging. Further aging caused hardening attained maxima at different times for different aging temperatures and again decreases in later stages of aging. These variations in hardness were endorsed to the nucleation and growth of the precipitate particles with simultaneous dissolution of the pre-existing particles.

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