EFFECT OF 0.5WT% CR ADDITION ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURE OF HEAT TREATED PLAIN CARBON LOW ALLOY STEEL

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ABSTRACT
Alloy addition increases the tensile strength with increasing lesser amount of ductility for the development of high strength low alloy steels (HSLA). Improvement of mechanical properties and microstructures, heat treatment was carried out which provide high strength, high yield point combined with adequate ductility and toughness. An attempt has been taken to study the effect of 0.5wt% Cr on structure and properties of ~ 0.10% carbon (low carbon) steel. Samples of the steels were annealed and normalized by R.F. Generator machine from their respective heat treatment temperatures. The standard tensile specimens made from the annealed and normalized steel bars were tested to obtain data on tensile properties such as yield strength, ultimate tensile strength, percentage of elongation and percentage of reduction in area. 0.5wt% Cr content steel (Steel-2) shows the better yield strength and tensile strength but poor ductility than plain carbon steel (Steel-1)in the heat treated conditions. The corresponding heat treatments change the microstructures of the examined alloys.

Keywords: Plain carbon steel; heat treatment; tensile properties; microstructure

INTRODUCTION
During the last decays, there has been a great demand for steels with higher mechanical strength, sufficient ductility and toughness. Moreover, the lightness of the steel is attractive, as in the automobile and aircraft applications. These requirements can be achieved by an increase in carbon content in a limited way, but even in the heat-treated condition the maximum strength of alloy steel can reach 700 MPa above this value; the ductility dramatically decreases (Avner, 1974). Heat treated alloy steels provide high strength, high yield point, combined with appreciable ductility even in large sections. The use of plain carbon steels frequently necessitates water quenching accompanied by the danger of distortion and cracking, and even so only thin sections can be hardened throughout. For resisting corrosion and oxidation at elevated temperatures, alloy steels are essential. High-strength low-alloy (HSLA) steels, or micro-alloyed steels, are designed to provide better mechanical properties and/or greater resistance to atmospheric corrosion than conventional carbon steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition. The HSLA steels have low carbon contents (0.05-0.25% C) in order to produce adequate formability and weldability, and they have manganese contents up to 2.0%. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium and zirconium are used in various combinations (Aver, 1974; Hossain and Kabir, 2006).
According to the Alloy Steels Research Committee (ASRC): “Carbon steels are regarded as steels containing not more than 0.5% manganese and 0.5% silicon, all other steels being regarded as alloy steels (American Society for Metals, 1964). The basic alloying elements added to steel are manganese, lead, nickel, chromium, molybdenum, vanadium, niobium, silicon and cobalt. The effect heat treatment of low-alloy steel was extensively studied by many researchers during the last decays (Frihat, 2015). Low-alloy steels constitute a category of ferrous materials that exhibit mechanical properties superior to plain carbon steels as the result of additions of alloying elements such as nickel,

chromium, molybdenum and niobium. For many low-alloy steels, the primary function of the alloying elements is to increase hardenability in order to optimize mechanical properties and toughness after heat treatment. In some cases, however, alloy additions are used to reduce environmental degradation under certain specified service conditions (Aver, 1974; Hossain and Kabir, 2006).

Mechanical properties of steels are strongly connected to their microstructure obtained after heat treatments that are generally performed in order to achieve a good hardness and/or tensile strength with sufficient ductility (Mebarki et al., 2004). Currently, there is a strong interest in the effect of cooling rate on the mechanical properties and microstructure of industrial processed steels. It has been shown that oil quenching produce an essentially ferrite-martensite dual phase structure with about 4 volume pct of fine particle and thin film retained austenite. In contrast, the slower air cooling results in a larger amount (about 10volume pct) of retained austenite in addition to the ferrite and martensite phases. On the other hand, with the applied cooling rate increasing, the transformed structure evolves from granular bainite, lower bainite, self-tempered martensite, to finally martensite without self tempering (Qiao et al., 2009). Among them, self-tempered martensite, obtained in the transformed specimens cooled with rates of 25 - 80°C/min, exhibits the highest hardness values due to the precipitation of fine carbides.

It has been shown that yield strength increases with increasing cooling rate, while ultimate tensile strength and strain-to-failure is unaffected. Although many papers have been published on the effect of cooling rate on the tensile behaviors of steel (Chao and Gonzales-Carrasco, 1998; Perdrix et al., 2000; Serre and Vogt, 2008) there has been little research on the effects of cooling rate on the microstructure and micro-hardness (Nagpal and Baker, 1990; Lu et al., 2009).

The influence of Mn, Cr and Mo on hardenability is well known. These elements promote the formation of hard phases such as bainite and martensite. Chromium, manganese (both having high affinity for oxygen) and molybdenum all enhance hardenability. Cr, Mo and Mn influence on the formation of bainite and/or martensite during continuous cooling of medium-carbon steels and respective mechanical properties (Sarasola, et al., 2005; Sulowski and Cias, 2011). It was investigated the effects of Cr and Ni on low carbon steel with undissolved carbide particles on the refining the austenite grain size (Razzak, 2011). Low carbon steel with Cr content showed a lower Widmanstatten ferrite content, whereas the proportion of acicular ferrite was increased. Acicular ferrite improves the toughness and acts as an obstacle to cleavage fracture. Higher impact absorption energy was measured in a specimen with finer acicular ferrite structures. Cr is a ferrite-stabilizing element and increases the corrosion resistance of plain carbon low alloy steel (Lee and Lee, 2015).

The present study is aimed at understanding the effect of 0.5wt% Cr addition on the mechanical properties and microstructures of heat treated plain carbon low alloy steels.

EPERIMENTAL PROCEDURE

Two different steels containing about 0.10 % carbon were used in this study. The compositions of the steels are presented in Table 1. Steel-1 is the base steel with which the structure and properties of the Steel-2 compared. The steels were made in an air induction furnace. All the melts were poured into a cylindrical metal mould and sound ingots were produced. These ingots were rolled down to 16mm diameter bars.

The heat treatments of the specimens were carried out in the Induction R. F. Generator (Radio Frequency). The steels were held at their respective heat treatment temperatures for pre selected periods. Then they were allowed to cool at two different cooling rates, namely 67, ~4ºC/min. These cooling rates indicate the natural cooling or normalizing (67ºC/min) and annealing (4ºC/min). The heat treated bars were then machined into standard tensile specimens with a nominal diameter and minimum parallel length of 3.99 mm and 25 mm respectively.

The tensile specimens were then tested with a Universal Tensile Testing Machine (INSTRON) to obtain data on yield strength (YS), ultimate tensile strength (UTS), percentage of elongation (%EL), and percentage of reduction in area (% RA).

For metallographic observation, the heat treated specimens were taken for micro examination. The samples were then ground, polished up to gamma-aluminum powder and then etched in 2% nital. The microstructure of these specimens was then studied with the help of an optical microscope and photograph of these structures of each specimen were taken. Chemical compositions of the examined steels have shown in Table.1.

Table 1: Chemical compositions of the examined steels

Steel Name	Composition weight percentage						
	C	Si	Mn	S	P	Cr	Fe
Steel-1	0.10	0.28	1.18	0.021	0.028	-	Bal.
Steel-2	0.11	0.20	1.28	0.022	0.022	0.5	Bal.

RESULTS AND DISCUSSION

Tensile Properties

The results of the tensile test of the heat treated (both annealed and normalized) tensile specimens of the Steel-1 and Steel-2 are shown in Fig.1. It is evident from Fig.1.a that yield strength of the Steel-2 is higher than the Steel-1.Between the alloy steels; Steel-2 with Cr produces the higher yield strength than Steel-1 all over the applied heat treatment. This indicates that chromium increase the yield strength. A similar trend was found with the ultimate tensile strength of these steels. Chromium (Cr) in the form of CrC precipitates increases the strength by means of precipitation strengthening. CrC also pins the grain boundaries and inhibits the grain growth. This results in grain refinement and hence higher strength.

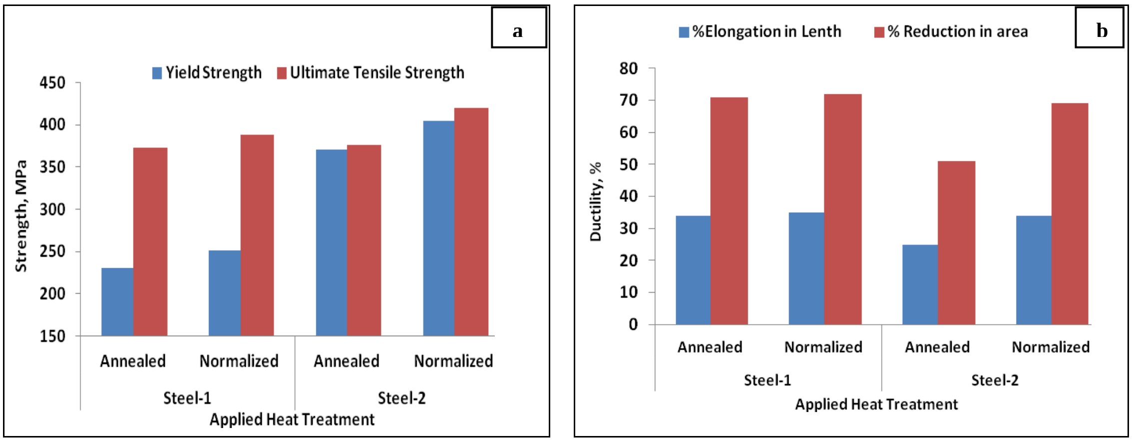

Fig 1: (a) Tensile strength and (b) Ductility at annealed and normalized condition

Fig.1.b shows that ductility i.e. percentage of elongation and reduction in area in Steel-1 and Steel-2 in both annealed and normalized condition. Steel-2 showed lower percentage of elongation than Steel-1 in both heat treatment conditions. This may be due to the presence of precipitates (CrC in Steel-2). This indicates that CrC is harmful for increasing the ductility. The percentage of reduction in area also decreases due to present CrC. This happens because ductile behaviour is normally inversely proportional to yield strength.

Microstructural Investigation

The microstructure of annealed and normalized Steel-1 and Steel-2 are shown in Fig.2.a and Fig.2.b respectively. It has been observed that Steel-1 showed regular ferrite pearlite structure in the annealed condition (Fig.2.a) and fine ferrite pearlite & few Widmanstatten structure & bianite in the normalized condition (Fig.3.a). The finer structure in the normalized condition is due to the faster cooling rate. In the annealed condition Steel-2 revealed regular ferrite pearlite structure (Fig.3.b) finer than Steel-1 revealed ferrite pearlite. In the normalized condition Steel-1 showed some Widmanstatten structure along with regular ferrite pearlite. The amount of Widmanstatten structure is only small in Steel-1. The Steel-2 showed only regular ferrite pearlite in the normalized condition (Fig.3.b). Optical microscopy also revealed finer ferrite pearlite in Steel-2 than plain carbon Steel-1.

Steel-2 showed more or less same grain size of ferrite pearlite compared to Steel-1. Steel-1 is a plain carbon steel. It does not contain any alloying element. So, there are no second phase particles to inhibit grain growth. In the annealed condition Steel-1 also revealed very fine ferrite pearlite in some areas. This is may be due to the segregation effect. The finest grain size in Steel -2 containing Cr and Cr is due to the precipitation of finer CrC during cooling. For this reason Steel-2 showed finest grain size than Steel-1.

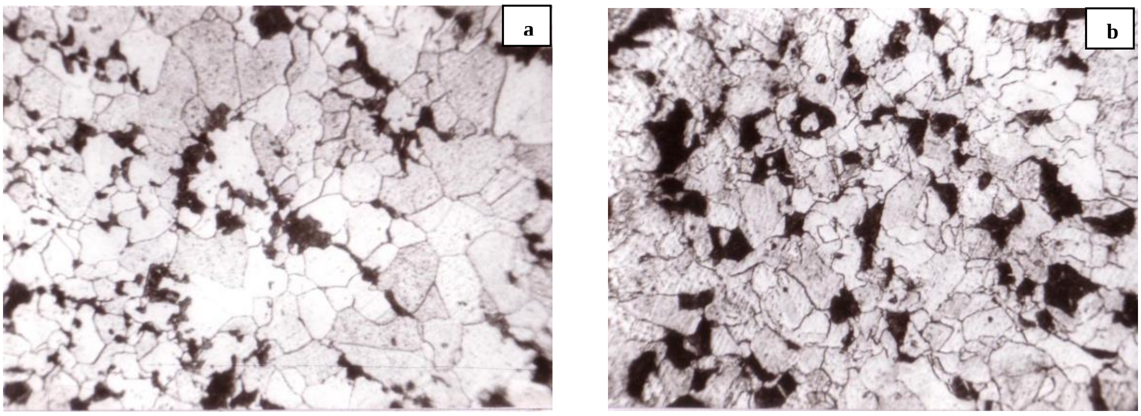

Fig 2: Optical microstructures of (a) Steel-1 and (b) Steel-2 at annealed condition, X600

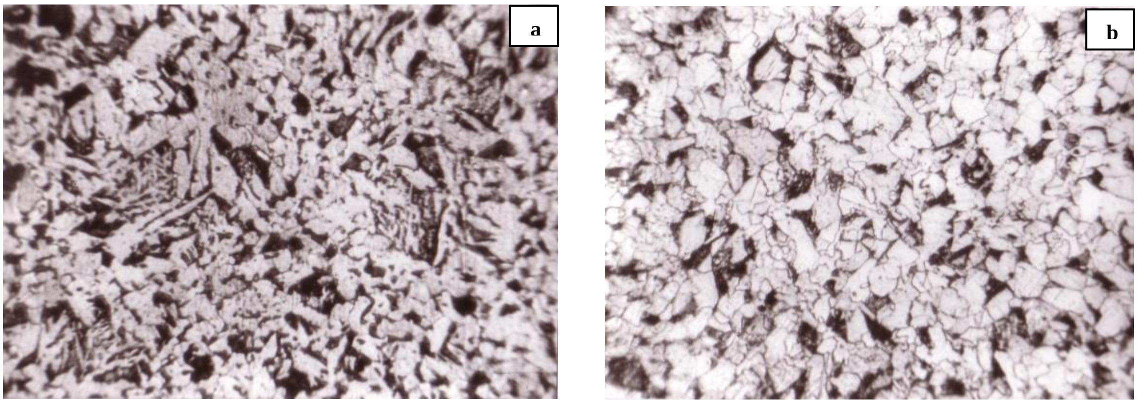

Fig 3: Optical microstructures of (a) Steel-1 and (b) Steel-2 at Normalized condition, X600

CONCLUSION

Heat treatment affects the microstructure and tensile properties of the experimental low alloy steels remarkably. At annealed condition, Cr in Steel-2 revealed regular ferrite pearlite structure, finer than plain carbon Steel-1. Steel-2, it has been observed that fine ferrite pearlite & few Widmanstatten structure & bianite in the normalized condition (faster cooling rate).The yield and ultimate tensile strength of Cr content Steel-2 is higher than steel-1 but the ductility is lower all over the heat treated condition.

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