The influence of alloying elements to achieving the mechanical properties of high tensile bolts and nuts

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Abstract

In this paper, the influence of alloying elements on mechanical properties and microstructure of steel grade, according to (ASTM) has been studied for manufacturing of high tensile bolts and nuts. Three materials, one plain carbon steel and other two low alloys steel were selected for the purpose of heat treatment. The three materials were austenised and tempered at different temperatures. As the microstructure and mechanical properties of tempered steel depend on the temperature and duration of tempering and the carbide particles become large and fewer in number as the temperature and time increase, this change in microstructure lower the hardness and strength but higher ductility and toughness. Tempered at very low tempering temperature may not show change in hardness but yield strength may increase. In case of alloy steel which contain one or more of strongly carbide forming elements (Cr, Mo, V and W) are capable of secondary hardening and these steel harden on tempering. The temperability of plain carbon steel decreases with an increase in carbon content, in case of alloy steel, the alloying elements increase hardenability and retard the softening rate. Increased strength based on martensite transformation alone generally means a drastic reduction in ductility and high sensitivity to notches. In the development of high strength steels attempt has been made to overcome these produced during rapid cooling. Small amount of alloying elements are used to increase hardenability and matrix strength and some ductility. Plain carbon steel can be heat treated to bring about high tensile properties but this material has been found unsuitable for high temperature applications such as headers for refineries,
while tow alloy steel can be heat treated to bring about high tensile properties.

Keywords: Alloying elements, Mechanical properties, High tensile bolts and nuts.

1. Introduction

Steel is the world's most important material, multi-functional and most adaptable material. About 5% of iron element is present in earth's crust [1]. Without steel, the world as we know it would not exist: from oil tankers to thumb tacks, from trucks to tin cans, from transmission towers to toasters [2]. We can say steel is arguably world's most "advanced" material. It is

very versatile material with a wide range of attractive properties which can be produced at a very competitive production cost [3].
Carbon steel is by far the most widely used kind of steel. The properties of carbon steel depend primarily on the amount of carbon it contains. Most carbon steel has a carbon content of less than 1% [4]. Low carbon steel is easily available and cheap having all material properties that are acceptable for many applications , including structural beams, car parts and bodies, kitchen appliances, cans, pipe line, railways, tractors, agriculture implement, …etc. [1 and 5]. Iron has a great importance in human life, human performance has been developed in various fields and scopes especially industrial activities in which considers a significant turning point for the whole life of the human being whereas machinery, building, architecture in addition to all engineering application have been duly developed[6].
Bolts and nuts are common fasteners which are used in fastening parts of device, equipment and machines. But there are applications like high pressure bolted joints (like headers in the refineries), air craft gas turbines, steam turbines in steamships, impellers of a cement plant, high pressure pipe joints in a pressure vessel, submarines, portal and overhead cranes and all other places where ordinary machine bolts and nuts fail. Although a high tensile bolt and nut seem to be a very small components of machinery, but the safety of that big machine wisely depends upon the high-strength bolts and nuts which are used in the machine or assembly.

There are several examples in the failure of machinery parts due to failure of bolts and nuts, irrespective of the defect in material or carelessness on the part operator or any other cause. So the high tensile bolts and nuts play a vital role in the safety of a big assembly and in turn of safety of human life involved. Increased strength based on martensite transformation alone generally means a drastic reduction in ductility and high sensitivity to notches. In the development of high strength steels attempt has been made to overcome these disadvantages. In conventional martensitic steels the strength is all derived from martensitic transformation produced during rapid cooling. Small amount of alloying elements are used to increase hardenability and matrix strength and some ductility. Majority of alloying steel contain 0.25 to 0.55%C, or less if for carburized parts which are widely used in automotive and other machinery and almost always quenched and tempered for high strength and toughness. Manganese, silicon, nickel, chromium, molybdenum, vanadium, aluminum and boron are commonly present in these steels to enhance the properties obtainable after quenching and tempering [7].

2. Materials

The material in this work has been selected as low carbon steel and low alloy steel of chemical composition as shown in table 1.

Specimens	C%	Si%	Man%	S%	P%	Ni%	Mo%	Cr%
1	0.38	0.23	0.62	0.03	0.02	1.52	0.23	1.11
2	0.31	0.45	0.02	0.02	-	4.12	0.24	1.30
D	0.39	0.23	0.60	0.024	0.023	-	-	-

Table 1. The chemical composition of samples.

3. Results (Tensile testing results)

Tests	Specimen 1	Specimen 2	Specimen marked D
Tensile strength (MPa)	927.51	1895.82	788
Elongation (%)	13.91	8.76	13.57
Reduction in area (%)	40.48	44.90	25.64
Hardness Rockwell	26.15	46.57	21.4

Table 2. Tensile test and hardness results for specimens as received conditions.

Tests	Oil quenched at 900ºC	Tempering temperature at		
		460ºC	560ºC	660ºC
Tensile strength (MPa)	2038.5	1131.4	978.5	764
Elongation (%)	6.70	8.7	12.6	18
Reduction in area (%)	28.967	44.81	52.98	64
Hardness Rockwell	50.25	35.4	28	24.3

Table 3. Tensile test and hardness results for specimen (1) after heat treatment.

Tests	Oil quenched at 900ºC	Tempering temperature at		
		460ºC	560ºC	660ºC
Tensile strength (MPa)	1681.84	1141	988	1080.45
Elongation (%)	9.02	13.14	17.78	9.79
Reduction in area (%)	75	40.49	56.82	36
Hardness Rockwell	44.6	34.0	31.2	32.6

Table 4. Tensile test and hardness results for specimen (2) after heat treatment.

Tests	Oil quenched at 900ºC	Tempering at 420ºC
Tensile strength (MPa)	1301.0	989.5
% elongation	7.14	10.14
Reduction in area	5	36.46
Hardness Rockwell	24.3	22

Table 5. Tensile test and hardness results for specimen (D) after heat treatment

4. Discussion

Three materials, one plain carbon steel and other two low alloy steel were selected for the purpose of heat treatment. The three materials were austenised and tempered at different temperatures. As the microstructure and mechanical properties of tempered steel depend on the temperature and duration of tempering and the carbide particles become large and fewer in number as the temperature and time increase, this change in microstructure lower the hardness and strength but higher ductility and toughness. Tempered at very low tempering temperature may not show change in hardness but yield strength may increase. In case of alloy steel which contain one or more of strongly carbide forming elements (Cr, Mo, V and W)are capable of secondary hardening and these steel harden on tempering. The temperability of plain carbon steel decreases with an increase in carbon content, in case of alloy steel, the alloying elements increase hardenability and retard the softening rate. Taking the case of sample (D), the tensile strength in as received conditions Table. 2, was 788 MPa which increased to over 1300 $\mu pa/m^2$ when hardened in oil from 900C which shows an improvement of 65.1% Table 5, where percentage elongation decreased from about 14% to 7% and reduction in area percent decreased drastically from 26% to 5%. There is slight increase in the hardness from 21.4 to 24.3 due to carbon percent content because it's the carbon content in plain carbon steels that produced martensitic structure. In order to improve upon the ductility and toughness the same material was subjected to various tempering temperatures. The time at tempering temperatures was kept one hour in each case. The results of tempering at 420ºC show the tensile strength decreased from 1300 to 990 MPa, but elongation % increased from 7% to 10% and reduction in area % also improved from 5% to 36% which indicated that ductility increased. Tempering at 460ºC, 580ºC and 660ºC was also done but their mechanical tests were not conducted. The hardness values progressively decreased with increasing tempering temperature. The results of plain carbon steel (marked D) show that the material is suitable for manufacturing high tensile bolts for room temperature, application only and cannot be used for high pressure-high temperature application.

Sample marked (1) being low alloy steel has been found to possess marked characteristic to develop high strength on suitable heat treatment. In as received condition Table. 2, it possessed tensile strength 928 MPa which on hardening from austenizing temperature 900ºC in oil, increased to 2038 MPa and % elongation and reduction in area % decreased from 13.9 to 6.7% and 40% to 29% respectively Table3. The hardness value recorded was RC 26.15 Table. 2, with three tempering temperature were selected 460ºC, 560ºC and 660ºC, it has been established that most appropriate temperature was 460ºC for one hour which conforms to the requirements of STM A490.

Sample marked (2) was also hardened simultaneously with marked (1) and tempered at the same temperature. The results in Table 4, indicate that this material also developed heat treatment properties at 460ºC tempering temperature. The value of tensile strength 1141 MPa, elongation 13% , reduction in area 41% and hardness Rc 34 show that the material is suitable for producing heat treatment bolts. Since this material contains about 4% nickel, so the grain size was reduced accordingly and hardenability increased.

The microstructure examination of sample D in original condition shows that the sample was supplied in normalized condition. The structure is fine normalized pearlite (dark) and ferrite (white). Fig.1, in oil quenching from 900ºC the structure obtained was martensite. Figure 2 shows ferrite at prior austenite grain boundaries, acicular structure is probably bainite, pearlite matrix (dark area).

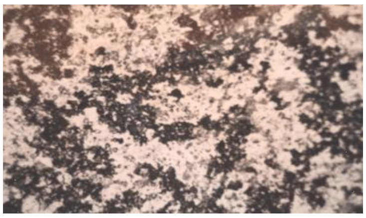

Fig. 1, The structure is fine normalized pearlite (dark) and ferrite (white).

Fig. 2, Ferrite at prior austenite grain boundaries, acicular structure is probably bainite, pearlite matrix (dark area)

The same specimen on tempering at 420ºC figure. 3, shows fine lamellar pearlite (dark) and ferrite (white). The tensile strength obtained by tempering is very close to the standard A-490 but it is felt that temperature +_5ºC to 400ºC will give good results. Figure 4 shows material (1) in original condition, this show fine grain structure of ferrite and pearlite. The same specimen on tempering at 420ºC figure. 3, shows fine lamellar pearlite (dark) and ferrite (white). The tensile strength obtained by tempering is very close to the standard A-490ºC but it is felt that temperature +_5ºC to 400ºC will give good results. Figure 4 shows material (1) in original condition, this show fine grain structure of ferrite and pearlite.

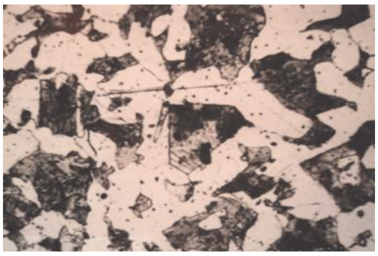

Fig. 3, Fine lamellar pearlite (dark) and ferrite (white).

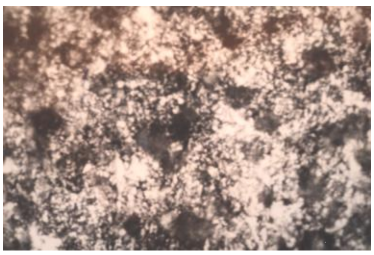

Fig. 4, Fine grain structure of ferrite and pearlite.

This low alloy steel on oil quenching from 900ºC produced martensite which clear from the well defined acicular structure (Figure 5). The tensile strength and hardness values were very high as shown in Table 3. Figures 6, 7 and 8 show the microstructures of sample (1) in three different tempering temperatures.

Fig. 5, Martensite which clear from the well defined acicular structure

Fig. 6, Sample 1 after 450 C tempering temperature

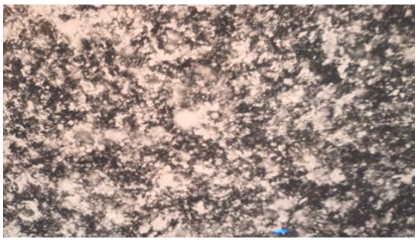

Fig. 7, Sample 1 after 550 C tempering temperature

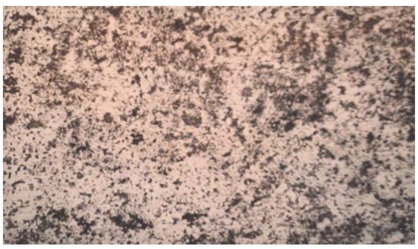

Fig. 8, Sample 1 after 650 C tempering temperature

These structures are of tempered martensite showing reduced size of circular needless. The best structure has been found of figure 6 which has produced the desired results of tensile strength. Figures 9 and 10 show the specimen 2 in original condition showing very fine grain size of ferrite and pearlite, it appears in normalized condition, when austenised at 900ºC for one hour and oil quenched Figure 10 the structure showed needle like acicular martensitic structure having high tensile strength and hardness as shown in table 4.The same structure in tempering at 460ºC showed tempered martensite in uniform condition (Figure 11).This structure is desirable and meet the requirement of standard bolts. The structure of tempering at 650ºC and 660ºC have not been shown.

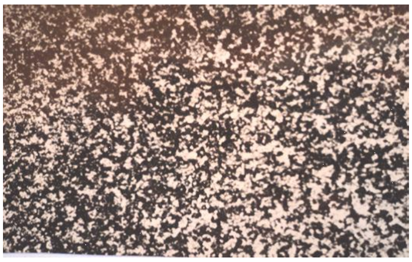

Fig. 9, The specimen 2 in original condition showing very fine grain size of ferrite and pearlite

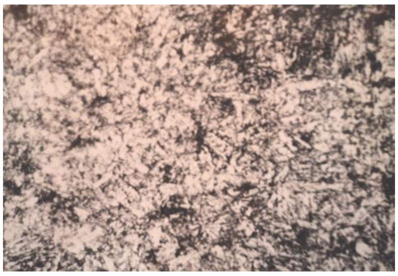

Fig. 10, The specimen 2 the structure showed needle like acicular martensitic structure after oil quenching

Fig. 11, The specimen 2 same structure in tempering at 460ºC showed tempered martensite in uniform condition.

Conclusions

1-It has been established that carbon steel specimen (D) can be heat treated to bring about high tensile properties but this material has been found unsuitable for high temperature applications such as headers for refineries,

2-Material marked (1) and (42) being low alloy steels both shown excellent response to heat treatment process for developing high tensile properties for making bolts and nuts.

3-the tensile strength and hardness values increased markedly on all the three materials on hardening but the ductility decreased.

4-For material (D) the heat treatment properties at 420ºC tempering temperature were marginal but for material (1) and (2) the recommended process of heat treatment was

- Harden in oil at 900ºC by giving one hour soaking time.

-Tempering in furnace at 460ºC for one hour

The above process produced the product conforming to ASTM A490.

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