

Effect of Cooling Media and Tempering Temperature on the Mechanical Properties of Reinforcement Steel

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Abstract

The object of this research is study the effect of cooling media and temperature on the mechanical properties for reinforcement steel which is tempering used in concrete at explosive and burning building. Many mechanical tests like tensile, hardness impact test, and microstructure to the samples at different temperature (900,600,400) C° were carried out. The samples were subjected to different heat treatment (Normalizing, hardening, Periodization, Recrystallization Annealing) and compared the results with samples without heat treatment. The results shows effect of presence of martensite in the samples which is heated to (900) C° and quenching in Water increasing in values of hardness and decreasing impact and tensile for found martensite at room temperature. At heating (600) C° show the hardness decreased, but the tensile down at quenching in Water and increase at normalizing. At heating (400) C° show the hardness increases at quenching, the tensile strength increase at quenching and decrease at normalizing, the impact test is down in general. In the hardening heat treatment process, this deals with quenching and tempering. At quenching outer surface is cooled quicker than the center so the transformation of the austenite is proceeding in microstructure at different rates. Optical Microscopy results showing at (900) C° and hardening or normalizing the microstructure produced (Fe₃C+M) in the different percentage. The spheroidized structure is desirable when minimum hardness maximum ductility, at normalizing occurring remove the residual stress and distrpution of carbide, at (400) C° and quenching produced (Fe₃C) has large size in (α +P) base, at normalizing occurring distribution of carbide.

Keywords: Reinforcement steel, Heat treatment, Mechanical properties, cooling media.

INTRODUCTION

After a fire, it is necessary to ascertain whether the residual safety level of R/C structures is still sufficient in spite of the mechanical of the materials are decayed [1].

Now a days there are incidents of fires in buildings are often heard which are increasing day by day and also the repair and rehabilitation of fire damaged structures has become an area for study and research. Many efforts are been laid down to carry out research in these related fields. To build a structure usable again after fire damage is a

discipline of great concern by civil engineering community. We totally recognize that fire cause damage in terms of deprivation of life, families and livelihoods. Structural design for fire safety is chiefly based upon "Authoritative Approach." The Authoritative Approach involves fire resistance rating of structures & was developed almost 100 years back. The data of course is being changed with new findings, but is still cautious. After half of the nineties brought in a paradigm shift in the fire safety engineering with the onset of the performance based design approach. The fire fighting period is calculated and then corrected to read account of the probability of occurrence of a flame, the effects of structural failure and the effects of an automatic suppression system[2].

The structural response of buildings to fire conditions has been the focus of intensive research activity in recent years. For composite steel/concrete buildings, this has been driven by the motivation to achieve more cost-effective designs and, more generally, by the need to attain a greater understanding of the underlying behavioral mechanisms that occur in fire. As a result, there has been an increasing recognition of the benefits of employing performance-based fire design, in comparison with prescriptive approaches which are based on unrealistic idealizations[3].

Reinforcing steel is one of the most used steel products in the world. The total world consumption of reinforcing steel in 1998 was about 95 million tons. in comparison with the total product of steel at that time, about 13 % of steel was allocated for the reinforcement of concrete. the second material consumed in the compound "steel-concrete" is the cement of about (1,6) billion tons. These results in a portion of 20 kg of reinforcing steel per m³ of concrete. This makes it is clear that reinforcing steel depends on the amount of reinforced concrete which is the followed method over all world [4].

The reasons that lead to use the steel as optimal reinforcement steel summarized in [5]:

- The limitation of length due to the transfer the load from concrete to reinforcement and vice versa.
- A high modulus of elasticity in order to gain a high degree of stiffness for the construction.
- Free of disadvantages of chemical and physical phenomena between concrete and reinforcement

- The reinforcement has simple forms in shape and length which fit with the various constructions.

The reinforcing steels usage depends on their application according to their systems of structural analysis. Numerous of methods used to analyze the structural of reinforcement steels; linear elastic analysis, plastic methods of analysis and non-linear analysis. Further, obtaining a good rationalization in producing solid cages of reinforcement and to perform splices weld ability is a greatest interest [6].

Carbon and manganese were used as the first steels for reinforcement basis after these the engineers find out that cold working improves the resistance but decreases the ductility. In twenty years ago, micro alloying in grade 400 and 500 N/mm² appeared on the market. In Parallel, the heat treatment process of bars were developed and cold working of large sizes has been important in the past but disappeared totally due to economical reasons [7].

EXPERIMENTAL WORK

The material that has been studied in present work was made of Reinforcing steel which is widely used in building Chemical composition of steel was analyzed in the Specialized Institution of Engineering Industries-Baghdad. The chemical composition of material is shown in Table (1).

Table 1. Chemical composition of reinforcing steel.

Comp. Wt %	C	Cr	Co	Ni	Mn	Mo	Fe
standard	0.4	0.2	0.1	0.03	0.1	0.05	Balans

Preparing nineteen samples of reinforcing steel bar are shown in Figure (1) at different diameter (12, 10) mm.



Figure 1. Reinforcing steel samples

Applied heat treatment on the samples of reinforced steel bar in laboratory of civil engineering department (University of Diyala) by using the Furnace as shown in Figure (2).



Figure 2. Furnace at 1200 C°

- 1- Heating five samples in the furnace at 900 C° for (1hr) then cooling it in air at room temperature (Normalizing) shown in Figure(3).



Figure 3. Normalized reinforcing steel bar at 900 C°

- 2- Heating five samples in furnace at 900 C° for (1hr) and cooling it in water for (5min) and then cooling it in air at room temperature (hardening).

- 3-Heating two samples in furnace at 600 C° for (1hr) then cooling it in air at room temperature(Spheroidization) shown in Figure(4).



Figure 4. Spheroidization reinforcing steel bar at 600 C°

4- Heating two samples in furnace at 600 C° for (1hr) then cooling it in water for (5min) and then cooling it in air at room temperature (Spheroidization).

5- Heating two samples in furnace at 400 C° for (1hr) then cooling it in air at room temperature (Recrystallization Annealing) shown in Figure(5).



Figure 5. Normalized reinforcing steel bar at 400 C°

6- Heating two samples in furnace at 400 C° for (1hr) then cooling it in water for (5min) and then cooling it in air at room temperature (Quenching).

And then cleaning all samples used in our research, cutting the samples to provided for mounting to prepare it to hardness test shown in Figure(6).



Figure 6. Reinforcing steel samples that is mounting.

Prepare the samples to impact test shown in Figure (7).



Figure 7. Reinforcing steel samples that are prepare to impact test.

Test the mechanical properties for the sample without heat treated and test another type of samples that heat treated are:-

1. Tensile test.
2. Hardness test.
3. Impact test.

The tests are the performer Technician Academe (Baquba) shown in Figure (8), (9).



Figure 8. Tensile test machine



Figure 9. Impact test machine

In this work the tensile stress calculated from the following equation [8]:

$$\frac{P}{A} = \left[\frac{\Delta L}{L} \right] E \dots \dots \dots (1)$$

Where:

- P: Force
- A: Area
- ΔL : Extension
- L: Length
- E: young modules

The microstructures of the specimens where examined by in optical microscope. The test was done in Technician Academe (Baqubah).

The hardness test by Rockwell method, Let the indenter is a diamond cone the minor load is 10 kgf and the major load is 140 kgf, the total load is 50 kgf.

RESULTS AND DISCUSSION

The results from mechanical tests that applied on reinforcement steel samples without heat treated and the other samples that heat treated are:-

Hardness test

The results from hardness test by Rockwell method is shown in Table (2) and Table (3).

Table 2. Hardness result of sample without heat treated

No.	Hardness
1.	40

Table 3. The results of hardness test of the samples that heat treated

No.	Temperature	Heat treatment	Hardness HRC
1.	900 C°	Normalizing	44
2.	900 C°	hardening	53
3.	600 C°	Spheroidization	45
4.	600 C°	Cooling in air	44
5.	400 C°	Recrystallization Annealing	40
6.	400 C°	Cooling in air	49

Tensile test

The result of tensile test is shown in Table (4) and Table (5).

Table 4. Tensile test result of sample without heat treated

NO.	D	L	L°	ΔL (mm)	Load (Max)	speed	Extension	Extension (%)	Tensile stress	Yield stress	Area
1.	12	185	193	207	77.3	8	76.90	16.54	683	458	78.5

Table 5. The tensile test results of samples that heat treated

No.	Temp C°	Heat treatments	D (mm)	L (mm)	L° (mm)	ΔL (mm)	Load (Max) (KN)	Speed mm/ min	Extension (mm)	Extension (%)	Tensile Stress (Mpa)	Area (mm²)
1.	900	hardening	12	255	125	136	143.4	5	15.35	12.23	1268	113.04
2.	900	Normalizin	12	220	122	168	43.5	5	49.07	12.42	384.8	113.04
3.	600	Spheroidization	10	220	111	115	21.3	5	5.62	5.06	271.33	78.5
4.	600	Cooling in air	10	210	114	133	40.4	5	22.68	20.17	514.64	78.5
5.	400	Recrystallization Annealing	10	220	120	153	51.8	5	19.09	15.81	659	78.5
6.	400	Cooling in air	10	246	119	126	38.1	5	9.49	7.63	485	78.5

Impact test

The results of impact test by charpoy method are shown in Table (6) and Table (7).

Table 6. The impact test result of the sample without heat treated

N0	Impact force (Joul)
1.	110

Table 7. The impact test results of the samples that heat treated

N0.	Temp.	Type of Heat treatment	Impact force(Jowl)
1.	900 C°	hardening	250
2.	900 C°	Normalizing	191
3.	600 C°	Spheroidization	289
4.	600 C°	Cooling in air	272
5.	400 C°	Recrystallization Annealing	264
6.	400 C°	Cooling in air	275

Series of mechanical tests have been carried out on prepared samples to evaluate the heat treatments. Table(8) Showing the results of mechanical properties (hardness, tensile, and impact) during heating with varying temperature (400 C°, 600 C°, and 900 C°) and cooling in two different medium which represented by water and air as described below.

Table 8. The mechanical properties of reinforcement steel after heat treated

Mechanical Property	Cooling Media	900 C° heating	600 C° heating	400 C° heating
Hardness	Air	44	45	40
	Water	53	44	49
Tensile	Air	348	514	485
	Water	1268	271	659
Impact	Air	191	272	275
	Water	250	289	264

According to the results shown in the table above there are four main points of discussion are reviewed in the following paragraph:

- For each test and after completion of a typical thermal cycle consisting of heating followed by cooling, it can be concluded that there an obvious change in values of the mechanical properties. Depending upon the maximum exposure temperature, visually observable changes were seen in the damaged steel reinforcement bars after heating. It is believed that the main reason led to this changing is the material mode of the steel which is altering significantly.

For example, exposing high temperature of 900 C° and according to the sketch of the Carbon steel, the reinforcement steel reaches the austenite phase while after the sudden cooling with water a martensite structure is obtained.

This structure is characterized by its high hardness and strength as a result to carbides formation on the crystal boundaries reaching austenite phase. However this extraordinary values of hardness and strength decrease with respect to the velocity of cooling. Further the velocity of cooling in water is much higher than that in air. Also, the medium cooling rate by water gave best fatigue life than other type of cooling media [4].In conclusion, the results of the current study are coincident with the scientific theory background as described above as showing in Fig.(10) [5].

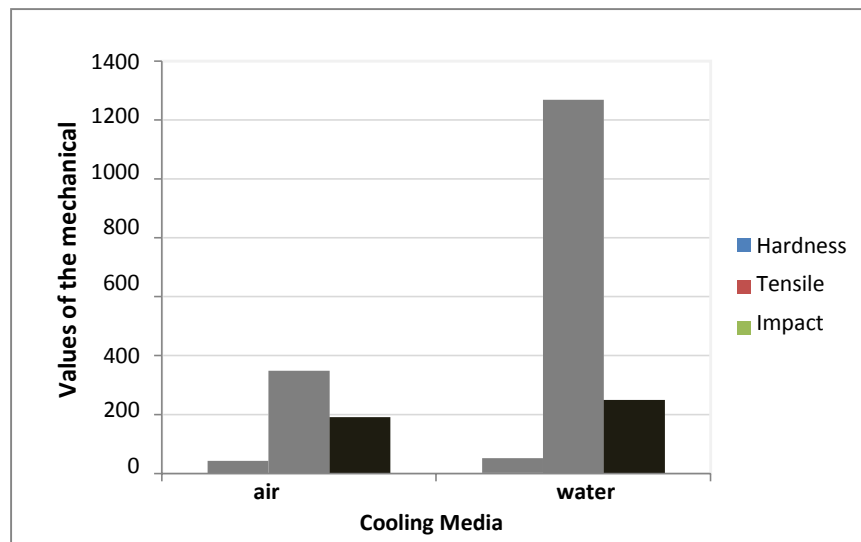


Figure 10. The influence of cooling media on the mechanical Properties at 900 C°

- In heating corresponding to 600 C°, the bar charts showed a different trend as illustrated below in Fig. (11). The hardness of sample has given the value of (44HR150N) while it increases to(45HR150N) in air that could belong to fact of

not reaching the austenite phase. Also, it worth mentioning that a similar behavior is reported at 400 C° heating as a result to stress relief see Fig.(12).

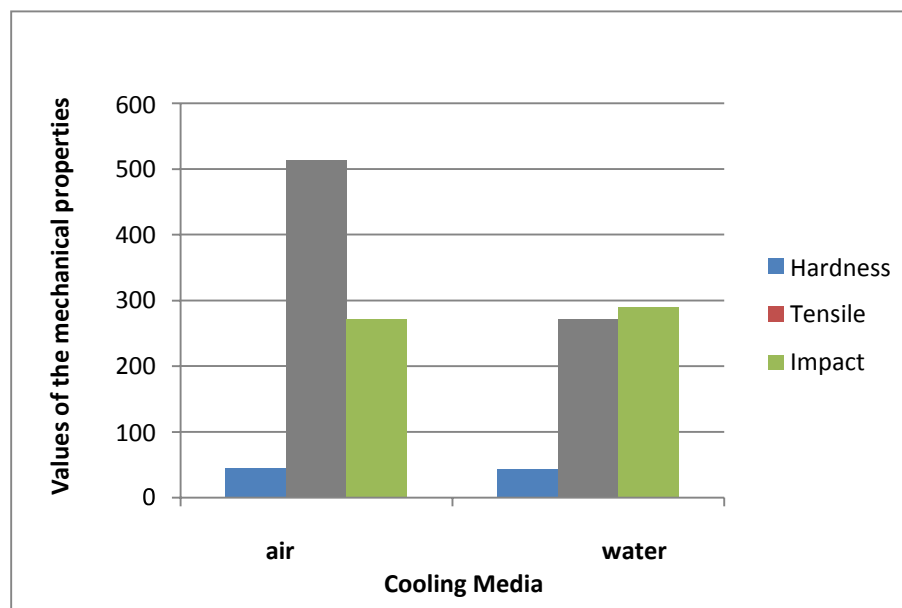


Figure 11. The influence of cooling media on the mechanical Properties of the steel bars at 600 C°

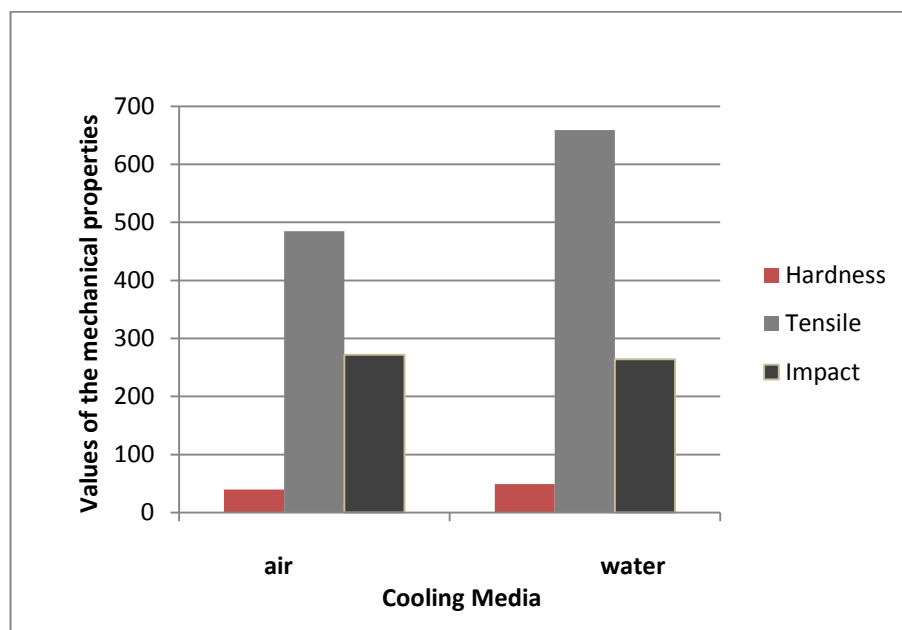


Figure 12. The influence of cooling media on the mechanical Properties of the steel bars at 400 C°

- Regarding the impact strength and as it is observed from figures (10), (11), & (12) above, there is a noticeable change in those values depending on the microstructure obtained after completion of each heating stage. For example at 900 C° heating, the value of the impact would be much more than that without any thermal treatment. During cooling with water, the impact value was (250 J) while it was (191 J) during cooling by air. However, for heating at 400 C° and 600 C° respectively, the heat treatment has not reached the austenite phase. So cooling in both water and air gave considerable values of Impact strength. As this structure sustains stability in the mechanical properties of the steel bars unless they have been subjected to stress relieve only. However, with comparison with hardness and tensile strength values, this structure would not be effective for reusing.

- According to the results shown, there is an increasing in tensile strength at heating up to 900 C°. However, there is a decreasing in the impact strength. Under such circumstances and a result of the diversity from engineering point of view, it can be concluded that the test of the steel bars is failed. Across all pre-damage states and exposure temperatures of up to 800C, the stress–strain relationship of the cold-worked bars was characterized by a linear ascending branch followed by a

yield plateau which in turn was followed by a strain hardening phase culminating in failure. On other hand according to our results, there is need to understand the residual properties of the bars. Their results showed that the mechanical properties of the reinforcement after fire is very necessary for R/C structures [2]. As results of the good insulating properties of the concrete, the question to be answered is whether the residual bearing capacity the reinforcement is sufficient or should be increased, by strengthening the damaged members. For these reasons, different indicators for different steels commonly used in R/C and P/C structures.

Microstructural Observation

Optical Microscopy results showing in fig (13) at (900) C° (A) normalizing the microstructure produced (Fe₃C+M),(B) quenching the microstructure produced large Fe₃C+M. At (600)C° in fig (14) (A) tempering occurring remove the residual stress and distrpution of carbide,(B) quenching produced martensite has small size in (α +p) base. At (400) C° in fig (15) (A) normalizing produced fine perlite,(B) quenching produced (Fe₃C) has large size in (α +p) base.

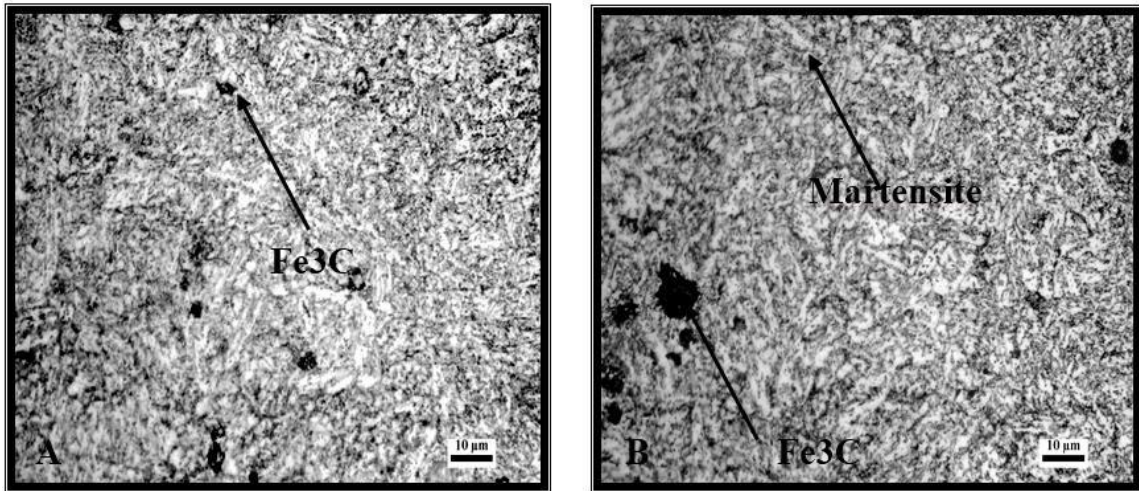


Figure 13. Microstructural of reinforcement steel at 900 C°
 (A) Normalizing (B) Quenching

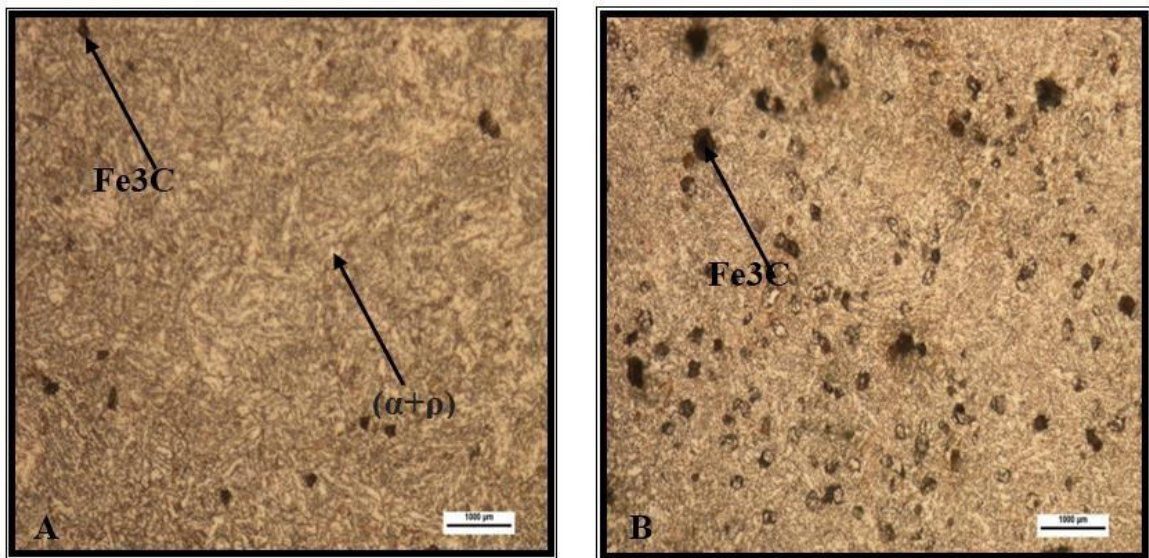


Figure 14. Microstructural of reinforcement steel at 600 C°
 (A) Normalizing (B) Quenching

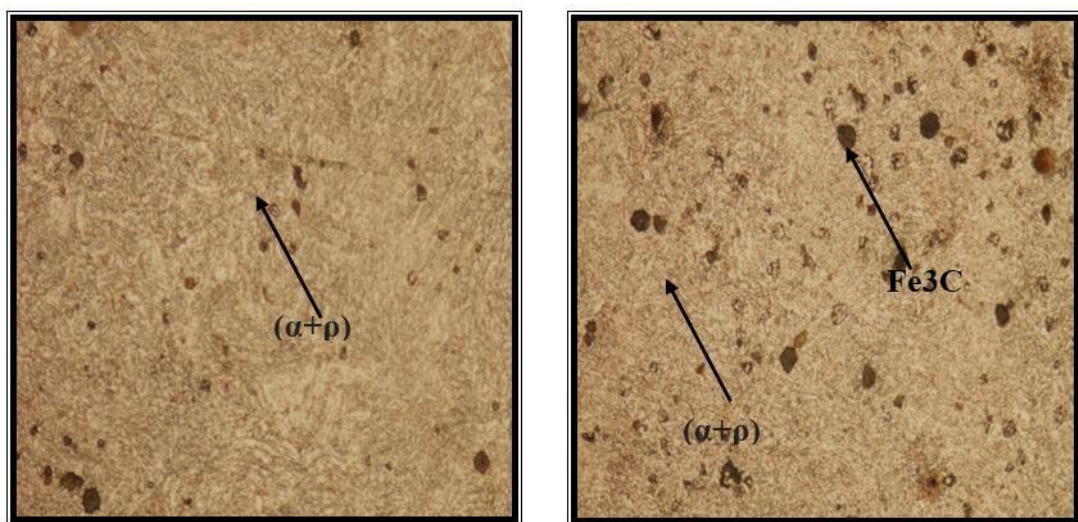


Figure 15. Microstructural of reinforcement steel at 400 C°
 (A) Normalizing (B) Quenching

CONCLUSIONS

- 1- At heating to 900 C° and cooling in water obtained the best mechanical properties by obtained martensitic microstructure.
- 2- If the applied temperature was ranging from 400°C to 900°C, samples showed a considerable change in their mechanical properties.
- 3- It is observed that the resultant significant change in the mechanical characteristics of the steel bars is proportional with the severity of the fire. So high temperature bars exposed the high change in the overall performance and vice versa.

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