

THE EFFECT OF COOLING RATE ON MECHANICAL PROPERTIES OF CARBON STEEL (St 35)

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ABSTRACT: - This paper is aimed to study the effect of cooling rate on mechanical properties of Steel 35. Specimens prepared to apply tensile, torsion, impact and hardness tests.

Many prepared specimens heat treated at (850°C) for one hour and subsequently were cooled by three different media [Water-Air-furnace] to show the effect of Medias cooling rate on mechanical properties. Microstructures of all specimens examined before and after heat treatment by an optical microscopy.

To figure the phases obtained after heat treatment and its effect on the mechanical properties Experimental results have shown that the microstructure of steel can be changed and significantly improved by varying line cooling rate thus, improving one property will effect on the others because of the relationship between all properties.

In water media tensile, torsion and hardness improved while impact results reduced. Air media contributed in improving most of the mechanical properties because of grain size homogeneity. At furnace media ductility and impact improved.

Keywords: Carbon Steel, Heat treatment, cooling rate and mechanical properties.

INTRODUCTION

Mechanical properties of steels are strongly connected to their microstructure obtained after heat treatment. These are generally performed in order to achieve good hardness, toughness, tensile strength with sufficient ductility.

Heat treatment of steel is the process of heating and cooling of carbon steel to change the steels physical and mechanical properties without changing the original shape and size. Therefore it becomes necessary to control heating and cooling of metals to alter their physical and mechanical properties It 'soften associated with increasing the strength of the steel, but it can also be used to alter certain manufacturability objectives such as improves machinability,

formability, restore ductility etc. Thus heat treating is a very useful process to help other manufacturing processes and also improve product performance by increasing strength or provides other desirable characteristics ⁽¹⁾.

Currently there is a strong interest in the effect of cooling rate on the mechanical properties and microstructure of industrial processed Steel ⁽²⁾, the influence of cooling rate on the microstructure of Steel₃₅ has been shown that water quenching produces Martensitic phase structure and in contract the slower air cooling results *Ferrite* and *pearlite* and also in furnace cooling but with the large grain size and heat treatment had the effect on torsion resistance which is mainly used for determination the modules of rigidity of material also during this test the shear behavior of material during elastic and plastic limit can be studied material deform elasticity until reaching yield point during elastic limit the distribution of shear stress will be zero at the center and maximum periphery also during this limit the shear is linearly proportional to shear strain. While during plastic limit the material deforms plastically because Torsion test specimen is not subjected to necking as in tension or barreling as in compression. Torsion test carry out on axial loading and little work on torsion ⁽³⁾.

Carbon increases the hardenability of steels by transforming the formation of pearlite and ferrite to martensitic courage's the formation of martensitic at slower cooling rates ⁽⁴⁾.

The Charpy impact test, is destructive mechanical test, it's a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness ⁽⁵⁾.

EXPERIMENTAL PROCEDURE

The Experimental part is summarized as follows:-

1- Metal Selection

To specify the chemical composition of carbon steel (St35), its chemical analysis is indicated in Table (1) which was conducted by ARL Spectrometer in the specialized institution of engineering industries of Industry ministry.

2- Preparation of Test Specimen

Many specimens of steel used according to the standard specification for testing (ASTM) were prepared by machining process. The test specimen dimension is shown in fig (1).

3- Categorization of Specimens

After finishing the preparation process of the steel specimens (cutting the bar and machining process) the specimens were arranging into four groups as shown in Table (2).

4) Heat Treatment

Heat treatment was implemented on specimens groups (B, C, D) in Table (2) including heating the specimen to evaluated temperature for one hour and cooling at different rates, group (B) is cooled in water, group (C) cooled in air, and group (D) cooled in furnace.

5) Test and Examinations

1. Microstructure Test

Microstructure examination was implemented on specimen in the Table (2). The specimens were prepared as follow:

- a) Grinding the specimen by emery paper no. (180,240, 400, 800 &1000) with use of water.
- b) Polishing operation by use a special polishing cloth with use of alumina solution (AL_2O_3), the particle size is (0.3 μ).
- c) Developing solution for the structure by using Nital solution (2% nitric acid HNO_3 with 98% methyl)
- d) Photographing the microstructure by program microscope type (metallurgical microscope MTJ Corporation

2-hardness

In this work, the hardness of steel for all specimens was done by using Vickers method and the result calculated according the equation below

$$HV=1.8544* F/d^2 \text{ ----- (1)}$$

Where (F): is the force applied to the diamond in (Kilograms).

(d): the indepater diameter (Square Millimeters).

Hardness results are shown in Table (3).

3-tensile test

By using (Instron machine 1195) at a speed of 2mm/min, the specimens were prepared according to the ASTM shown in fig.(1-B), Tensile test implemented for all specimen in Table (2) to determine the tensile strength prosperities, The obtained results are shown in Table (3).

4-Torsion test

The specimens in table (2) were subject to torsion test. The large twisting angle of scratched line we see a large amount of plastic deformation this angle represented the relation between a twist angle and the force which used on each specimen. The yield Torque (T) and yield angle of twist θ were determined from the elastic zone θ , γ and modules of rigidity (G) were calculated by using the following formulas

$$\tau = \frac{16 T}{\pi d^2} \text{ ----- (1)}$$

where

τ =shear stress in N/mm²

T= torque N .mm

$$Y = \frac{\theta r}{L} \text{ ----- (2)}$$

Where

Θ= twist angle in rad

$$\theta = N * d * \frac{\pi}{180}$$

L= specimen gauge length in mm

r= specimen radius

$$G = \frac{\tau}{\gamma} \text{ ----- (3)}$$

Where

G=modulus of rigidity

$$T = F * r \text{ [N.m] ----- (4)}$$

$$\tau = \frac{T.r}{J} \text{ [N/mm}^2\text{] ----- (5)}$$

The experimental results for specimen's (A, B, C and D) respectively are shown in Fig (3).

Results of torsion are shown in Table (3) and fig. (4), (5)

5) Impact Test.

To determine the impact strength for all specimens sharbey test implemented to measure the energy required to break a material under impact loading.

Impact stress equation was implemented to calculate the metal strength the results are shown in Table (3)

$$\frac{E}{A} = \sigma a \text{ kg. m/cm}^2 \text{ -----(1)}$$

A: specimen area in cm²

E: Energy in Kg. m

σa=metal strength

$$E = W L (\text{COS}\beta - \text{COS}\alpha) \text{ ----- (2)}$$

W: Mass of hammer in kilogram.

L: length in centimeter.

α: Angle of fall in degree.

β: Angles at the end of the swing in degree.

DISCUSSION

From Table (3) which represent all results for testing specimens we see that, the specimen group (B) has low torsion strength comparing with strength of other group (A, C, D)

respectively as shown in Table (3), because of the small number of cycles give small value of twist angle that cause the fail.

On the other hand the hardness, impact and tensile stress was high, because of forming the Austenite phase by the heat treatment, which obtained it wherein heating specimen to (850 C°) then quenching in water. Then the transformed occurs to get fine needle structure which called Martensite, it was hard but brittle ⁽²⁾.

The plastic depth is important factor where gives the amount of plastic deformation which consider very useful for heat treated metal. Always, observing the less plastic deformation at the specimen which has maximum value of torsion.

The specimen (D) has high torsion strength, as appear in Fig (3), and where the fail happens when the specimen reaching to a large number of cycles.

This proves; the specimen (D) owns a large amount of plastically deformation when it is subjected to torsion load. But hardness and impact was low because cooling rat was low in furnace therefore, the transformed Austenite into Ferrite and Pearlite by precipitate as laminated form ⁽¹²⁾.

The specimen (C) give high value of torsion strength and impact comparing with the specimen without heat treated. Because the normalizing heat treated cause rearing meant of the laminated Ferrite and Pearlite structure ⁽¹³⁾.

Hence, we can improve the desirable Mechanical properties from through control on cooling rate.

The photographs of microstructure of specimens (A, B, C, and D) are shown in Fig (2).

CONCLUSIONS

From the various results to obtain during the

1. Mechanical properties which desirable and applications required we should go for a suitable heat treatment processes.
2. Heat treatment contributes to improving the mechanical properties such hardness, ductility and toughness.
3. Mechanical properties varies are depending upon heat treatment processes variety.

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Table (1): Chemical composition of steel.

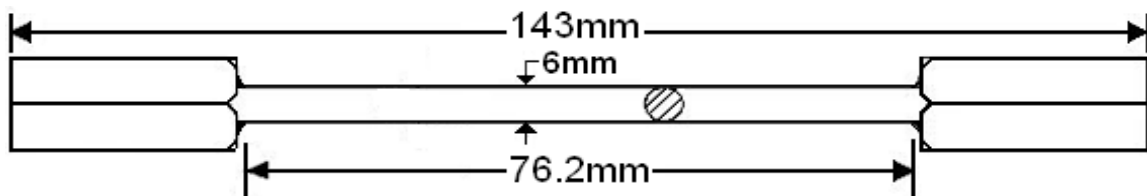
Element wt %	C	Mn	Si	Ni	Cr	Mo	S	P	Fe
Actual	0.39	0.57	0.18	—	0.07	—	—	—	
Standard	0.32- 0.39	0.5- 0.6	0.4	—	—	—	0.045	0.095	

Table (2): Categorization of specimen.

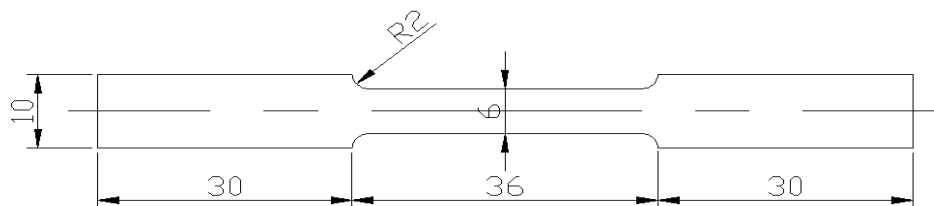
Specimen symbol	State of specimen
A	Specimen without heat treatment(as received)
B	heated to (850°C), for one hour and water quenched
C	heated to (850°C), for one hour and air cooled
D	heated to (850°C),for one hour and furnace cooled

Table (3): Tests results of mechanical properties for tested specimens.

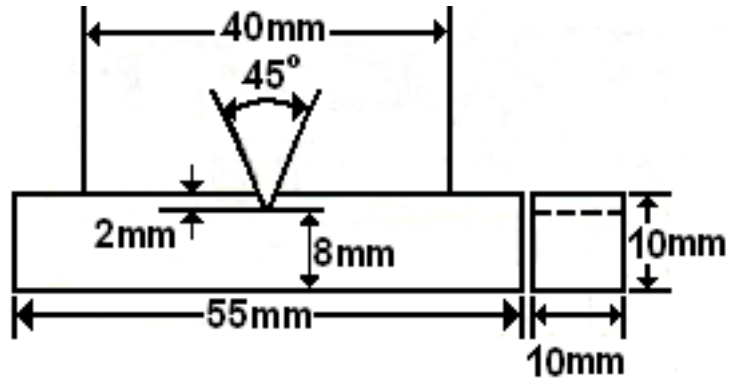
Conditions	HV Hardness (Kg/mm ²)	Torsion Strength (Kg/mm ²)	Impact Strength (Kg.m/cm ²)	Yield strength (Mpa)	Ultimate strength (Mpa)	Elongation %
(A) as received	132	67.4	11.0	492	701	20
(B) water quenched	556	87	8.6	-	885	18
(C) air cooled	210	45	43.0	505	702	11
(D) furnace cooled	155	52.5	80.3	317	496	25



Sample (A) torsion specimen



Sample (B) tensile specimen



Sample (C) Impact specimen

Figure (1): sketch of testing specimens.

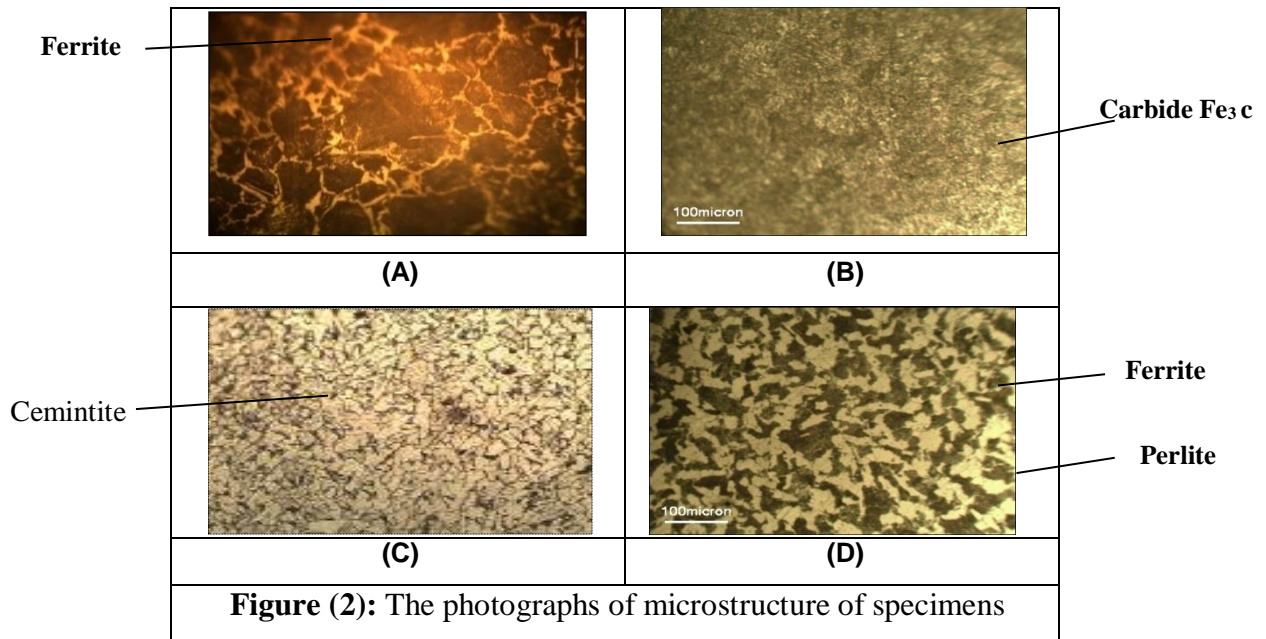


Figure (3): The photos show fracture shape experienced Specimens.

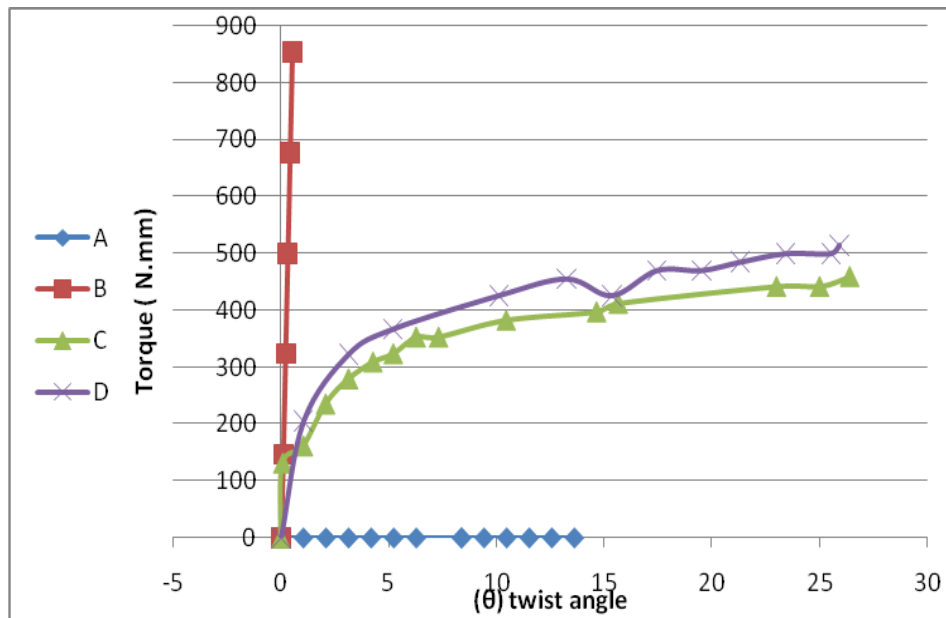


Figure (4): Relationships between Torque and twist angle.

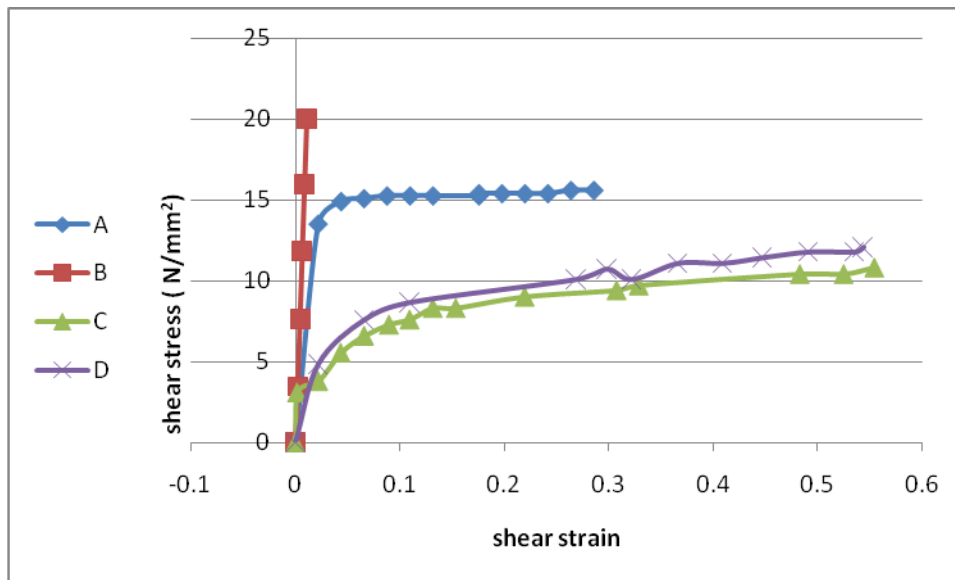


Figure (5): Relationship between shear stress and shear strain.

تأثير معدل التبريد على الخواص الميكانيكية لفولاذ كاربوني St 35

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الخلاصة

يهدف البحث الى دراسة تأثير معدل التبريد على الخواص الميكانيكية للفولاذ كاربوني (St 35) حيث تم تصنيع عينات اختبار (الشدواللي والصدمة والصلادة) ثم اجريت معاملات حرارية متضمنة تسخين المعدن الى درجة حرارة (850°C) لمدة ساعة ثم التبريد في ثلاث اوساط مختلفة (الماء - الهواء - الفرن). اجريت الاختبارات الميكانيكية اعلاه قبل وبعد المعاملة الحرارية لغرض المقارنة وكذلك تم اجراء فحص للبنية المجهرية باستخدام المجهر الضوئي للتعرف على الاطوار التي تم الحصول عليها لبيان تأثيرها على الخواص اعلاه. من النتائج التي تم الحصول عليها بعد الاختبارات الميكانيكية تبين ان لوسط التبريد دورا في تغيير الخواص الميكانيكية وان تغيير احدها سيؤثر على الخاصية الاخرى. فقد زادت قيمة الصلادة وقوة الشد واللي بينما قلت قابلية الصدمة في الوسط المائي بينما حدث عكس هذه النتائج في التبريد بالفرن اما عند التبريد بالهواء تحسنت اكثر الخواص بسبب التجانس في حجم الحبيبات وتحسنت خواص مطيلية وقوة صدمة المعدن.