International Journal of Civil and Structural Engineering– IJCSE
Volume 1 : Issue 3 *[ISSN 2372 – 3971]*
Publication Date : 30 September, 2014

Effect of Annealing Temperature on Toughness of low carbon steel

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Abstract*— mostly steel are heat treated under controlled sequence of heating and cooling to modify mechanical properties to meet desired requirements of engineering applications. The main objective of this study is to investigate the effect of different annealing temperature on the impact toughness of low carbon steel grade Fe-415D. Sample of steel was purchased from local market. The steel samples were heat treated (annealed) in electric muffle furnace at different temperature level and holding times and then cooled in furnace. The toughness properties of the heat treated and untreated samples were determined using impact testing machine. Results showed that toughness properties of steel can be changed and improved by annealing heat treatment process. *(Abstract)

Keywords—Annealing, Toughness, Izod Testing machine, Muffle Furnace (key words)

I. Introduction

Despite constant development of new materials steel is still one of the most reliable, most used, and most important materials of today. Depending on the chemical composition and the thermo mechanical processing history during the manufacturing process. Its mechanical properties can vary tremendously, covering an extensive range of strength, toughness and ductility. Steel can also be relatively cheaply manufactured in large quantities to very precise specifications. Therefore, it is not surprising that irons and steels account for over 80% by weight of the alloys used in industry, as per [3].

Impact properties of steel are primarily depending on the chemical composition and heat treatment [4]. In the present study, a comparison has been made for impact strength of different heat treated steel.

II. Composition of the Material

A 10 mm square cross section mild steel bar had been purchased from local market for the purpose of research.

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Chemical composition of the steel has shown in Table I and section weight of steel has shown in Table II. Indian standard for steel is IS: 1786-2008 and Steel Grade is Fe-415D. Mechanical Properties of steel are such as Yield stress is 415 N/mm^2, Tensile strength is 500 N/mm^2 and percentage elongation is 18.

TABLE I. CHEMICAL COMPOSITION OF STEEL (IS:1786-2008)

Steel Designation	Constituent percentage in weight					
	C	*MN*	*Si*	*S*	*P*	*Fe*
Grade Fe-415D	0.23	0.60	0.30	0.040	0.040	rest

TABLE II. SECTION WEIGHT OF STEEL (IS:1786-2008)

Size of bar	*Kg/meter.*
10mm Square	0.617[a]

a. Formula for section weight=10×10/162=0.617

III. Heat-treatment of specimens

To obtain the improvement in the toughness of Fe-415D Steel material will have to be heat treated the effect of heat treatment are inter allied with the metallurgies of metals. The object of heat treatment is to refine the grain structure and thus obtain the required mechanical properties and also to relieve internal stresses setup during manufacture as steel is heated or cooled up to the specific temperature in muffle furnace, structural changes take place due to molecular re-arrangement in the steel constituents.

The process of heat treating is the method by which metals are heated and cooled in a series of specific operations that never allow the metal to reach the molten state. Through heat treating, we can make a metal harder, stronger, and more resistant to impact. Also, heat treating can make a metal softer and more ductile.

A. *Heat treating theory*

The various types of heat treating processes are similar because they all involve the heating and cooling of metals. They are differs in the heating temperatures and the cooling rates used and the final results. The usual methods of heat treating ferrous metals are annealing, normalizing, hardening and tempering.

B. Stages of heat treatment

Heat treating is accomplished in three major stages:

- Stage 1 – Heating the metals slowly to ensure a uniform temperature.
- Stage 2 – Soaking (holding) the metal at a given temperature for a given time and cooling the metal to room temperature.
- Stage 3 - Cooling the metal to room temperature.

C. Annealing: a heat treatment

Annealing is done for metals to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. Annealing consists of heating a metal to a specific temperature holding it at that temperature for a set length of time and then cooling the metal into the furnace up to the room temperature.

D. Rectangular Muffle Furnace for Heat treatment

Muffle furnace, which is used for heat treatment of specimens, is as shown in Figure 1. Here Specifications for Muffle furnace has being described. The Outer shell of furnace made out of thick mild steel duly finished in attractive stoving enamel paint. Fitted with grooved refractory for supporting the heating elements made outs of Kanthal wire and is easily replaceable max.temp.1000^0C with working temp. 900 ^{0}C controlled by digital temp. Indicator-cum-controller.

Figure 1. Rectangular Muffle furnace for heat treatment

E. Heat treatment for specimen

Annealing heat treatment is done on various specimens for different annealing temperature and holding time for achieving toughness properties. Different annealing conditions are shown in Table III.

TABLE III. TEMPERATURE AND HOLDING TIME FOR ANNEALING OF SPECIMEN

Carbon Steel Specimen	*Annealing Temperature(^{0}C)*	*Holding Time(min)*
Specimen A	825	27
Specimen B	865	30
Specimen C	900	33
Specimen D	935	36

IV. Toughness (Izod Impact) testing

The purpose of impact testing is to measure an ability of object to resist high rate loading. It is usually thought of in terms of two objects striking each other at high relative speeds. A part or material's ability to resist impact often is one of a part, or in the suitability of a designated material for a particular application. Impact resistance can be one of the most difficult properties to quantify. The ability to quantify this property is a great advantage in product liability and safety, as per [1].

The text is conducted for the specimen of different samples after heat treated less than 950^0 C in muffle furnace. The test consists of measuring the energy absorbed in breaking v-notch specimen by giving a single blow by swinging hammer. The specimens are mounted vertically in die of the impact machine. As the velocity of striking body is changed, there must occur a transfer of energy. Work is done on the parts receiving the blow. The mechanics of impact involves not only the questions of stresses induced, but also a consideration of energy transfer and of energy absorption and dissipation.

The ability of material to absorbed energy and deform plastically before fracture is called "toughness". It is usually measured by the energy absorbed in a notched impact test like Izod test. In present work for each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case.

A. Specifications of Impact testing machines

Impact testing machine as shown in figure 2 and figure 4 is designed to meet the essential requirements of IS: 1757-1974, IS: 1598-1977 and IS: 1499-1977 for conducting Charpy and Izod impact test on both V-notch and U-notch test specimen. It is calibrated in accordance with IS:3766-1877.The maximum energy of the pendulum is 300 J for Charpy test and 164 J for Izod test and the scale is calibrated to indicate directly the energy absorbed in Joule.

Following are the specifications for the Izod Impact tester:

- Impact capacity-164 Joule
- Least count of scale-2 Joule
- Swing diameter of hammer -1860mm
- Angle of hammer- 90^0
- Weight of striking hammer- 18.75 kg
- Overall dimensions – length × width× height - 770×430×1180 mm

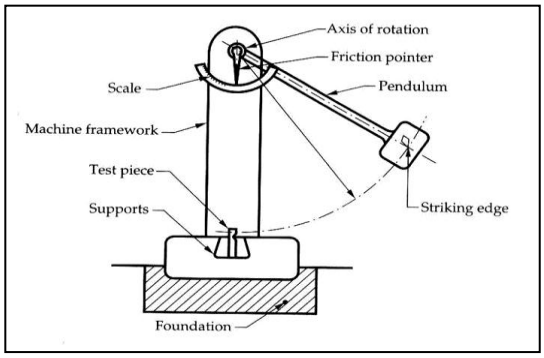

Figure 2. Izod Impact testing machine

B. *Izod-Impact Specimen for test*

Impact test measure the strength of a material under dynamic loading, most of the structural components are subjected to dynamic loading. Hence knowledge of tensile strength alone will not be sufficient use as a design parameter. Impact strength of a material is defined as the compatibility of the material to absorb energy without failure under impact loading. The Izod specimen has square cross section here as described in figure 3. The specimen has a V-shape notch. The depth of notch is 2 mm and included angle is 45^0 . In this test, a hammer strikes the specimen which is fixed in vertical position and the notch faces the hammer.

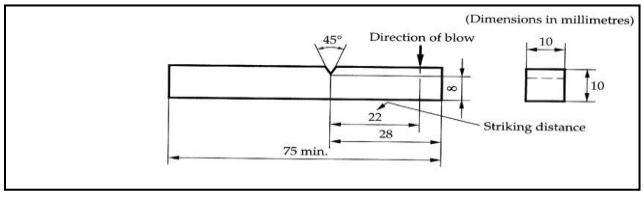

Figure 3. Izod Impact testing Specimen

C. *Izod-Impact test for different heat treated (annealing) specimen*

Annealing is a heat treatment process by which toughness properties of the material changes. Specimens are heat treated according to annealing conditions given in Table III. After completing heat treatment (annealing process), three specimens for every conditions are tested for toughness properties on Impact –Izod testing machine and average of value of toughness of three specimens for every annealing condition has been shown in Table IV.

Impact –Izod testing machine, which is used for testing is shown in figure 4. The Specimen (without heat treatment), which has been tested on Impact-Izod testing machine has shown in figure 5.

Figure 4. Izod Impact testing Machine

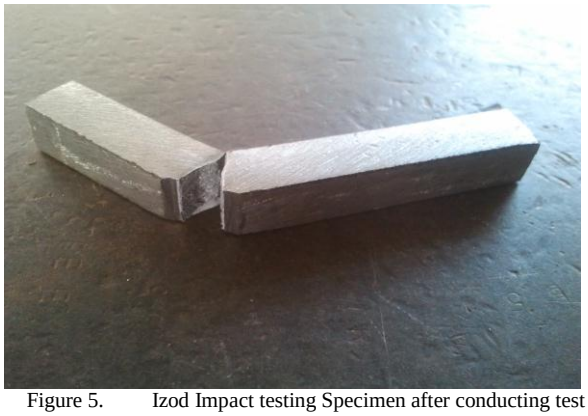

Figure 5. Izod Impact testing Specimen after conducting test

TABLE IV. IMPACT STRENGTH OF DIFFERENT ANNEALED SPECIMEN

Carbon Steel Specimen	***Impact strength (in Joule)***
Specimen (O)	20
Specimen (A)	16
Specimen (B)	22
Specimen (C)	24
Specimen (D)	20

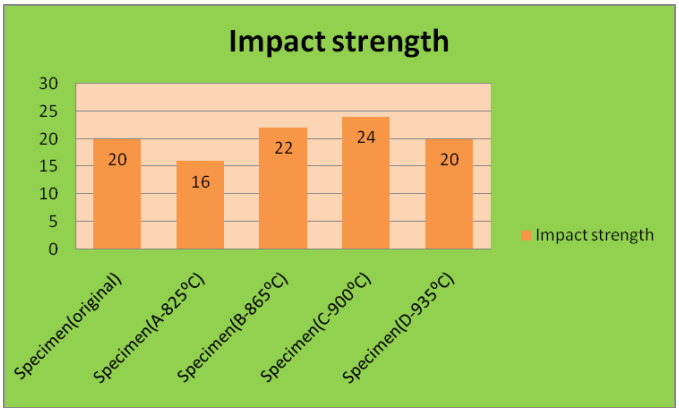

Figure 6. Impact strength for different annealing temperature Specimen

v. Results and Conclusion

It can be seen from the histogram of the figure 6 that the impact toughness in general increases as the annealing temperature increases, the maximum is 50% that achieved at 825^0 C and Impact strength increases 20% that achieved without heat treatment. This indicates that the annealed steel will sustain.

Following points can be concluded as follows:

a) ***The impact strength of steel increases in annealing process.***

b) ***Impact strength of specimen will be more in annealing heat treatment process than without heat treatment.***

c) ***Impact toughness of steel in general increases as the annealing temperature increases.***

d) ***Impact toughness of steel in general decreases after 900^0C.***

e) ***Maximum impact strength is 50% than that achieved at 825^0C.***

Acknowledgment

We are thankful to the effort of the technical staff of laboratories and workshop of Department of Mechanical engineering of Roorkee Institute of Technology, Roorkee(India).

Further, we are very thankful to Prof. A. K. Mathur, Director General and Dr. S. K. Saini, Director of Roorkee Institute of Technology, Roorkee for motivating and providing research facilities at the Institute.

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