# Effect of Annealing Temperature on the Microstructure, Microhardness, Mechanical Behavior and Impact Toughness of Low Carbon Steel Grade 45

**S.M.A. Al-Qawabah*, Nabeel Alshabatat*, U.F. Al-Qawabeha***
*(Department of Mechanical Engineering, Tafila Technical University, Jordan
P.O.Box 13720, Amman 11942)

## ABSTRACT
**Due to the high usage of low carbon steel in multiplications, previous work was focused toward its mechanical characteristics, this work rely on studying the effect of multi-régimes of annealing temperatures namely; 820,860, 900, and 940 ˚C on the impact toughness, microstructure, microhardness and mechanical characteristics. A set of test specimens for impact, compression test, and microstructure test were prepared using CNC machine. It was found that the impact energy is increased as the annealing temperature increase; the maximum is 22.5 % that achieved at 820˚C. it was found that the microhardness decrease as the annealing temperature increase except at 940 ˚C it return back to increase, the maximum decrease was 31.6 % that achieved at 900 ˚C.**

*Keywords* : impact energy, microhardness, steel C45, toughness.

## 1. Introduction
Low carbon steel has carbon content of 0.45%. Low carbon steel is the most common form of steel as it's provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile due to its lower carbon content. It has lower tensile strength and malleable. Steel with low carbon steel has properties similar to iron. As the carbon content increases, the metal becomes harder and stronger but less ductile and more difficult to weld. The process heat treatment is carried out first by heating the metal and then cooling it in water, oil and brine water. The purpose of heat treatment is to soften the metal, to change the grain size, to modify the structure of the material and relive the stress set up in the material. The various heat treatment processes are annealing, normalizing, hardening, tempering, and surface hardening. Annealing to improve ductility and toughness, to reduce hardness and to remove Carbides. Annealing is heat treatment of steel by heating the steel to a temperature above hypoeutectoid SLT (Upper Critical Temperature). Steel is heated to approximately 100F on the SLT program. Then cooled in the furnace very slowly to room temperature. Formation of austenite to destroy all existing structures prior to heating. Slow cooling produces original phases of ferrite and pearlite Hypereutectoid steel consists of pearlite and cementite. Cementite is fragile tissue around the pearlite. To improve the machinability of steel annealing hypereutectoid spheroidize applied. This process will produce a round shape or a ball of carbide in the ferritic matrix which makes the machine easy. At the high temperature will break perlitik structure and cementite network, this structure is called spheroidite. This structure is desirable for the violence acquired a minimum, with maximum ductility and maximum machinability. Low carbon steel spheroidized rare for machines, because they are too soft and sticky in spheoridized conditions. Cutting tools will tend to push the material rather than cut, causing excessive heat and wear on the cutting edge. Stress-Relief Annealing sometimes called subcritical annealing, useful to eliminate residual stress due to heavy machining or cold-employment benefits. This is usually done at temperatures below the LCT, which is usually chosen around 1000F. Benefits annealing are Improve the ductility, Remove residual stresses that result from cold-working or machine and Improve machinability. And several test we don on this project which are impact test, microstructure test and hardening test. In literature it is possible to find many works regarding the quenching heat treatment with very encouraging results [1–3]. Current processes leading to carbide spheroidisation rely on diffusion of carbon in a workpiece heated to a temperature close to or slightly below Ac1 [4]. During annealing, softening processes are under way in the microstructure and, in some cases, recovery and recrystallization take place as well. Naturally, the morphology of carbides changes as well [5].

The purpose of impact testing is to measure an object's ability 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 the determining factors in the service life 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. The Charpy tests are conducted on instrumented machines capable of measuring less than 1ft.lb. To 300ft. lbs. at temperatures ranging from 320° F to over 2000°F. Specimen types include notch configurations such as V-Notch, U-Notch, Key-Hole Notch, as well as Un-notched and ISO (DIN) V-Notch, with capabilities of testing subsize specimens down to 1/4 size. IZOD testing can be done up to 240ft.lbs. On standard single notch and type-X3 specimens [5].

Hardness tests are limited in practical use and do not provide accurate numeric data or scales particularly for modern day metals and materials. The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry [5].

The main objectives of this study are to investigate the effect of different annealing temperatures on the impact toughness, microhardness and mechanical behavior of low carbon steel grade 45.

## 2. Material and Procedures

2.1 Material

In this study a set of low carbon steel C45 specimens have been used, the density is 7.85 gm/$cm^3$, where the chemical composition is ( 0.42 C, 0.24Si, 0.69 Mn, 0.019P, 0.016Cr, 0.12Ni, 0.16Cu, 0.12Mo, 0.02Ti, 0.002V, 0.004W).

2.2 Experimental Procedures

2.2.1 Annealing process

Annealing is a heat treatment process by which the material characteristics changes such as hardness and strength of the material, where the annealing conditions are shown in Table 1.

Table 1. Temperatures and holding times for annealing process.

| Carbon steel C45 | Annealing Temperature (˚C) | Holding time (min) |
|---|---|---|
| A | 820 | 27 |
| B | 860 | 30 |
| C | 900 | 33 |
| D | 940 | 36 |

The annealing regimes are shown in Fig. 1.

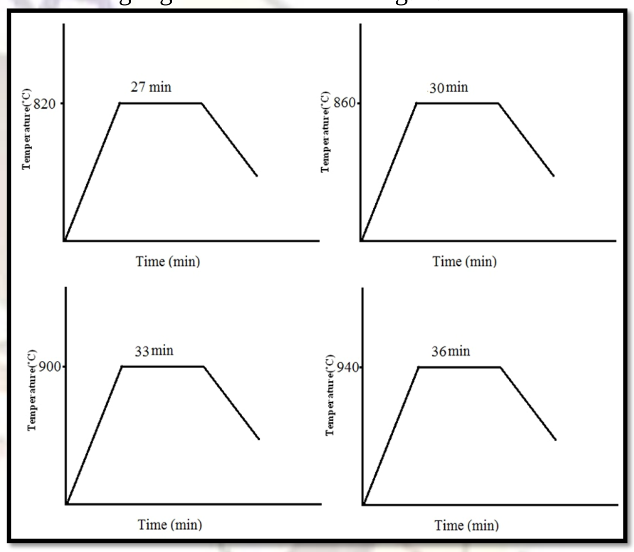


Fig.1: Annealing regimes of low carbon steel grade 45

2.2.2 Charpy impact test

Impact tests are designed to measure the resistance to failure of a material to a suddenly applied force. The test measures the impact energy, or the energy absorbed prior to fracture. Charpy bar test pieces (10*10*55 $mm^3$) were machined using CNC machine. Three specimens of each regime were tested to ensure the repeatability from which the average is calculated.

2.2.3 Compression test

Compression test determining the behavior of materials under crushing loads. Specimens of 10 mm in diameter and 10mm height (H/D =1) are compressed, and deformation at various loads is recorded where the procedure of compression test was performed in the following steps:

1- Centered the specimens on a table of compression device.

2- Move the punch downward to the specimen where uniaxial compressive load is applied using Qusar of 100 KN capacity.

3- Starting the compressed of specimen using strain rate of $3.96*10^{-1}$/s .

4- Load-Deflection curves were obtained from the true stress- true strain was investigated.

2.2.4 Microstructure

A specimen of each regime was prepared for the microstructure test using microscope type (Nikon 208) at 200x manufacturing using (98% alcohol ethanol +2% nitric acid) as etching solution.

2.2.5 Hardening test

A digital microhardness tester model HWDM-3 is used to investigate the hardness of low carbon steel specimens at 300 gmf load; five readings were taken from which the average was determined.

**3. Result and Discussion**

3.1 Effect of annealing temperature on the microstructure of low carbon steel C45

It can be seen from Fig.2 that the grain size becomes larger as the annealing temperature increase this due to lower cooling rate. This will resulted in changing the mechanical characteristics of low carbon steel grade C45 according to hall-pitch equation.

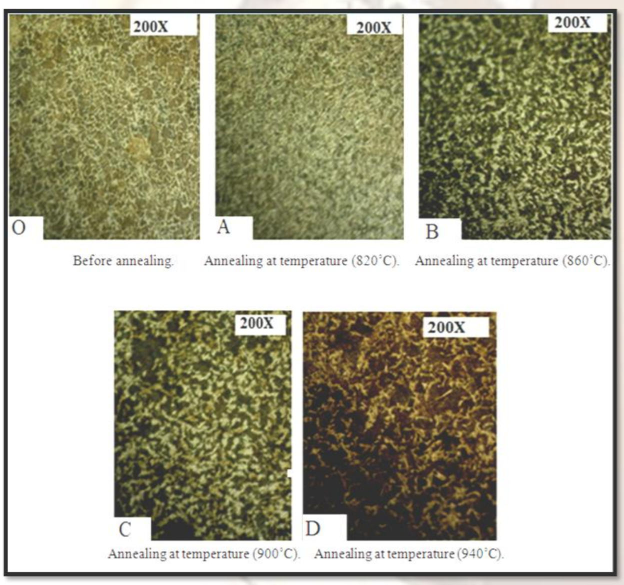


Fig.2: Photomicroscan of carbon steel C45 before and after annealing at 200x.

3.2 Effect of annealing temperature on the microhardness of low carbon steel C45

From the histogram of Fig. 3 it can be seen that the microhardness decrease as the annealing temperature increase except at 940 ˚C it return back to increase, the maximum decrease was 31.6 % that achieved at 900 ˚C. This can be attributed to the coarse grains as shown in Fig.2.

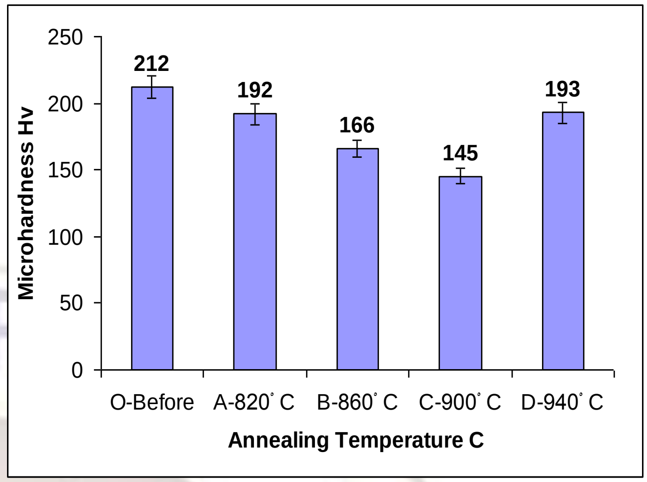


Fig.3: Effect of annealing temperature on the microhardness of low carbon steel C45.

3.3 Effect of upsetting process on the microhardness of low carbon steel C45

It obviously clear from Fig.4 that the microhardness affected by the plastic deformation, the microhardness increased after upsetting process the maximum is 75 % that attained after 860 ˚C annealed temperature.

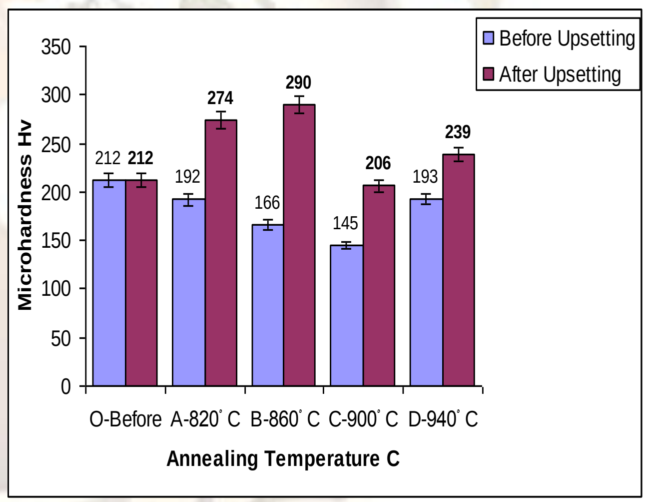


Fig.4: Effect of upsetting process on the microhardness of low carbon steel C45 and its regimes.

3.4 Effect of annealing temperature on the mechanical behavior of low carbon steel C45

It can be seen from Fig.5 that as the annealing temperature increase to 900 ˚C the mechanical behavior decrease, but at 940 ˚C the mechanical characteristics enhanced, this finding is consistent with the microhardness results.

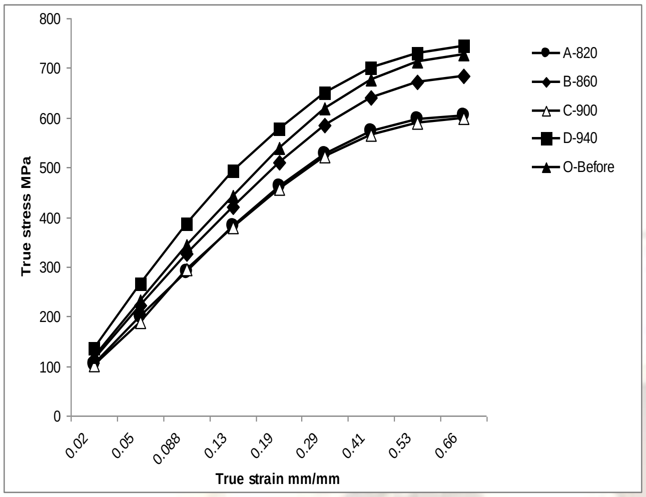


Fig.5: Effect of annealing temperature on the mechanical behavior of low carbon steel C45.

3.4 Effect of annealing temperature on the impact energy of low carbon steel C45

It can be seen from the histogram of Fig. 6 that the impact toughness in general increase as the annealing temperature increase, the maximum is 22.5 % that achieved at 820˚C. This indicates that the annealed steel will sustain
further plastic deformation during the forming processes, however the formability of low carbon steel C45 will be enhanced.

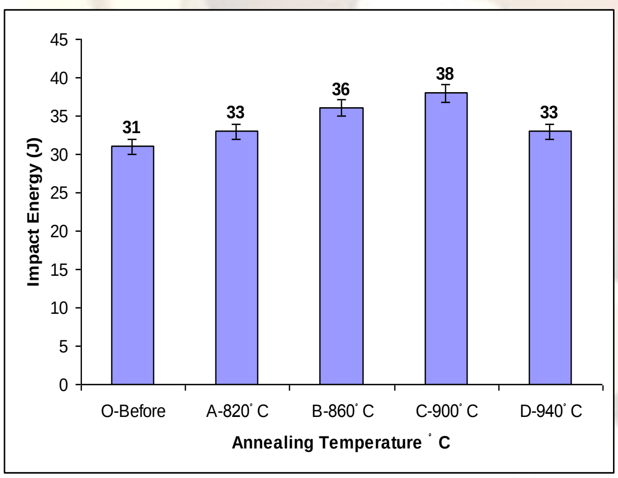


Fig.6: Effect of annealing temperature on the impact energy of low carbon steel C45 and its regimes
.

## 4. Conclusions

The following points can be concluded:

1- The impact toughness in general increase as the annealing temperature increase, the maximum is 22.5 % that achieved at 820˚C.

2- Microhardness is increased after upsetting process the maximum is 75 % that attained at 860 ˚C.

3- The microhardness decrease as the annealing temperature increases except at 940 ˚C it returns back to increase, the maximum decrease was 31.6 % that achieved at 900 ˚C.

4- The grain size becomes larger as the annealing temperature increase.

## 5. Acknowledgment

This work has been supported by Tafila Technical University which is acknowledged. The efforts of the technical staff at mechanical engineering laboratories and workshops are highly appreciated.

## References

[1] K.F. Wang,S. Chandrasekar,H.T.Y. Yang, Experimental and computational study of the quenching of carbon steel,J. Manuf.Sci. Eng. 119 (1997) 257–265.

[2] Y. Toshioka,Heat treatment deformation of steel products,Mater. Sci. Technol. 1 (1985) 883–892.

[3] J. Fuhrmann,D. Homberg,Numeric al simulation of the surface hardening of steel,Int. J. Numer. Method Heat Fluid Flow 9 (6) (1999) 705–724,MCB University press.

[4] Ghosh S. (2010), Rate-controlling parameters in the coarsening kinetics of cementite in Fe–0.6C steels during tempering.*Scripta Materialia*, Vol. 63, No. 3, 273-276, ISSN 1359-6462.

[5] Nam W. J. & Bae C. M. (1999), Coarsening Behavior of Cementite Particles at a Subcritical temperature in a medium Carbon Steel. *Scripta Materialia*, Vol. 41, No. 3, pp. 313-318, ISSN 1359-6462