EUROPEAN ACADEMIC RESEARCH
Vol. VIII, Issue 3/ June 2020

ISSN 2286-4822
www.euacademic.org

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

# Changes in mechanical properties of steel 42 CrMo4 with manganese addition (Part B)

FATIMA KAREEMALDEEN
FATIMA HOMEIDA
MUSAB HAJALFADUL
ELJACK BABIKER
Faculty of Engineering, University of Khartoum
Khartoum, Sudan

**Abstract**

*This work investigates the effect of adding the manganese as an alloying element to the alloy steel. The great variations and flexibility of steel in making different types and grades of alloy steel. Impact tests methods are discussed, and detailed literature has been provided. Hardness test is also conducted and discussed too. Mechanical tests are conducted and discussed in detail in this work. From Charpy impact it was noticed that the toughness of steel 42CrMn4 increased when the mass percentage of manganese increases. From Rockwell hardness tests it was noticed that hardness decreased when mass percentage of manganese increased.*

**Keywords:** Metal alloys, Mechanical Behavior, Impact damages

## INTRODUCTION

Properties of material are classified into physical, chemical, and mechanical properties. This research is focusing on mechanical properties. Mechanical properties describe how a material will response to applied load or force, which is the dominant factor in material selection. These mechanical properties are determined by subjecting prepared specimens to standard laboratory tests designed to evaluate the material reaction to applied force [1].

Metal alloys, by virtue composition are often grouped into two classes, ferrous and nonferrous. Ferrous alloys, are those in which iron is the principal constituent, include steels and cast irons. They are produced in larger quantities than any other metal type and are especially important as engineering construction materials. Their widespread use is due to three factors: Iron-containing compounds exist in abundant quantities within the Earth's crust.

Metallic iron and steel alloys may be produced using relatively economical extraction, refining, alloying, and fabrication techniques. Ferrous alloys are extremely versatile, in that they may be tailored to have a wide range of mechanical and physical properties. The principal disadvantage of many ferrous alloys is their susceptibility to corrosion.

For alloy steel, more alloying elements are intentionally added in specific concentration. The differentiation between "plain carbon" and "alloy steel" is often somewhat arbitrary. Both contain carbon, manganese, and usually silicon. Copper and boron are also possible additions to both classes. Steels containing more than 1.65% manganese, 0.60% silicon, or 0.60% copper are designated as alloy steels. Also, a steel is considered an alloy steel if a definite amount or minimum of another alloying element is specified or required.

The most common alloy elements are chromium, nickel, molybdenum, vanadium, tungsten, cobalt, boron, and copper, as well as manganese, silicon, phosphorus, and Sulphur in amounts greater than are normally present.

## MECHANICAL PROPERTIES

Many materials, when in service, are subjected to forces or loads; examples include the aluminum alloy from which an airplane wing is constructed and the steel in an automobile axle. In such situations it is necessary to know the characteristics of the material and to design the member from which it is made such that any resulting deformation will not be excessive, and fracture will not occur.

The mechanical behavior of a material reflects the relationship between its response or deformation to an applied load or force. Important mechanical properties are strength, hardness, ductility, and stiffness. The mechanical properties of materials are ascertained by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. Factors to be considered include the nature of the applied load and its duration, as well as the environmental condition.

It is possible for the load to be tensile [2-4], compressive [5,6], or shear [7-9], impact [10-14] and its magnitude may be constant with time, or it may fluctuate continuously. Application time may be only a fraction of a second, or it may extend over a period of many years. Service temperature may be an important factor. Mechanical properties are of concern to a variety of parties (e.g., producers and consumers of materials, research organizations, and government agencies) that have differing interests.

Consequently, it is imperative that there be some consistency in the manner in which tests are conducted, and in the interpretation of their results. This consistency is accomplished by using standardized testing techniques. Establishment and publication of these standards are often coordinated by professional societies. In the United States the most active organization is the American Society for Testing and Materials (ASTM) [14]. Its Annual Book of ASTM Standards comprises numerous volumes, which are issued and updated yearly; a large number of these standards relate to mechanical testing techniques.

Several of these are referenced by footnote in this and subsequent parts. The role of structural engineers is to determine stresses and stress distributions within members that are subjected to well-defined loads. This may be accomplished by experimental testing techniques and/or by theoretical and mathematical stress analyses.

These topics are treated in traditional stress analysis and strength of materials texts. Materials and metallurgical engineers, on the other hand, are concerned with producing and fabricating materials to meet service requirements as predicted by these stress analyses. This necessarily involves an understanding of the relationships between the microstructure (i.e., internal features) of materials and their mechanical properties. Materials are frequently chosen for structural applications because they have desirable combinations of mechanical characteristics.

## MECHANICAL TEST

### Impact test

A material may have a high tensile strength and yet be unsuitable for shock loading conditions. To determine this the impact resistance is usually measured by means of the drop tower [15-19] or Charpy impact test [20,21]. In this test a load swings from a given height to strike the specimen, and the energy dissipated in the fracture is measured. The test is particularly useful in showing the decrease in ductility and impact strength of materials of bcc structure at moderately low temperatures. For example, carbon steels have a relatively high ductile–brittle transition temperature and, consequently, they may be used with safety at sub-zero temperatures only if the transition temperature is lowered by suitable alloying additions or by refining the grain size.

Nowadays, increasing importance is given to defining a fracture toughness parameter Kc for an alloy, since many alloys contain small cracks which, when subjected to some critical stress, propagate; Kc defines the critical combination of stress and crack length.

### Hardness test

The hardness test measures the resistance to penetration of the surface of a material by a hard object. Hardness cannot be defined precisely [22,23]. Hardness, depending upon the context, represents resistance to scratching or indentation and a qualitative measure of the strength of the material. In general, in macro hardness measurements the load applied is at 2 N. A variety of hardness tests have been devised, but the most commonly used are the Rockwell test and the Brinell test. Different indentors used in these tests are shown in Figure 1. In the Brinell hardness test, the indentor is a hard steel sphere (usually 10 mm in diameter) that is forced into the surface of the material. The diameter of the impression, typically 2 to 6 mm, is measured and the Brinell hardness number (abbreviated as HB or BHN) is calculated from the following equation:

$$\boldsymbol{HB} = \frac{2F}{\pi D\left[D-\sqrt{D^2-D^2{}_i}\right]}$$

Where F is the applied load in kilograms, D is the diameter of the indentor in millimeters, and Di is the diameter of the impression in millimeters. The Brinell hardness has the units of stress (e.g., kg/mm2).

The Rockwell hardness test uses a small-diameter steel ball for soft materials and a diamond cone, or Brale, for harder materials. The depth of penetration of the indentor is automatically measured by the testing machine and converted to a Rockwell hardness number: hardness Rockwell (HR). Since an optical measurement of the indention dimensions is not needed, the Rockwell test tends to be more popular than the Brinell test.

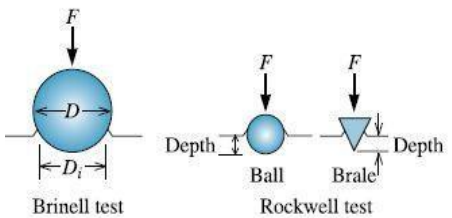


**Figure 1: Indentor for the Brinell and Rockwell hardness tests.**

## Steel 42 CrMo4 Sample specifications

*General properties:* CrMo-alloyed steel, engineering steel supplied in tempered and quenched conditions. Good machinability.
*Applications:* Components with high requirements on toughness, e.g. gear wheel, pinions, connecting rods, parts for mechanical engineering.
*Conditions of delivery:* quenched tempered.
*Chemical composition:* Contain C, Si, Mn, Cr, Mo, Ni, Al, Cu, Ti, V, Nb, Co, W, Pb and Fe

**Table 1: Sample specification (mechanical properties)**

| Diameter D (mm) | <16 | >16-40 | >40-100 | >100-160 | >160-250 |
|---|---|---|---|---|---|
| Thickness t (mm) | <8 | 8<t>20 | 20<t>60 | 60<t>100 | 100<t>160 |
| Yield strength Re (N/mm2) | Min.900 | Min.750 | Min.650 | Min.550 | Min.500 |
| Tensile strength Rm (N/mm2) | 1100-1300 | 1000-1200 | 900-1100 | 800-950 | 750-900 |
| Elongation (%) | Min.10 | Min. 11 | Min.12 | Min. 13 | Min.14 |
| Reduction of area (%) | Min.40 | Min.45 | Min.50 | Min.50 | Min.55 |
| Toughness J | Min.30 | Min.35 | Min.35 | Min.35 | Min.35 |

## Preparations for testing

For the chemical composition test, the sample was cleaned from impurities beforehand and then the chemical composition test was performed. For hardness test, the sample was cleaned to obtain more accurate properties. For tensile test, the sample was cut and formed to suitable shape in order to be fixed. The sample was cut to standard size for impact tests.

## Hardness test

The hardness test measures the resistance to penetration of the surface of a material by a hard object. In this research to measure the hardness of the specimen, the Rockwell hardness test was conducted.
*Hardness test procedures*:

- The sample was correctly placed on the anvil of the Rockwell hardness device.
- The base of the device was slowly rotated until the LED reached 'SET'.
- The test was automatically started.
- The reading was taken, and these steps were repeated for other areas of the sample.

## Impact test

Impact resistance was measured by the Charpy analysis. In this test, a load is swung from a given height to strike the specimen, and the energy dissipated in the fracture was measured.
*Impact test procedures*

- The specimen was placed into the support with the notch facing the back side of the striking load.
- Using the setting gauge, the notch was centered between the anvil.
- The pointer was placed to read the amount of energy that the specimen has absorbed.
- The hammer was released, and the pointer indicated the amount of energy absorbed by the specimen,

## RESULTS AND ANALYSIS

Impact test:

**Table 2: toughness of specimen**

| Specimen number | Mn% | Toughness(j) |
|---|---|---|
| 1 | 0.342 | 35 |
| 2 | 0.545 | 40 |
| 3 | 0.689 | 43 |

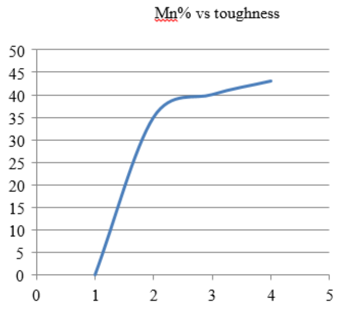


**Figure 2: Mn% vs toughness of specimen**

### Hardness properties:

When conducting hardness tests for each specimen the following readings were obtained:

**Table 2: hardness test results**

| Specimen number | Mn% | Hardness(HRC) |
|---|---|---|
| 1 | 0.342 | 33 |
| 2 | 0.545 | 26 |
| 3 | 0.689 | 22 |

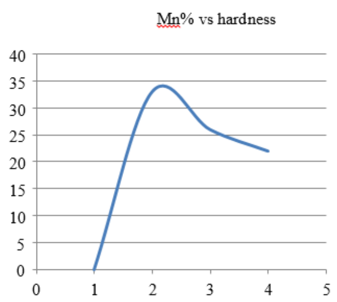


**Figure 1: Mn% vs hardness of specimen**

## CONCLUSION

- From Charpy impact it was noticed that the toughness of steel 42CrMn4 increased when the mass percentage of manganese increases.
- From the impact test, the toughness of the specimen decreased when the mass percentage of manganese was increased, which is not an unexpected result.
- From Rockwell hardness tests it was noticed that hardness decreased when mass percentage of manganese increased.
- The specimen that contains high concentration of manganese, has high tensile strength and yield strength and vice versa.
- The specimen that contains high concentration of manganese, has low hardness which is not reasonable due to the of effects of chromium, because high percentages of chromium in the specimen increased the hardness of steel.

## REFERENCES

1.Pelleg, Joshua. Mechanical properties of materials. Vol. 190. Springer Science & Business Media, 2012.
2.Hollomon, John H. "Tensile deformation." Aime Trans 12.4 (1945): 1-22.
3.Abbassi, Fethi, Sebastien Mistou, and Ali Zghal. "Failure analysis based on microvoid growth for sheet metal during uniaxial and biaxial tensile tests." Materials & Design 49 (2013): 638-646.
4.Hoffmann, H., and S. Hong. "Tensile test of very thin sheet metal and determination of flow stress considering the scaling effect." CIRP annals 55.1 (2006): 263-266.
5.Sun, Chaoyang, et al. "Constitutive relationship of IN690 superalloy by using uniaxial compression tests." Rare Metals 30.1 (2011): 81-86.
6.Lee, Woei-Shyan, and Chi-Feng Lin. "High-temperature deformation behaviour of Ti6Al4V alloy evaluated by high strain-rate compression tests." Journal of Materials Processing Technology 75.1-3 (1998): 127-136.
7.Lee, Woei-Shyan, and Chi-Feng Lin. "High-temperature deformation behaviour of Ti6Al4V alloy evaluated by high strain-rate compression tests." Journal of Materials Processing Technology 75.1-3 (1998): 127-136.
8.May, Michael, and Stephen R. Hallett. "An assessment of through-thickness shear tests for initiation of fatigue failure." Composites Part A: Applied Science and Manufacturing 41.11 (2010): 1570-1578.

9.Yin, Qing, et al. "An experimental and numerical investigation of different shear test configurations for sheet metal characterization." International Journal of Solids and Structures 51.5 (2014): 1066-1074.
10.Elamin, Mohammed, Bing Li, and K. T. Tan. "Impact damage of composite sandwich structures in arctic condition." Composite Structures 192 (2018): 422-433.
11.Khan, M. H., et al. "X-ray micro-computed tomography analysis of impact damage morphology in composite sandwich structures due to cold temperature arctic condition." Journal of Composite Materials 52.25 (2018): 3509-3522.
12.Bertholf, L. D., et al. "Damage in steel plates from hypervelocity impact. II. Numerical results and spall measurement." Journal of Applied Physics 46.9 (1975): 3776-3783.
13.Mohammed, Mohammed. "Impact and Post Impact Response of Composite Sandwich Structures in Arctic Condition" Electronic Thesis or Dissertation. University of Akron, 2018. OhioLINK Electronic Theses and Dissertations Center. 17 Jun 2020.
14.ASTM, C. "ASTM Standards." Philadelphia: American Society for Testing Materials, 1958.
15.Elamin, M., B. Li, and K. T. Tan. "Impact Performance of Stitched and Unstitched Composites in Extreme Low Temperature Arctic Conditions." Journal of Dynamic Behavior of Materials 4.3 (2018): 317-327.
16.Tan, KT, Mohammed Elamin, and Bing Li. "Impact Performance and Damage Behavior of Composite Sandwich Structures in Arctic Condition." Proceedings of the American Society for Composites—Thirty-second Technical Conference. 2017.
17.Elamin, Mohammed, Bing Li, and K. T. Tan. "Effect of Low Temperature on Impact Behavior of Composite Sandwich Structures."
18.Zeinoddini, M., J. E. Harding, and G. A. R. Parke. "Dynamic behaviour of axially pre-loaded tubular steel members of offshore structures subjected to impact damage." Ocean engineering 26.10 (1999): 963-978.
19.Elamin, M., and J. Varga. "Plate impact method for shock physics testing." Material Sci & Eng 4.1 (2020): 31-35.
20.Toshiro, Kobayashi, Yamamoto Isamu, and Niinomi Mitsuo. "Evaluation of dynamic fracture toughness parameters by instrumented Charpy impact test." Engineering Fracture Mechanics 24.5 (1986): 773-782.
21.Rossoll, A., et al. "Mechanical aspects of the Charpy impact test." Nuclear Engineering and Design 188.2 (1999): 217-229.
22.Hill, Robert, Bertil Storåkers, and A. B. Zdunek. "A theoretical study of the Brinell hardness test." Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences 423.1865 (1989): 301-330.

23.Richmond, O., H. L. Morrison, and M. L. Devenpeck. "Sphere indentation with application to the Brinell hardness test." International journal of mechanical sciences 16.1 (1974): 75-82.