

QUENCHING EFFECTS OF WATER AND BRINE ON THE HARDENING PROPERTIES OF PLAIN CARBON STEELS

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Abstract

The hardening responses of plain carbon steel materials which were quenched from the austenitizing temperature region to room temperature were evaluated using Vickers hardness values. Results obtained for edge and center hardness measurements presented in increasing order of hardness is as follows: As-received plain carbon steel specimens, water quenched specimens, and brine quenched specimens. The higher the carbon content of the steel material, the higher the hardness values attainable for the as received, water quenched and brine quenched specimens. The results show that water and brine quenchants are good for shallow hardening of plain carbon steels.

Introduction

Steels have been known to man since 1000BC Patrick (2001). In those days, the great majority of steel parts were made of cheap low carbon steel that would machine and fabricate easily. However, these days new technical applications and operating requirements have created continued need for steels of optimum mechanical properties such as higher strength as used in almost all the aspects of engineering, depending principally on the carbon and alloying elements present in the steel.

The mechanical properties of steel are greatly enhanced by heat treatment. All basic heat-treating processes for steel, involve the transformation or decomposition of austenite. The nature of appearance of these transformation products determine the physical and mechanical properties of any given steel, Callister (1997), in his book states that the cooling rate of a specimen depends on the rate of heat energy extraction, which is a function of the characteristics of quenching medium in contact with specimen surface, as well as specimen geometry.

Plain carbon steels have been known to adequately respond to heat treatment, Avner (1984). Therefore, this work is aimed at studying the effectiveness of water and brine as quenching media for plain carbon steels.

Plain Carbon Steels

These are metallic materials which are primarily composed of iron (Fe) and carbon(C). They often contain silicon (Si), manganese (Mn), Sulphur(S) and Phosphorus(P) which are introduced in small quantities as a result of processing technique limitations or intentionally added to enhanced certain mechanical properties. The composition of these steels varies but has a maximum level of 1.5%C., HoneyCombe (1980), Dauda (1995). Several methods have been adopted to classify steels. The classification method may be based on any of the following:

- Production method,
- Deoxidation practice,
- Area of application of the product,
- Microstructural make-up of the product, and
- Chemical composition.

The Society of Automotive Engineers (SAE) has developed a more detailed system for designating steels, which was later adopted by the American Iron and Steel Institute -(AIS1). The system is based on chemical composition of the steel, Avner (1984).

Condition of Plain Carbon Steels as Heat Treated

Plain carbon steels have shallow depth of hardening with hard case and tough core. In the hardened condition, a surface hardness of the high carbon grade of 600 - 800HV is possible. This hardness reduces rapidly from edge to the center as indicated in Fig. 1 below, Robert et -al (1965).

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The influence of carbon content on the hardness of austenite and martensite can be appreciated from Table 1.

Table 1 Typical percentages of retained austenite for carbon steels quenched to room temperature. Dell (1979).

Initial Carbon Content, (%)	Retained Austenite at room temperature (%)
0.20	0-2
0.40	0-4
0.60	2-7
0.80	5-14
1.00	15-23
1.20	30-38

Carbon composition is approximately directly related to the attainable hardness of the steel, beyond 0.7% retained austenite becomes prominent and this will cause a slight drop in the hardness of the steel because austenite is softer than martensite, Dell (1979).

Water Quenching

Generally, water as a quenching medium is restricted to plain carbon steels and a few grades of low alloy steels, because they are characterised by low hardenability values. Water is readily available, not expensive and can be disposed of without health problems. However, specimens can be distorted or could crack when quenched in water due its high rate of cooling. Hence, water is restricted to the quenching of simple symmetrical parts made of shallow hardening grades of steel Avner (1984).

'Brine Quenching

Brine is here referred to as an aqueous solution containing various percentages of salt (NaCl or CaCl₂) together with special additives and corrosion inhibitors. The presence of these additives materially decrease the duration of the vapour stage. It has also been shown by Dell (1979) that crystals of salts are precipitated momentarily and are explosively thrown away from the steel surface, during the initial stages of brine quenching, continuously causing the film of steam to be disrupted and leading to violent agitation. Brine solutions have also been known to have the potential of removing scales on quenched metals more rapidly than water.

Experimental Technique

Materials

Six grades of plain carbon steels obtained locally from the market were investigated. The chemical composition and hardness values of the steels as supplied are given in table 2 below.

Table 2: Chemical Composition and Hardness Values (HV) of the Supplied Specimens

S/NO.	%C	%Mn	%Si	%P	%S	VHN Centre	Edge
1.	0.15	0.5	0.45	0.03	0.03	127	127
2.	0.25	0.5	0.45	0.03	0.03	150	158
3.	0.40	0.40	0.45	0.03	0.03	183	216
4.	0.75	0.40	0.45	0.03	0.03	222	231
5.	1.00	0.04	0.45	0.03	0.03	222	231
6.	1.20	0.04	0.45	0.03	0.03	222	231

Methodology

The investigation of the hardening effects of plain carbon steels (0.15% to 1.20%C) was based on hardness measurements of the hardened specimens.

The following procedures was followed:

1. The as - supplied steel samples were cut to the same size of standard geometry, with the ratio of length to diameter of 1 to 4.

2. One flat surface of each specimen was ground smooth for easy hardness measurements.
3. A normalizing treatment was given to the steel samples to remove unfavourable structure before the real hardening operation.
4. All the heat treatment samples were packed into a fireclay ceramic crucible with cast iron chips and pulverized charcoal. The crucible was then covered and sealed with clay to prevent air ingress.
5. The furnace (carbolite electric muffle furnace) was then loaded with the fire clay crucible containing the specimens, and heated to the required austenitising temperature of 850°C.
6. Two test samples of each of the specimens were austenitised for a period of thirty minutes, one was quenched in water and other in brine. This was done for all the six grades of steel under investigation.
7. Hardness measurements at the edge and center of the specimens were taken and the results are shown in figure 2.

Results and Discussion

Table 2 shows the chemical composition and hardness values of the steels in the supplied condition. The variation of hardness values (VHN) with carbon content of the specimens is plotted in Figure 2. It can be observed that the hardness measured at the edges and centers of the specimens increases as the amount of carbon increases reaching a maximum of 222 and 232 VHN at the center and edge respectively for 0.75% C, 1.00% C and 1.20% C steels. This may be as a result of the increase in harder microconstituents because of increase in carbon content. The resultant effect is that more volume of pearlite is formed with a decrease of its interlamellar spacing as well as a decrease in ferrite content, thus yielding harder steel material. This behaviour is peculiar to low and medium carbon steels. However, the high carbon steels, which have cementite in a pearlite matrix, are known to be harder than steels with a combination of pearlite and ferrite due to the hardness of cementite, Brookes (1979). As can be observed from the curve, the hardness profile rises with carbon content upto 0.75% C, beyond this, it tends to level off. This perhaps is as a result of the presence of a sizeable amount of retained austenite. The microconstituent austenite is softer than cementite, Robert et al (1965). The hardness of the water quenched specimens which are also presented in Fig.2 shows a trend very similar to that of the as-supplied specimens, that is, hardness values increasing with increase in carbon content. The values are, however, higher attaining a maximum of 590 and 640 VHN at the center and edge respectively at 1.00% C. Beyond 1.00% C the hardness level drops. The low carbon specimen (0.15 and 0.25% C) show no appreciable difference in hardness measured at both the centers and the edges, perhaps due to the fact that they are not hardenable steels, Raghavan (1989). There is basically no amount of fast-cooling that could enable high temperature transformation to be avoided. The S-curve of these steels as given by Avner (1984) are so close to the left that cutting through the nose is a spontaneous event.

In the case of medium carbon (0.4% C) and high carbon steels (0.75 to 1.20% C), the hardness values at the edges are higher than at the centers. High carbon content and coarse grains in steels have the potential of shifting the S-curve to the right. This can result in austenite transforming into harder microconstituents. Since the exposure of the edges to the furnace environment is more severe than the centers, grain coarsening therefore takes place at the edges, hence, the higher the hardness of the specimens at the edges.

For the brine quenched specimens, the variations in hardness follow the same trend with the water-quenched and the as-supplied specimens, however, the effect is more pronounced. This may be explained from the perspective of the role being played by the addition of inorganic salts to water (brine). Dell (1979) has shown that crystals of salts precipitate momentarily on the steel surface thereby decreasing the duration of the vapour film stage, it causes the continuous disruption of the vapour film with improved wetting of the steel and increased heat removal through rapid cooling with the resultant effect of austenite not transforming to higher transformation products of ferrites and pearlites. However, at the center, heat removal is much slower than at the surface. The hardness values are also lower than those at the edges and also bear the same relationship with the water quenched specimens.

Therefore, in considering the various specimens quenched in water and brine media, the following observations are made:

For all the steel specimens, the highest center and edge hardness values (VHN) are recorded in brine.

* The center and edge hardness values followed a similar trend except at high carbon contents, beyond 0.75% C where the curves start to level off as a result of retained austenite.

■ For all the results, the increase in hardness values observed as the percentage of carbon increases

could be attributed to the relative proportion of the phases present, their shapes and distribution, Raghavan (1989).

Conclusion

From the foregoing discussions, the following conclusions may be inferred. The higher the carbon content of the steel, the higher the hardness values attainable for the as - supplied, water quenched, and brine quenched specimens.

The variation in hardness of the medium (0.4%C) to high carbon steels (0.75 - 1.29%C) quenched in water and brine with respect to the as - supplied steel hardness values is more for brine quenched specimens than those quenched in water. The hardness values are generally higher in the brine quenched specimens. The variation in the case of the low carbon steel grade is less.

Water and brine quenchants are good for hardening plain carbon steels if shallow hardening is desired.

References

- Avner, S.H. (1984). *Introduction to Physical Metallurgy*, 2nd Edition. London: McGraw - Hill International Book Company. Pp 249-345.
- Brooks, C.R. (1979). *Heat Treatment of Ferrous Alloys*. Washington: Flemisphere Publishing Corporation. Pp1-4.
- Callister, W.D. (1994). *Material Science and Engineering*. New York: John Wiley and Sons i, Incorporated. Pp 324-340.
- Dauda, E.T. (1995). The study of Hardening Characteristics of High Carbon Steels and Ductile Cast Iron. Zaria: M.Sc. Thesis, Alunadu Bello University. Pp 26-28.
- Dell, K.A. (1979). *Metallurgy - Theory and Practice*. Chicago: American Technical Society. Pp 195-199.
- HoneyCombe, R.W.K. (1982). *Steels Microstructure and Properties*. Bangalore: Macmillan Company. Pp 28-31
- Patrick, S.S. (2001). The Effect of Heat Treatment on the Tensile Properties of 0.1%C, 0.2%C, and 0.7%C Plain Carbon Steels. Zaria: Final year Project, Alunadu Bello University. Pp1-2.
- Raghavan, V. (1989). *Physical Metallurgy Principles and Practice*. New Delhi: Prentice Hall of India Ltd. Pp 109-130
- Robert, G.A, Hamaker, J.C., and Johnson, A.R. (1992). *Tool Steels*. 3rd Edition. Ohio: American Society of Metals. Pp 291 -295.