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Evaluation of As-Quenched Hardness of 1.2% Carbon Steels in Different Quenching Media

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Abstract

The As-quenched hardness behaviour of 1.2% carbon steels in different quenching media was investigated. The hardness values were studied on two grades of high carbon steel materials, namely 1.2% carbon and low-alloy 1.2% carbon steels respectively. Specimens were prepared and given both spheroidizing and normalizing heat treatments before they were hardened. Hardening was done at both 800oC and 850oC and quenching was carried out in water, cold water, brine, cold brine and SAE engine oil. Then hardness measurements were carried out on the specimens in the pre-hardening and as-quenched conditions, results obtained showed that in the as-quenched condition, oil quenching resulted in partial hardening in both steels; the addition of 1.2% tungsten to the 1.2% carbon steel was not sufficient to cause full hardening. Full hardening was only attained when quenched in water or brine. Cold brine quenching produced maximum as-quenched hardness values in both steels; in conclusion, higher as-quenched hardness values were obtained for the case of normalized pre-hardening structure than the other case of spheroidized pre-hardening structure when quenched from 800oC, it is the reverse when they were quenched from 850oC. The two steels did not attain full hardening when quenched from 800oC or 850oC in SAE engine oil. Quenching in more severe media such as water and brine was found to result in adequate hardening, where hardness values of over 600VHN were obtained.

Keywords: quenching, spheroidizing, normalizing, high carbon steel, hardness

INTRODUCTION

Tool steels are very important in the manufacturing industries where machining of metals is predominant. In fact without metal-cutting tools, the bases for our present civilization would be seriously undermined.
Tool steels are used, not only for metal-cutting purposes, but also for shaping and forming of metals in operations such as drawing, forging, rolling and casting among many others. Plain carbon tools steels are by far the cheapest, and most readily applicable for simple jobs especially at the ambient temperatures. The carbon steels are deep hardening, and cannot be used where heat resistance should be maintained above 250^0C [Smallman and Bishop, 1999].

For this purpose, low-alloy high carbon steel is used instead. In addition, these low-alloy high carbon steels are reported to possess superior as-quenched, as well as, tempered hardness with enhanced toughness [Roberts et al, 1962]. For this reason, a comparative study of the as-quenched hardness of high carbon steel and a low alloy high carbon is desirable.

The research work was aimed at evaluating the as-quenched hardness behaviour of 1.2% carbon steels in different quenching media.

Heat Treatment of Ferrous Metals

Heat treatment processes are generally used to modify the microstructures of ferrous materials thereby enhancing the mechanical properties [Smallman and Bishop, 1999], of which hardness is one. Several researchers have worked on the hardness of heat treated ferrous metals such as Hassan [2004], Abu etal [2007], and Hassan et al., [2011].

High Carbon Steels

High carbon steels respond strongly to hardening by quenching, just as in the medium carbon steels. However, they do not attain high as-quenched toughness as in the medium carbon steels; this is because austenite is retained with martensite and /or bainite. The amount of the austenite retained increases with the carbon content. The hardening temperature also affects the amount of retained austenite. The presence of thus retained austenite is usually undesirable in many instances, hence there is need to remove it by a suitable post-quenching treatment, of which cold treatment by refrigeration or tempering is commonest. When the steel is hyper-eutectoid, there will be additional residual carbides present in the as-quenched structure. The presence of these residual carbides is responsible for the superior wear resistance of this grade of steels, though with some loss in toughness. Those high carbon steels, which are hypo-eutectoid, do not contain these residual carbides, and are prone to be of high elastic strength.

Hardening of High Carbon Steels

Though there are various quenching media used for hardening of ferrous metals, such as water, brine, air and oil, the important requirement is that cracking and excessive distortion should be prevented [Yawas and Ause, 2004]. Furthermore, there are different kinds of oil besides SAE engine oil that can be used as quenchants such as shea butter oil, cotton seed oil, palm oil, palm kernel oil, ground nut oil and soya bean oil [Oyinlola, 1997]. The basic process of hardening steel by heat treatment consists of heating the metal to a temperature at which austenite is formed, usually about 760^0C-870^0C and then cooling, or quenching rapidly in water or oil [Allen, 2007].The as-quenched hardness of the high carbon steels, increases further with carbon up to a maximum level which occurs at about 0.9%.However the as-quenched strength value begins to drop as from 0.7% level, which is just at the on-set of retained austenite in these steels. Hence this drop-off in the strength values for percentage carbon greater than 0.7 is caused by the presence of the retained austenite [Roberts et al, 1962]. The retained austenite in the as-quenched high carbon steels increases substantially as from about 1.2% carbon. Hence carbon steel for wear resistance with appreciable toughness is commonly limited to between 0.9-1.1% carbon.

Hardenability of High Carbon Steels

High carbon steels are generally low in hardenability. In most cases, water quenching is commonly used before substantially deep-hardening is achieved; though it may results in cracking and distortion, therefore oil quenching is generally preferred [Hassan, 2003]. This is because the presence of high carbon retards austenite transformation. The high carbon steels with 0.65-0.9% C are the classes which contain less than 20% retained austenite and contain practically no residual carbides [Lips, 1964]. Hence they are hardened from above the upper-critical temperatures, but as close to it as possible. The high carbon steels with 0.9-1.2% C are hyper-eutectoid steels with residual carbides being present at the hardening temperatures [Roberts et al, 1962]. On quenching; they contain considerably high retained austenite causing reduced hardenability and inferior mechanical properties. It was reported that water quenching at 800^0C and 850^0C produced quench cracks for small size samples [Dauda, 1995].

MATERIALS

The steel materials used in this study are 1.2% C and low- alloy 1.2% C steel. The compositions of the steels are given in Table 1

Table 1: Chemical Composition of Materials [%]

Materials		C	Mn	Si	Cr	V	W	P	S
High Carbon Steel	A	1.20	0.30	0.25	-	-	-	0.03	0.03
Low-alloy Steel	B	1.20	0.25	0.20	0.20	0.20	1.20	0.03	0.03

METHODOLOGY

The research work was carried out in the physical metallurgy laboratories of Ahmadu Bello University, Zaria. Twenty two samples were machined from each grade of steel, and each one was about 10mm long and 1.2mm in diameter, care was taken to ensure that the end surfaces were machined normal to their longitudinal axes. All the specimens were then normalized after which the flat end of each specimen was subjected to grinding on grinding papers starting from the 240 grit through 600 grit. This is to prevent difficulty in surface preparation for hardness measurements after hardening.

Preliminary Normalizing Treatment

The specimens were packed in a carbonaceous material, made up of a mixture of cast iron chips and charcoal, and the pack was heated in stages in a muffle furnace. It was first preheated to 650^0C, soaked for 30 minutes, and the heated slowly to 750^0C. It was finally heated to 900^0C, soaked for 1 hour and then air-cooled to room temperature.

Pre-hardening Spheroidizing Treatment

From the earlier normalized steel samples, a batch comprising 11 plain carbon grades and 11 low-alloy grades were packed in a similar carbonaceous environment as above, heated to 700^0C and allowed to soak for 2 hours. The furnace heat was shut – off and the pack was allowed to cool to below 650^0C before the samples were air cooled.

Hardening Treatment

Five plain high carbon steels, which were earlier normalized, were heated to 800^0C and soaked for one and half hours, after which one specimen was quenched in each of oil, water, 10% (by weight) brine, cold water at 0^0C and cold brine at about -5^0C.

This experiment was repeated for other sets of five specimens of:

a) spheroidized plain 1.2%C steels,

b) spheroidized low-alloy 1.2%C steels and

c) normalized low-alloy 1.2%C steel .

These gave a total of 20 hardened specimens, for each of the hardening heat treatments, the specimens were pre-hardened for 30 minutes at 650^0C followed by a slow heating to 750^0C before finally heating to the hardening temperature.

All these were to ensure proper conditioning of the prior structures before eventual transformation into austenite at the A1 point.

Hardening Measurements

The hardness measurements were done using the Avery Hardness Testing Machine. Before this; the surfaces of the specimens were subjected to grinding and polishing to obtain mirror-like surfaces. Hardness measurements were then taken on these surfaces by using a Vickers hardness indenter with a load of 30 kilogrammes.

The results are shown in Tables 2-4 for:

a) specimens in the normalized condition

b) specimens in the spheroidized condition

c) specimens in the as-quenched condition.

Figure 1: Variation of Pre-hardening Hardness of Plain Carbon and Low-alloy 1.2%C Steels in Normalized and Spheroidized Conditions

RESULTS AND DISCUSSION

Pre-hardening Hardness of the Normalized and Spheroidized Plain Carbon and Low-alloy 1.2%C Steels

Table 2 and figure 1 shows the hardness values for the steels in the various pre-hardening conditions. The hardness values for the two grades of steel were found to be quite low. The spheroidized plain carbon grade was significantly softer than the same in the normalized condition.

Table 2: Pre-hardening Hardness of Plain Carbon and Low-alloy 1.2%C Steels in Normalized and Spheroidized Condition [VHN]

Pre-hardening condition	Plain Carbon Steel	Low Alloy Steel
Spheroidized	245	273
Normalized	276	283

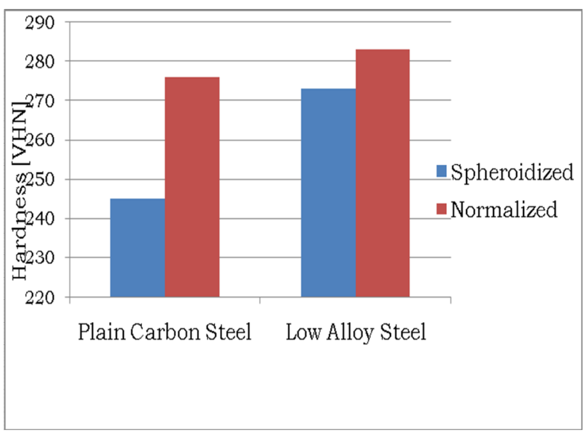

Figure 1: Variation of Pre-hardening Hardness of Plain Carbon and Low-alloy 1.2%C Steels in Normalized and Spheroidized Conditions

The values for the 1.2% W and 1.2% C grade were found to be significantly higher, for the spheroidized grade, than the corresponding grade of plain 1.2% C steel. This is due to the presence of harder and greater amount of alloy carbides. For the normalized grades; the low alloy 1.2% C steel was only slightly harder than the plain 1.2% C steel. This shows that the fine pearlite structure was significantly hardened as well as the presence of the hard alloy carbides.

As-quenched Hardness of Plain and low-alloy 1.2%C steels

From Tables 3 and 4 and the resulting figures 2 and 3, oil-quenching resulted in low as-quenched hardness, and this is especially the case for the plain 1.2% carbon steel. These values were less than 600 VHN value considered minimum for hardened steels.

The higher values for the low tungsten 1.2% C steel are expected, but the presence of 1.2% W was found not to be sufficient to make it hardenable by oil quenching. This is at variance with the work of Dauda, where he obtained low as –quenched hardness of 315 VHN for oil quenching the plain 1.2% C steel from 900^{0}C. However, he obtained high as-quenched hardness values of 800 VHN when oil-quenched from 850^{0}C. Higher severity of quenching in water and brine resulted in considerably higher as-quenched hardness values between 694 and 792 VHN for the plain high carbon steel and between 744 and 818 VHN for the low-alloy high carbon steel. These are considerably higher than the minimum value for hardened steels. Furthermore, higher as-quenched hardness values were obtained for the low-alloy grade, the average being 750 VHN for the plain 1.2% C and 780 VHN for the low-alloy grade.

Table 3: As-quenched Hardness of Plain 1.2% C Steel [VHN]

Hardening Temperature [^{o}C]	Pre-Hardening Condition	OQ	WQ	BQ	CWQ	CBQ
800	Spheroidized	341	732	764	755	754
800	Normalized	390	719	755	729	781
850	Spheroidized	371	699	694	710	749
850	Normalized	369	778	727	792	779

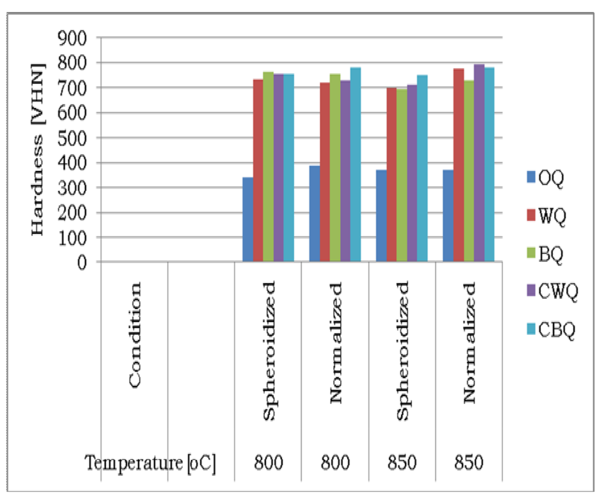

Figure 2: Variation of As-quenched Hardness of Plain 1.2%C Steel

Table 4: As-quenched Hardness of Low- alloy 1.2% C Steel [VHN]

Hardening Temperature [^{0C}]	Pre-hardening Condition	OQ	WQ	BQ	CWQ	CBQ
800	Spheroidized	520	816	763	814	762
800	Normalized	490	744	789	787	794
850	Spheroidized	352	752	758	793	772
850	Normalized	448	764	781	774	818

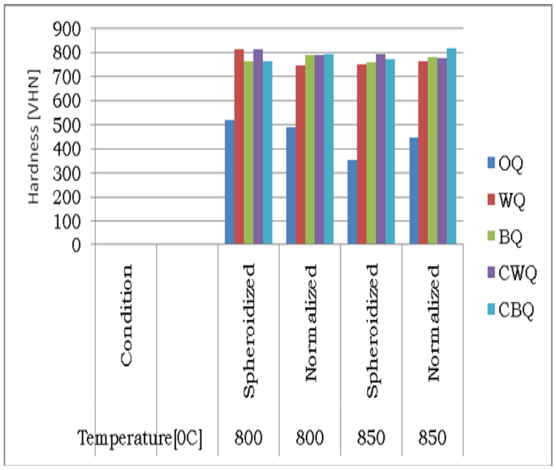

Figure 3: Variation of As-quenched Hardness of Low-alloy 1.2% C Steel

CONCLUSION

After quenching the two grades of high carbon steels in various media and varying the pre-hardening structures, the followings are the major conclusions.

(i) For the two steels, the effect of pre-hardening structure was not quite definitive. Generally higher as-quenched hardness values were obtained for the case of normalizing pre-hardening structure than the other case of spheroidizing pre-hardening structure when quenched from 800^{0}C, it is the reverse when they were quenched from 850^{0}C.

(ii) The two steels did not attain full hardening when quenched from 800 or 850^{0}C in oil.

(iii) Quenching in more severe media, such as water and brine, was found to result in adequate hardening. Hardness values of over 600 VHN were obtained for all quenching media.

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SYMBOLS

C ----- Carbon
W ----- Tungsten
Mn ----- Manganese
Si ----- Silicon
Cr ----- Chromium
V ----- Vanadium
P ----- Phosphorus
S ----- Sulphur
% -----Percentage
OQ -----Oil Quenching
WQ ----- Water Quenching
BQ ----- Brine Quenching
CWQ ----- Cold Water Quenching
CBQ -----Cold Brine Quenching
VHN ----- Vickers Hardness Number

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