EVALUATION OF THE COOLING RATE OF SOME FATTY-ACID BASED VEGETABLE OILS AS QUENCHANTS

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ABSTRACT

The cooling rate of a quenching medium is known to be one of the factors that affect the final properties of a quenched component. In this study experimental results are reported in which the cooling rate of different vegetable oils (ground nut oil, soy beans oil, cotton seed oil, palm kernel oil, pal. oil and shear butter oil) during quenching of 0.75%C steel has been investigated. All the vegetable oils investigated were found to have cooling rates within the acceptable range for the avoidance of distortion or cracks. The hardness develop in all the samples quenched in various media is found to be influence by the cooling rate of the media. Among the oils, pal. oil and palm kernel oil resulted to higher hardness followed by soy beans oil and then others. These oils are cheaply available; hence their usage in the heat treatment industry for machine components would lead to many advantages as outlined in this paper.

INTRODUCTION

Quenchants (water, brine, oils etc) generally constitute an important group of materials in the metal treatment processing industries. The heat treatment process of quench hardening remains one of the most industrially adaptable and acceptable techniques for hardening of most ferrous alloys. During quenching in a liquid medium heat transfer /extraction by convection is the major process that is in operation. According to Rajan, et al., (1988), there are three main stages of quenching mechanisms, namely, the vapour blanket stage, the boiling stage and the liquid cooling stage.

Water is the traditional quenchant commonly used; but when the chemical composition and the shape of the component to be quenched indicates danger of cracking in water, then oil (either mineral oil or vegetable oil) may alternatively be used. The effects of vegetable oils as quenching media have been a subject of intensive investigation in the recent past. While a great deal of literature exists on the use of SAE oil as a quenching medium for steels and cast irons, little fundamental work appears to have been done on the use of vegetable oils a s quenching media for ferrous alloys. However, Ajala (1982) conducted chemical characterization of vegetable oils in terms of elemental composition. Oyinlola (1992) investigated the mechanical properties of Aladja NST44-2 structural steel quenched in fatty –based local oils. Adeyemi (1999) carried out assessment of locally available vegetable oils as quenching media for carbon steels. There is therefore great need to intensify research efforts on those vegetable oils to ascertain their effectiveness as quenching media. These oils have been found to have good commercial adaptability because of their general availability; low cost; ease of handling; low fire hazards; non-corroding action on steel components, containers etc, and stable cooling characteristics with moderate changes in temperature. These vegetable oils are cheaply available; hence their usage in the heat treatment industry would lead to many advantages in terms of cost as compared to SAE oils.

The cooling rate of a quenching medium is one of the factors that affect the final properties of a quenched component. Accordingly, the primary aim of the present study was to investigate the cooling rate of different vegetable oils during quenching of 0.75%C steel using E.M.F millimeter with thermocouple and Brinell hardness tester. Particular e mphasis was placed on correlating the hardness characteristics from edge to edge across all the specimens investigated.

MATERIALS AND METHOD

Materials

22mm diameter plan carbon steel rods of average chemical composition 0.75%C was used for the investigation. The vegetable oils used as quenchants were: Groundnut oil, Soy beans oil, cotton seed oil, palm kernel oil, palm oil and shear butter oil. Water was also used as a reference medium.

An electrically heated carbolite muffle furnace with a maximum temperature of $1200^{O}C$ was used to austenitise the steel samples before quenching. A stop watch, and chromel-alumel constantan thermocouple w ith a multimeter were used for evaluating the cooling rate of the quenchants. Brinell hardness testing machine was used to measure the hardness.

METHOD

Heat Treatment and Cooling Rate Determination

The as-rolled 22mm diameter plain carbon steel rods were machined to standard hardness test samples. All the samples were first given a normalizing heat treatment in order to refine the grain structure. This was by heating the machined samples in the furnace to $900^{O}C$, held for one hour then removed and cooled in air. One normalized sample was taken and a thermocouple inserted into it and bolted. The thermocouple was extended and connected to a multimeter. The sample was taken back into the furnace and heated to $900^{O}C$, soaked for one hour, then removed and quenched in groundnut oil contained in galvanized iron bucket. The rate of cooling (temperature drop versus time) was read from the multimeter attached to the thermocouple via an adaptor. The readings were taken until the temperature became constant almost at room temperature. The thermocouple was removed from this quenched sample and inserted into another normalized sample. The process was repeated by quenching in Soy beans oil, cotton seed oil, palm, kernel oil, palm, oil, shear butter oil and tap water respectively. Tempering of the quenched samples was done at $300^{O}C$ for 1 hour.

Hardness Measurement

One sample in the as-rolled condition was taken, cut radically and subjected to metallographic sample preparation processes of filling, grinding successively on emery grinding papers. The sample was then polished and hardness test was carried out on the radial surface on a straight line at a regular interval of 1.14mm from one edge through the centre to the other edge of the sample.

The same process was carried out on all the samples in the as-quenched condition. The samples were then tempered at $300^{O}C$ for one hour. The hardness of the samples in the as-tempered condition were measured as described above and the hardness profiles plotted as shown in the various figures.

RESULTS AND DISCUSSIONS

Results of cooling rate in various quenchants

It is well known that convectional heat transfer is the major process that takes place during quenching in a liquid medium. The ability of a quenchant to extract heat faster from a hot sample implies that it is a good quenchant with high quenching severity. Such quenchants could be important in developing good mechanical properties in the quenched samples.

Fig 1 shows the cooling rate curves of water and various vegetable oils evaluated.

Water was used in this work to serve as a reference point because it is generally known to be a conventional quenchant which has a good quenching severity. It has been well established that most liquid quenching media exhibit three stages of quenching mechanisms: the vapour blanket, the boiling and liquid cooling stages. All these stages play significant roles during quenching process. It is seen in Fig. 1 that water has the highest rate of cooling while shear butter oil has the lowest. This is because water has the ability to extract heat faster by breaking the bubbles (films) in the vapour blanket stage faster hence giving way for further heat extraction. The lower cooling rate found in shear butter oil may be attributed to its inability to overcome quickly the vapour blanket stage due to its high viscosity. This may result to the bubbles insulating the sample from further cooling; hence slowing down the rate of heat extraction. The cooling rate of other vegetable oils however falls in between. This seems to be in agreement with the previous studies carried out by other researchers, Adeyemi (1999).

Effect of quenching medium on the hardness profile across the sample diameter

When a steel component is to be hardened, the steel is quenched to control the transformation of austenite in order to obtain the desired microconstituents. Martensite is the as-quenched microstructure which is usually desired. But to obtain the maximum amount of martensite, the cooling rate must be fast enough to avoid the nose of the time-temperature-transformation (TTT) curve. If not, austenite will transform to structures such as pearlite, ferrite and baninite which would decrease the amount of martensite hence, leading to lower hardness. This implies that whether more percentage of martensite will form or not depends on how fast the quenching medium is able to extract heat from the quenched steel sample.

Figures 2-8 shows the hardness profiles across the 22mm diameter 0.75%C steel rods austenitised and quenched in water, shear butter oil, palm, oil, palm, kernel oil, cotton seed oil, soy beans oil and groundnut oil respectively. The hardness test was conducted on the samples both in the as-quenched condition then in as tempered condition. The as-received samples indicated a uniform hardness profile of about 200HB across the section. It is seen that in all these figures, the general trend is that the hardness is higher at the edges than at the centre of the samples. This variation in hardness from edge to centre may be attributed to section size of the sample. Due to the size of the sample, heat was not extracted at the same rate from the surfaces to the centre. This trend is expected, and correlates well with what is obtained in literature. It has been shown by many researchers, Rajan (1988), Khanna (2002) that when a steel sample of a considerable diameter greater that critical diameter is austenitised and quenched in a liquid medium like water or oil, heat is extracted faster at surface but slower towards the centre of the sample, this usually leads to formation of higher amount of martensite structure around the edges while a mixture of other softer structures such as pearlite, bainite, ferrite is formed around the centre of the sample due to slower rate of cooling. This may be why the hardness at the centre drops.

It is also seen that the edge hardness of sample quenched in water (fig 2) is the highest (655HB) among all the queching media. This correlate well with the results of cooling rates shown in fig 1. This is as expected because water and other aqueous solutions of inorganic salts (e.g brine) are known to have the highest initial quenching speeds because the duration of the first stage of cooling (the vapour blanket stage) is very short. Among the vegetable oils, sample queched in palm kernel oil (fig 5) had next highest average edge hardness (611HB) followed by Soy beans (600HB). Then others as can be seen on the figures. The lower hardness obtained from the oils as compared with to that of water is due to the fact that oils are known generally to be slow quechants oils have low severity of quench which is an inherent characteristic of oils. The duration of the first stage of cooling in oils is known to be longer, this may be what resulted to lesser hardness in samples quenched in oil. However, one important advantage of oil quenching is that they have less risk of cracking and distortion of quenched sample.

As expected, the hardness of all the samples tempered decreased.

CONCLUSIONS

From the results of the investigation carried out; the following conclusions are drawn:

i. The hardness developed in all the samples quenched in various media is found to be influenced by the cooling rate of the media.

ii. All the vegetable oils investigated were found to have cooling rate less than water, thus confirming what are obtainable in literature.

iii. Among the vegetable oils, palm oil, and palm kernel oil resulted to higher hardness followed by Soy beans oil. If a steel component is to be hardened and there is a risk of it cracking when water quenched, then these oils may be used. For example, alley steels as a rule have high hardenability, therefore, it is advisable that they be oil quenched since oils have least danger of distortion of cracks.

Dies or special fixtures should be oil quenched to reduce warping of intricate shaped parts since the slower cooling rates of oils in the martensitic transformation range is an advantage.

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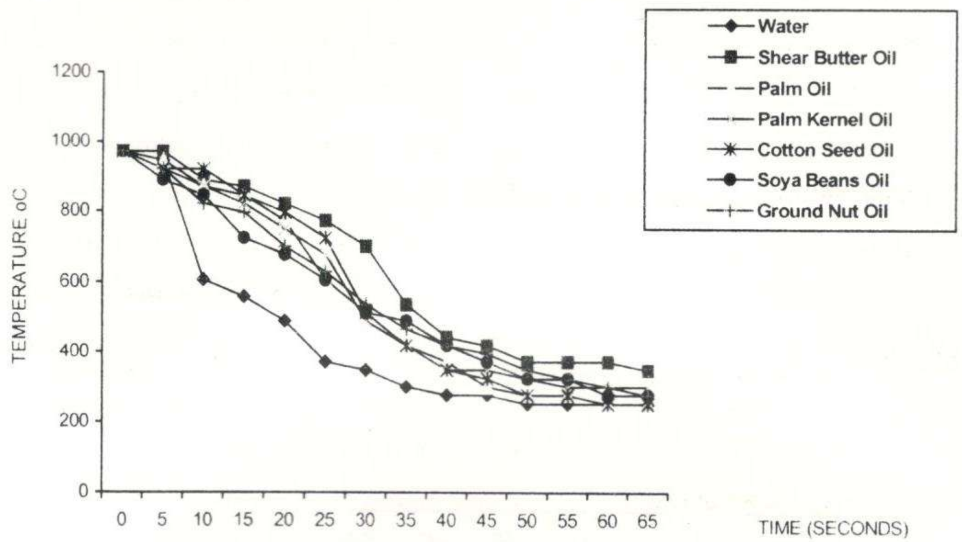

Fig. 1: COOLING RATES CURVES OF QUENCHANTS

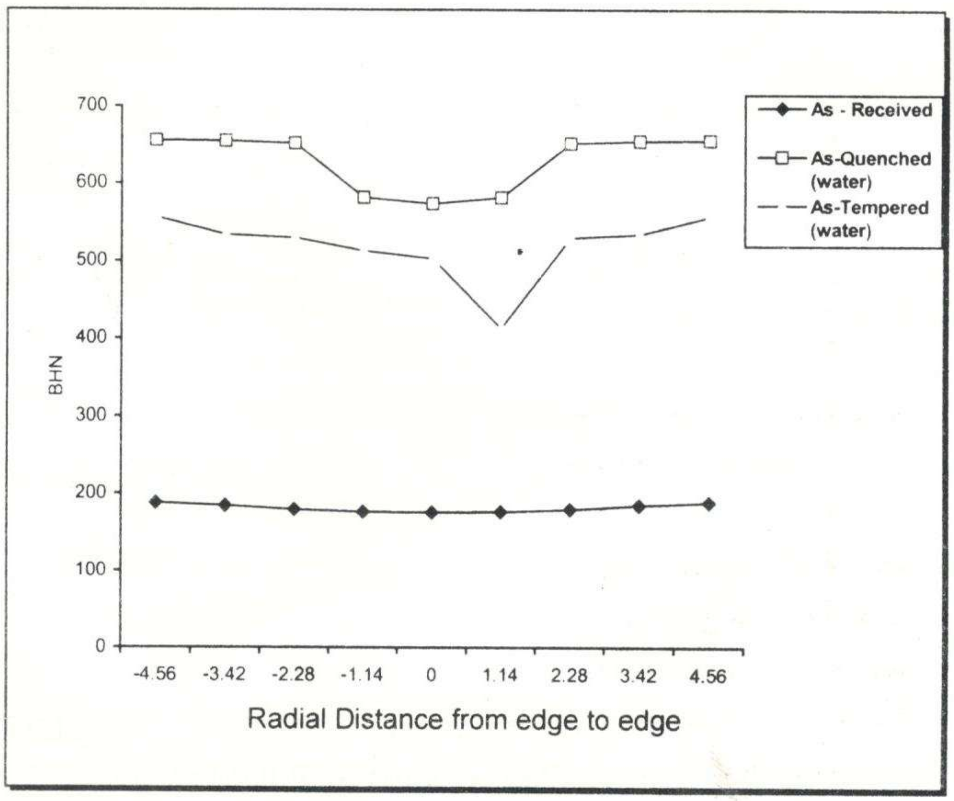

Figure 2: Hardness against Radial Distance (Water Quenchant)

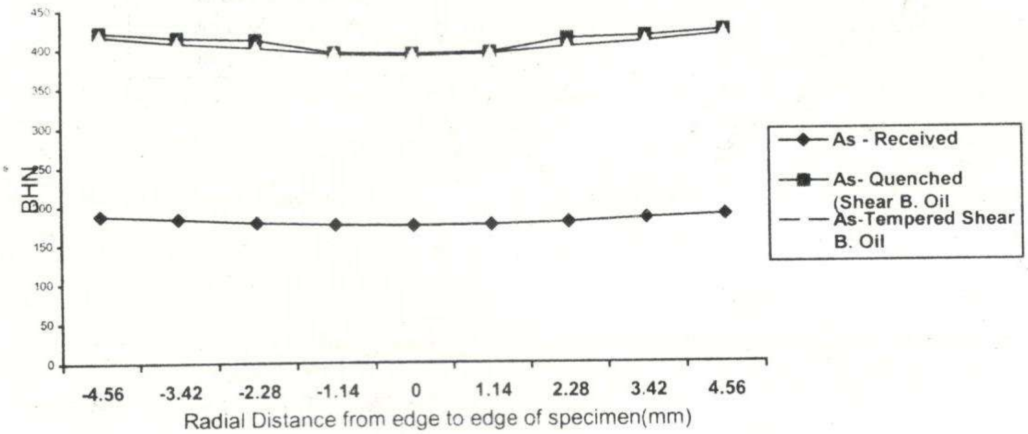

Fig. 3 Hardness value against Radial Distance (Shear Butter Oil Quenchant)

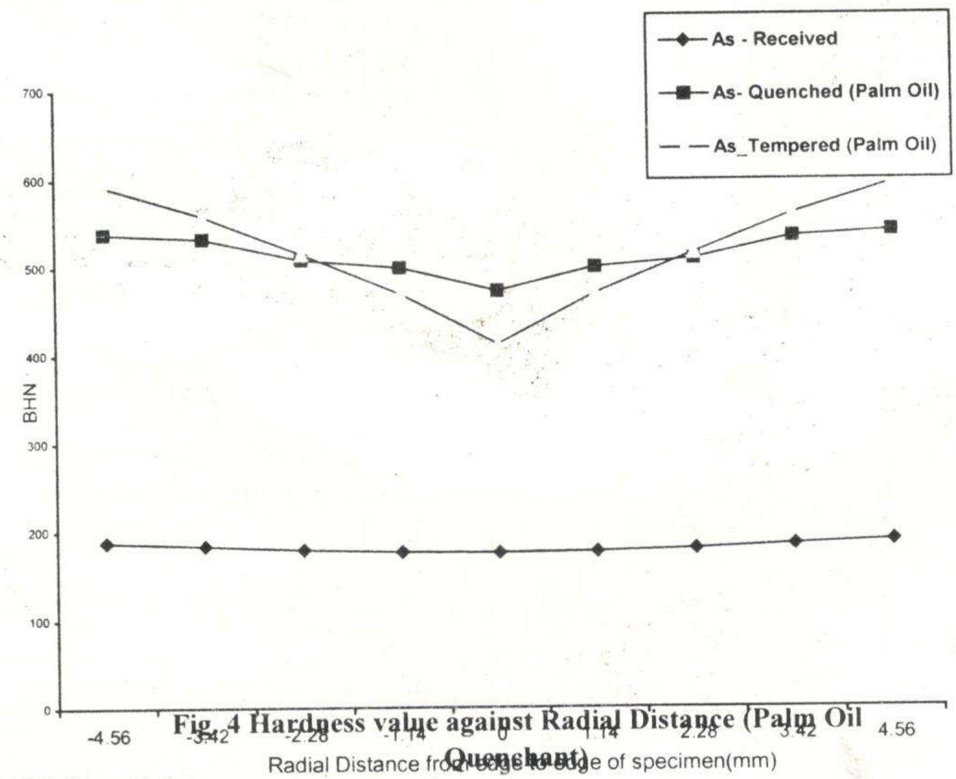

Fig. 4 Hardness value against Radial Distance (Palm Oil Quenchant)

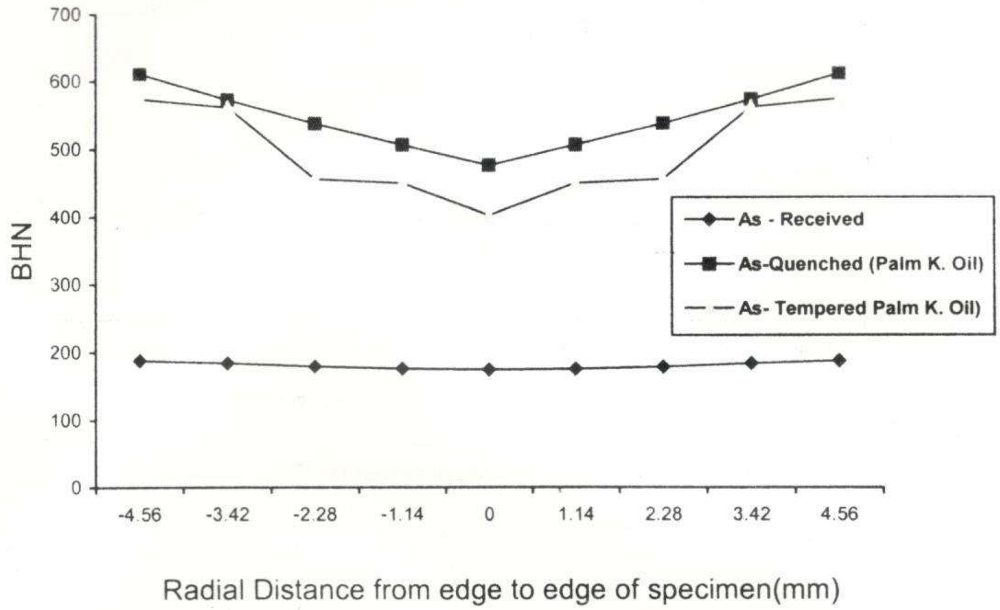

Fig. 5 Hardness value against Radial Distance (Palm Kernel Quenchant)

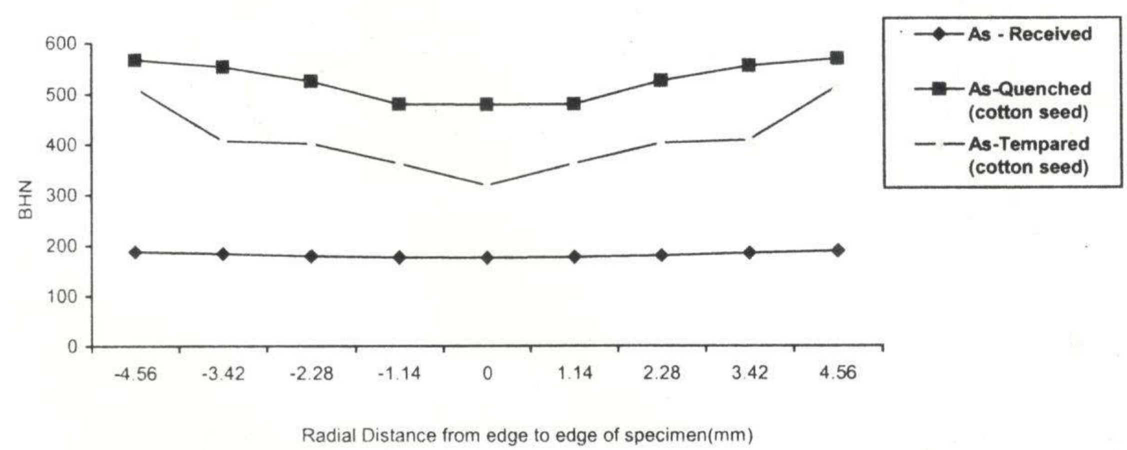

Fig. 6: Hardness value against Radial Distance (Cotton seed Quenchant)

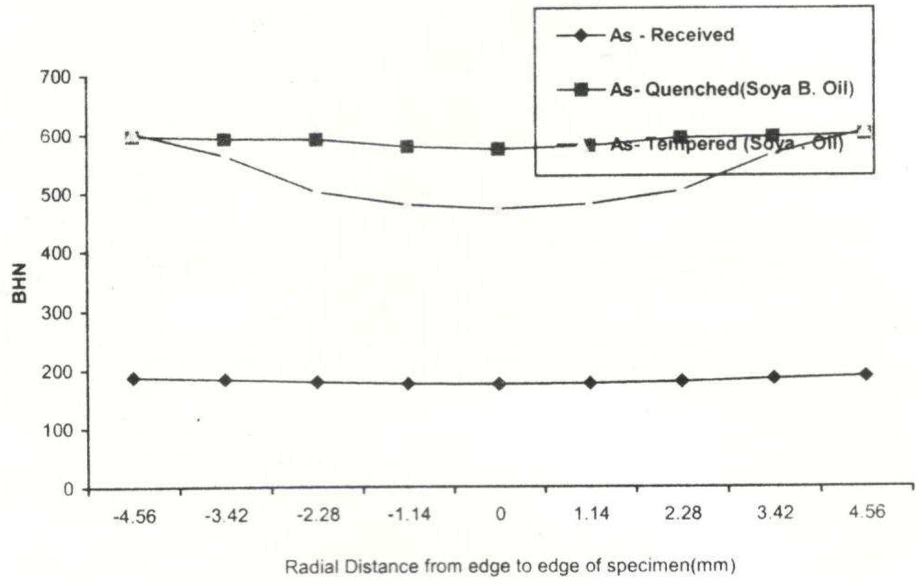

Fig. 7 Hardness value against Radial Distance (Soy bean Oil Quenchant)

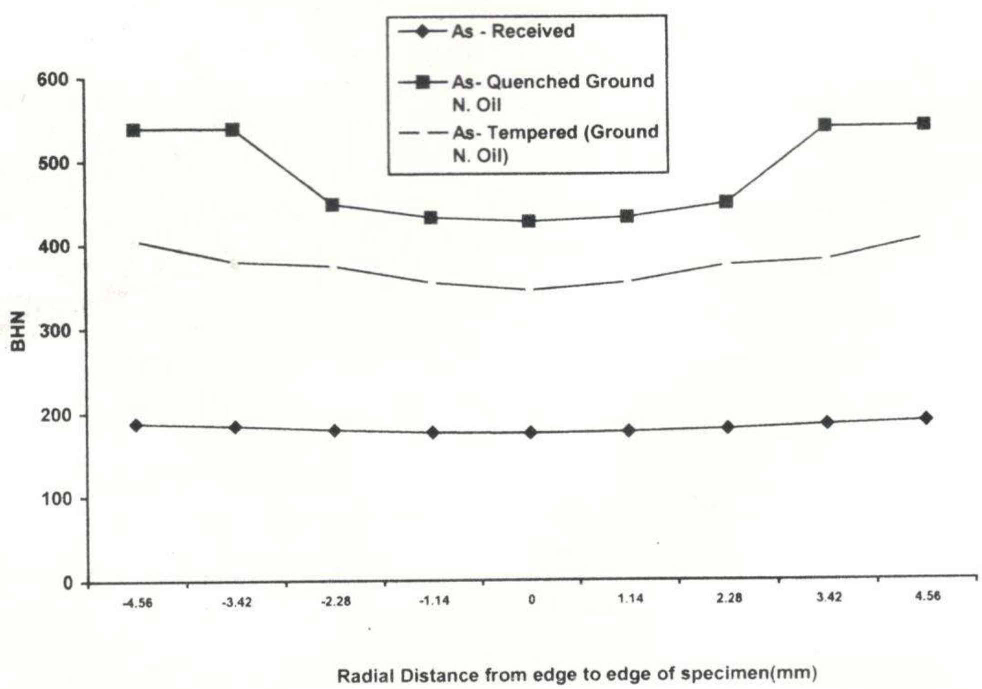

Fig. 8 Hardness value against Radial Distance (Groundnut Oil Quenchant)

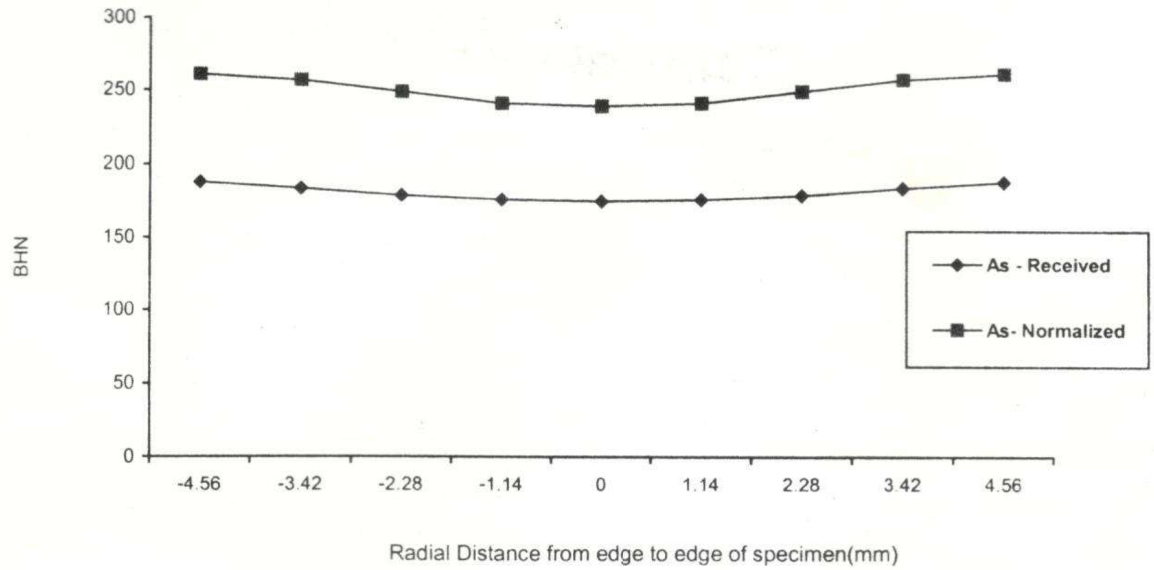

Fig.9 Hardness value against Radial Distance