

Study the effect of polymer solution and oil quenchants on hardening automotive camshaft

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Abstract

The type of quenchant is directly affect the cooling rate of a quenched part. In this paper, a comparative study of polymer solution and oil quenchants on hardening automotive camshaft was studied. Cooling curves and microstructure in cylindrical samples of automotive camshaft (grey cast iron) have been performed to investigate the effects of quenching media, polymer concentration and temperature of oil quenchant on the quenching behavior of automotive camshaft. Results showed that maximum hardness obtained by polymer quenching in the surface of gray cast iron, but minimum hardness obtained by oil quenchant in the core of gray cast iron. Various aspects of the organic and physico-chemical properties such as polymer concentration, temperature exhibit a great effects on both cooling rates and quench uniformity.

دراسة تأثير وسطي الإخماد بمحلول البوليمر والزيت على أصلا د عمود الـ دبات الآلي

خلاصة البحث

تؤثر نوعية وسط الإخماد بصورة مباشرة على معدل التبريد للجزء المخمـد. في هذا البحث أجريت دراسة مقارنة لوسائط الإخماد بمحلول البوليمر مع الزيت على أصلا د عمود الـ دبات الآلي. أنجزت معدلات التبريد والبنية المجهرية لعينات اسطوانية من عمود الـ دبات (حديد زهر رمادي) لدراسة تأثيرات وسط الإخماد، تركيز البوليمر ودرجة حرارة الزيت على سلوكية الإخماد لعمود الـ دبات. النتائج أظهرت إن أقصى صلادة عند الإخماد بمحلول البوليمر عند سطح عمود الـ دبات، ولكن أدنى صلادة حصلت عند الإخماد بالزيت في مركز حديد الزهر الرمادي. تبدي سمات متنوعة من الخواص العضوية، الفيزو- كيميائية ودرجة الحرارة تأثيرات كبيرة على كلا معدلات التبريد وانتظامية وسط الإخماد.

1. Introduction

Camshaft made of grey cast iron is very sensitive to crack and distortion during cooling from austenitizing temperature (see Fig.1). Because the brittleness and presence of graphite flakes in grey cast iron as a stress raiser, oil and aqueous polymer are the most media used to achieve a uniform heat removal during quenching and resulting in reduced thermal gradients and distortion. One of the most important factors affecting quench uniformity is the design of the quench system. Agitation is one of the most critical areas of the system design. The effect of agitation on the performance of various quench oils has been studied in detail. Liscis reported that the ability to through harden AISI 4135 in conventional quench oil increased with increasing agitation (Canale & Totten, 2005). Although decreasing oil temperature provided some improvement in through-hardening, it was considered less effective than increasing agitation rate. Kweon et al. have been shown that increasing agitation will be raising a cooling rate and the through-hardening ability of both oil and water quenchants for SNCM 21 steel. Vivas and Tardio have been studied the influence of both agitation and temperature on the distortion of various carburized steels (Canale & Totten, 2005). They showed that agitation of quench oil was necessary to destabilize film boiling processes if uniform heat transfer throughout the quenching operation was to be achieved (Totten, Bates & Clinton, 1993).

Polymeric solutions have been widely applied during more than 30 years. Aqueous solutions of polyalkaline glycol (PAG) are used to improve the cooling characteristics of the quenching medium and to reduce the machining requirements after the heat treatment. PAG concentrations vary from 40%--30% depending on the type of product being processed (Tensi, Stig & Totten, 1995).

Cooling curve analysis is an extremely useful tool in the development of new quenchants. It can be used to predict the metallurgical properties that may be achieved with both new and old bath. It is important to note that for a given quenchant it is necessary to optimize all three stages to insure maximum properties as shown in Fig1.

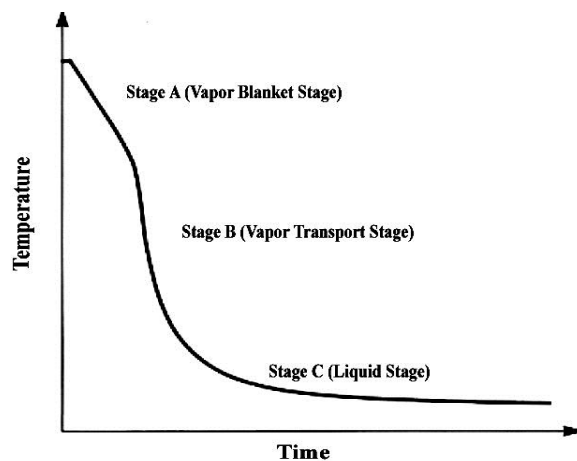


Figure 1: The principle of heat losses in quenching
(Totten, Bates & Clinton, 1993).

The present work deal with the comparative study of the cooling curve and microstructure in aqueous ethylene glycol and oil in cylindrical samples of automotive camshaft made of grey cast iron with concentration of 10, 20, 30, 40 % in water, with different temperatures

2. Experimental procedure

Material

Gray cast iron cylindrical samples of 25 mm in diameter, with a length 50 mm were used in this study(see Fig..2). Chemical composition of camshaft was used in this study is listed in Table 1. All samples were annealed to temperature 840 °C prior to hardening , then slow cooling in furnace to room temperature.

Table1: Chemical composition of automotive camshaft (wt%)

Metal	C	Mn	Si	Cr	Ni	Mo
Gray cast iron	3.2	0.7	2	1	1	0.4

Quenching Media

Two quenching media were used in this study. Polymer solution of ethylene glycol(ABRO industries(USA)). The concentration of the polymer quenchant was 10, 20, 30, 40 % in water. Oil engine used for these test was API SL / CF (Fuchs-Germany). Two temperature 22 °C and 50 °C selected for initial oil temperature.

Heat treatments

Camshaft made from grey cast iron has been heat treated to reach a maximum properties such as high hardness in the surface to resist both a wear in working and fatigue.(see Fig.2). All samples were heated to austenitize temperature 875 °C in the tube furnace as shown in Fig.4. After quenching , the samples are direct tempered at 375 °C for one hour, then cooling in air to room temperature. Some of samples cut as a disk(20*5mm) to heat treated and examined the microstructure then grinding in the series of silicon carbide emery papers 250, 500, 800, 1000 and finally polishing in paste of alumina to examine the microstructure by optical microscopy(Olympus type-Japan). Brinell hardness measured by universal tester(Fywee-Germany) with load 3000Kg and Vickers microhardness measured by tester (HV-1000, China) with load 200gm.

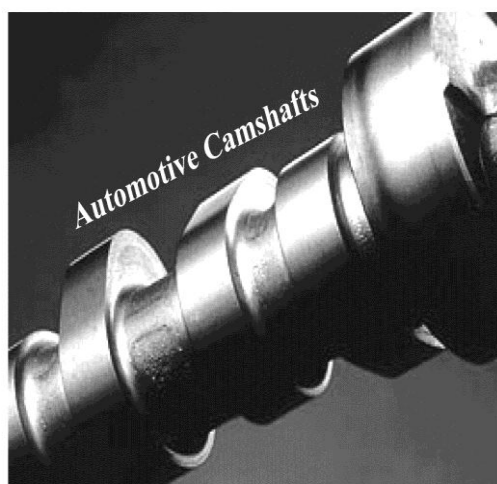


Figure 2: Section of automotive camshaft

Cooling curves

Ten samples have been heat treated in order to study the properties of two different quenchants (polymer solution and oil) as shown in Fig.5 and Fig.6. Temperatures variation with time during cooling process was measured by thermocouple type K inserted to the geometric center of a cylindrical cast iron samples. as shown in Fig.3 At the rapid quenching, digital camera was used to record the movie images with the time and then estimate the data between temperature and time. Also, infrared temperature reader was used to calibrated the digital reader and read the initial temperature of quenchants liquid as shown in Fig.5

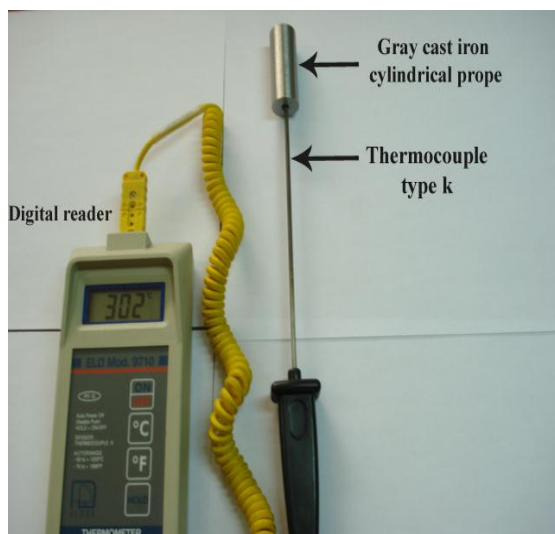


Figure 3: Gray cast iron cylindrical probe with thermocouple type k and temperature reader.

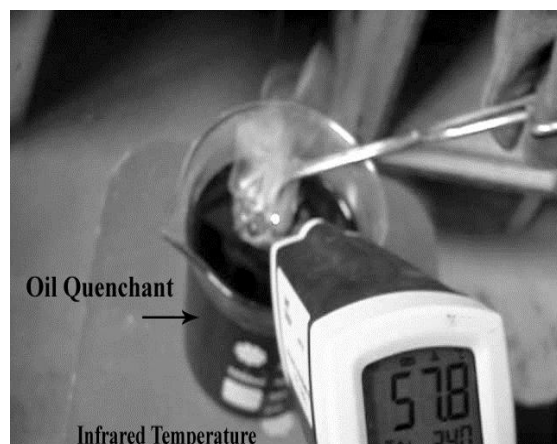


Figure 4 : Tube furnace.

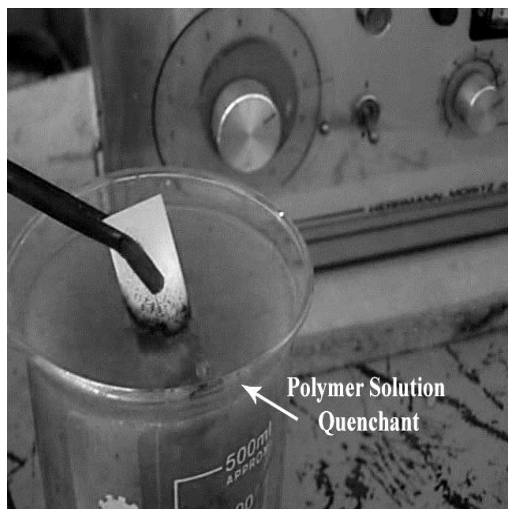


Figure 5 : Infrared temperature measurement of oil quenchant .

Figure 6 :Sample quenched after few second in polymer solution.

3. Results and Discussion

One of the objectives of the quenching process is to mediate heat transfer from the hot metal to the cooler quenchants to control the formation of the desired microstructure and related as quenched properties.

Polymer Quenchant

Fig. 7 shows the effect of polymer concentration on the temperature gradient during thermal cycle for hardening camshaft. Its clear that increasing of polymer concentration reduced the cooling rate and heat transfer coefficient. bonding. Also, polymer viscosity increased with polymer concentration and reduced the rate of the interfacial film-forming. The mechanism of polymer quenchants is different when compare with oil and other quenchants. Heat transfer from the gray cast iron to the quenchant is determined by three boiling phases: film boiling, nucleate boiling and convective heat transfer. Film boiling occur upon initial immersion. This is a slow cooling process because of the hot surface is surrounded by vapor blanket. As the gray cast iron cools, the vapor blanket collapses and nucleate boiling results. As a result a film boiling persists for longer time with increasing polymer concentration. When hot cast iron quenched into polymer solution, the metal surrounded by a polymer film., or membrane, which forms by polymer dehydration at the relatively higher temperatures at hot metal interface producing an Newtonian cooling process, without the more variability in heat transfer rates .due to different cooling processes described above for oil quenchant. This result, is agreement with (Totten, Tensi & Canale,2003). It is observed in polymer quenchant that an increase in a thickness of a vapor-film and more adherent with a surface of cast iron than oil film. In this situation, heat transfer is controlled by the viscosity, film thickness, and film strength of the polymer membrane.

Because automotive camshaft (gray cast iron) is very sensitive to crack when rapid quenching, and in the same time required high hardness in the surfaces to wear resisting , polymer with higher concentration is required to facilitate even slower cooling rate in the martenstic transformation temperature M_s region in order to optimally reduce both thermal and transformation stresses during quenching(see Fig.. For polymer quenchants, this can be accomplished by increasing the concentration of the polymer quenchant or increasing the initial temperature of polymer quenchant. The result obtained from this study showed that no cracking was observed with either polymer and oil quenchant..

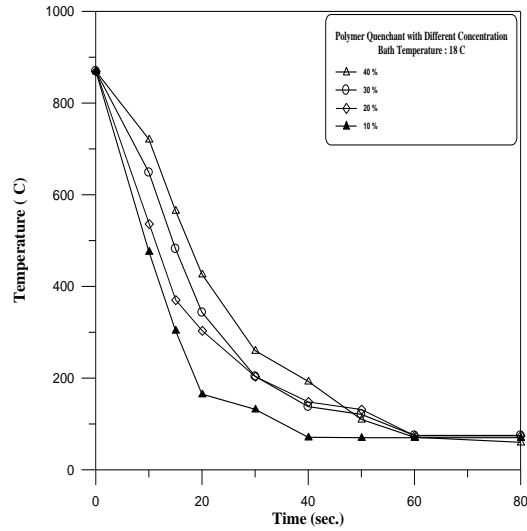


Figure 7 : Effect of polymer concentration on the cooling curve.

Oil Quenchant

Oil quenching is fundamentally different in mechanism of cooling rate, Fig 8 shows the cooling curve when quenching gray cast iron from temperature 875 °C in oil bath. Two temperature have been selected for oil bath: 22 °C and 50 °C. It is clear that slower rate of oil quenching with compare with polymer solution.

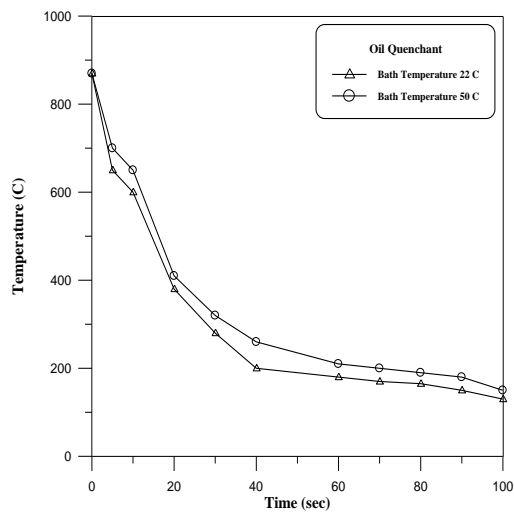


Figure 8 : Effect of initial oil temperature on cooling curve .

This behavior is explained, after hot gray cast iron first immersed in oil, the hot metal is surrounded by a vapor blanket resulting in a slow, film boiling mechanism(FB). When the temperature drops , the vapor blanket ruptures and cooling occurs by fast nucleate boiling mechanism(NB). as shown in Fig.1 When the surface temperature is less than the boiling point of the oil , cooling occurs by convection and conduction(CONV).

From literature, the heat transfer coefficients α of three cooling mechanism are typically approximately $\alpha_{FB}(100-250)Wm^{-2}K^{-1}$, $\alpha_{NB}(10-20) Wm^{-2}K^{-1}$, $\alpha_{CONV}(700) Wm^{-2}K^{-1}$ (Totten, Bates & Clinton ,1993; Przylecka. *et al*, 2001; Senatorova, *et al*,

2002). The time-dependent differences in the surface-cooling mechanisms and the difference in their values of α_{NB} , α_{NB} and α_{CONV} will affect the related time-dependent temperature distribution within the gray cast iron. It is clear from the Fig.8, that the values of cooling rate and heat transfer coefficients α_{FB} , α_{NB} in polymer quenchant is higher than oil quenchant, but the cooling rate and heat transfer coefficient α_{CONV} in polymer is less than oil quenching. This behavior in polymer quenching revealed two advantage, first, rapid quenching in the FB and NB stages required to remain austenite phase plus graphite do not transforming to another phase such as pearlite as shown in Fig.9. It was observed that the maximum cooling rate is required to obtain the microstructure consist of martensite plus graphite and some of returned austenite. Returned austenite was reduced in tempering to achieve high strength and hardness in whole section. Second, lower value in cooling rate in CONV(liquid) stage in polymer required to reduce thermal gradient in gray cast iron and allow the specimen to cool slowly to room temperature, this, stage is very impotent in quenching cast iron to minimize thermal stress and distortions.

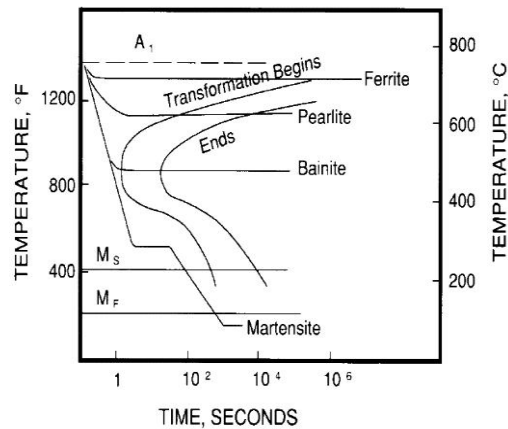


Figure 9 : Contiguous cooling transform of gray cast iron(Moore , Shugart., Hayrynen & Rundman, 1990)

Microstructure

Fig.10 shows the microstructure of base metal. It was observed that microstructure as received consist of pearlite and graphite with hardness in BHN 217. After quenching in polymer solution and oil, the microstructure consist of martensite plus graphite with some of returned austenite as shown in Fig.11.

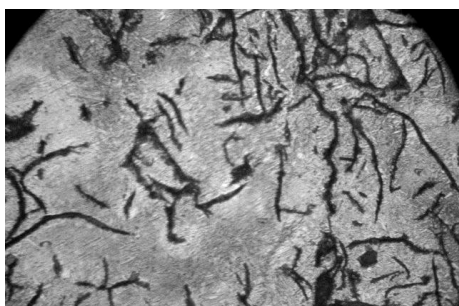
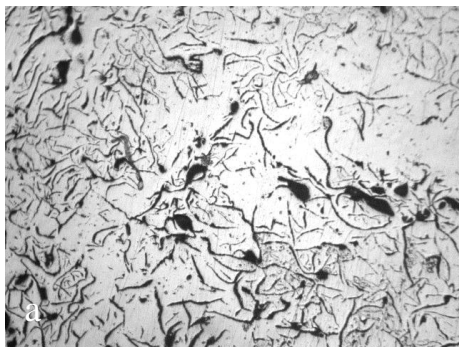


Figure 10 : (a) Microstructure of automotive camshaft, see flakes of graphite without etching 60 X(b) Microstructure of automotive camshaft, see flakes graphite impeded in lamellar pearlite matrix with etching in 2% nital,100X..

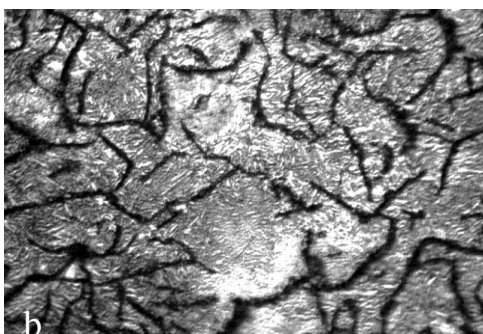
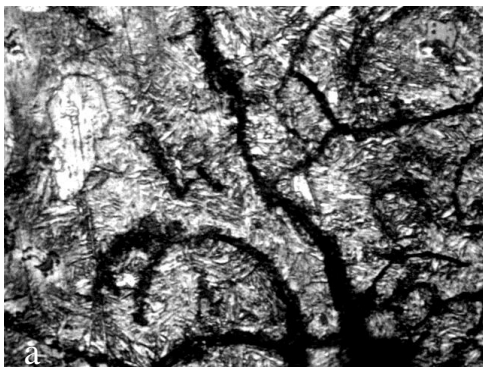


Figure 11 : (a)Microstructure of automotive camshaft, after quenching in polymer solution from 875 °C, see needles of martensite surrounding with returned austenite(white regions) 1000X (b) with magnification of 600X

The hardness of cast iron after quenched in polymer and oil are 420 BHN ,320 BHN respectively. The difference in the hardness values between polymer and oil quenchants may be existence another phases with less hardness such as bainite is presence. After quenching, gray cast iron reheating to temperature 375 °C to obtain a desire properties of camshafts such as stress relive and improvement the toughness to resist the vibration and shocks in the services . Fig 12 shows the microstructure of tempered camshafts in 375 °C. The hardness of tempered gray cast iron after quenched in polymer is about 300 BHN. It is interesting shows from microstructure after tempering many of small particles distributed in the matrix of cast iron. This particles are the carbides of alloying element such as carbon, chromium which precipitated from dissolution of martensite in the temperature of tempering especially at the holding temperature (1hr). The decomposition of brittle martensite to the carbides plus ferrite assist to increase the toughness of camshafts. This toughness is required, when the camshafts always rotated with starting the automotive and subjected to high impact from exhaust and inlet valves. The presence of graphite as a lubricant with high hardness of martensite results in a surface with good wear resistance for automotive camshaft.

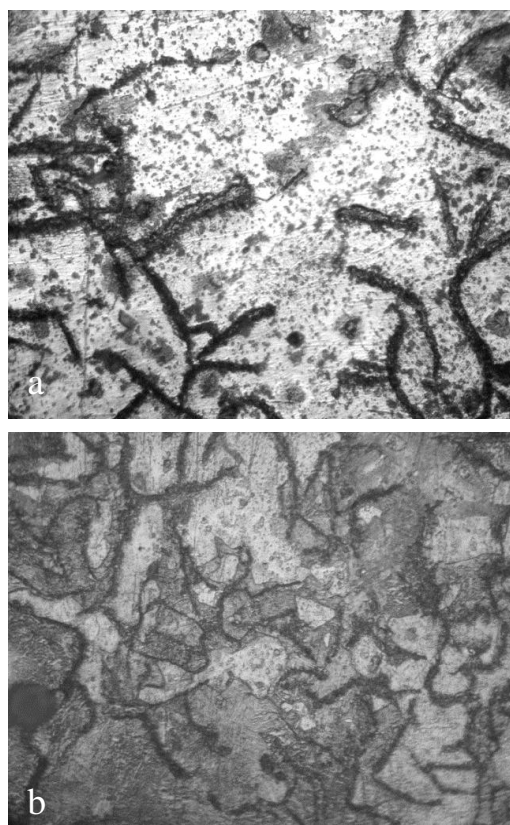


Figure 12 : Microstructure of tempered automotive camshaft, in 375 C, see fine particles of carbides precipitate imbedded in ferrite matrix(white regions)(a) polymer solution quenchant (b) oil quenchant

The microhardness of the gray cast iron was measured from the surface to the core after quenching in polymer and oil. The values of the hardness were taken after cutting the samples by milling along the center line. Fig .13 shows the maximum hardness at the surfaces and gradual reduced to the core .It is clear the hardness of polymer quenchant is greater than oil quenchant because the rapid loss in heat transfer between the hot metal and the polymer liquid and reached the critical cooling rate required to obtain high hardness. More uniform in the hardness line in polymer than oil quenchants. The presence of alloying element (Si, Ni, Cr) in the camshaft increased the depth of the hardness(hardenability) and this behavior required to reduce the cooling rate to obtain the martensite in the distance from the surface. It observed from the values of the hardness in the surface, that the hardness is lower in polymer and oil quenchants because the presence of retained austenite surrounding the martensite and the presence of more flakes of soft graphite reduced the intrinsic hardness. Retained austenite reduced or eliminated in the tempering of hardening gray cast iron but the graphite retained in the matrix.

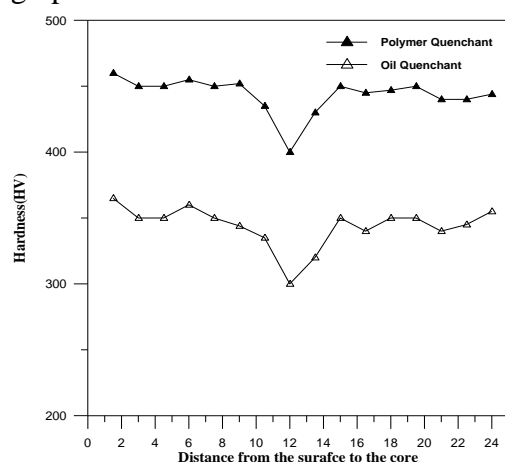


Figure13: Microhardness measurement of automotive camshaft section after hardening from 875 °C in polymer(initial temperature 20 °C) and oil quenching(initial temperature 50 °C).

4. Conclusion

The effects of process parameter, quenching media(oil, polymer), polymer concentration and temperature of initial oil quenchant, on the hardening of automotive camshaft were investigated :

- 1- Cooling rate is decreased with increasing in polymer concentration., and with various concentration can obtain desired quenching speed.
- 2- Cooling rate decreased with increasing in initial temperature of oil quenchant..
- 3- Surface hardness increased with polymer quenchant in camshaft that required to increase wear resistance in the surface but core hardness in camshaft decreased by oil quenchant that required to increase the toughness in the core to resist impact and vibration.
- 4- In both quenchants there is no cracks after the heat treatment of the cylindrical of gray cast iron.
- 5- Polymer quenchant eliminate the fire hazards and oil smoke normally with oil quenchant.

- 6- Polymer quenchant eliminating sludge and varnish buildup that can be associated with quenching oil.
- 7- Tempering of automotive camshaft in 375 °C after quenching in both oil and polymer reducing the hardness and improving the toughness by decomposition of martensite to fine particles of carbides in the ferrite matrix..

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