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Comparison of Microstructure and Surface Properties of AISI 1045 Steel After Quenching in Hot Alkaline Salt Bath and Oil

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The effect of quenching in molten alkaline salt bath medium on the microstructure and surface properties of AISI 1045 steel in comparison with oil was investigated. Salt bath medium used in this research contained 40% NaOH and 60% KOH with addition of 5 wt.% water at 205 °C. Hardening of 1045 steel in this medium resulted in an almost uniform microstructure, which consisted of fine martensite and bainite. In comparison, the microstructure of oil quenched sample was martensite, ferrite, widmanestatten ferrite, and pearlite. Quenching in salt bath lead to improved surface properties, i.e., decrease in surface roughness and a good bearing area curve.

Keywords alkaline media, bright hardening, quenching, salt bath, surface properties

1. Introduction

The cooling process and its effect on final properties is one of the most important factors in the design of heat treatment cycle. The choice of quenchant and control of quenching rate are a couple of the most important areas in providing desired properties. A proper quenching operation can result in desired mechanical properties and low residual stresses without distortion. The quenching rate must be controlled in such a way that the martensite structure is formed in the desired depth. In this regard, chemical composition, section thickness, quenching medium, and desired hardness are of primary importance (Ref 1, 2).

Molten salt baths are suitable mediums for quenching steel parts (Ref 3). Usually, the melting point of these mediums is higher than 150 °C (Ref 4, 5). They result in the least dimensional changes during quenching of steel parts (Ref 3). It is claimed that quenching in molten salt bath does not contain the vapor blanket stage (the first stage of formation of gaseous blanket around the quenched part in conventional quenchants), and thus, provides a better heat removal during this stage as temperature drops more rapidly. Therefore, it is expected that when a steel part is immersed into a molten salt bath, the heat is removed in a more uniform fashion (Ref 3).

Hot alkaline salt bath quenching mediums with proper cooling rates can provide desired quenching conditions to reduce the risk of distortion. The operating temperature of these mediums usually varies in the range of 150 to 700 °C. The alkaline baths, according to their melting temperature, may consist of different combinations of KOH and NaOH, as shown in Table 1 (Ref 2, 11). Different combinations provide different quenching abilities which can further be enhanced by adding 2-10% water to these combinations (Ref 5). The water addition to the alkaline bath can be done without any harmful reaction as encountered in nitride salt baths. A quenching process of this type is usually known as bright hardening (Ref 2, 11). Although the quenching salts used in this research have been introduced by some references in the past, very little work has exploited the benefits of quenching steel parts in these mediums.

In this study, the cooling effect of hot alkaline bath on the microstructure, roughness, and smoothness of the surface of AISI 1045 steel in comparison with oil quenching was investigated.

2. Experimental Procedure

The chemical composition of AISI 1045 steel used in this study is shown in Table 2. All test samples with dimensions of $6 \times 15 \times 40$ mm were austenitized at 845 °C for 1 h under protective atmosphere and quenched in the following mediums:

- Salt bath including 60% KOH and 40% NaOH held at 205 °C.
- Salt bath including 60% KOH and 40% NaOH with addition of 5 wt.% water at 205 °C.
- Stationary oil at room temperature.

Water percentage was kept constant by continuous addition of water.

The samples considered for surface measurements were then washed by an ultrasonic device in acetone media for 12 min and then the surface parameters (Roughness average (R_a), RMS

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Table1 Different alkaline chemical compositions and their melting points

Bath combination	Component, wt.%	Melting point, °C	Rang of temperature, °C
KOH	75	130	150–250
NaOH	25		
Water	6		
KOH	63	159	180–350
NaOH	37		
NaOH	100	322	350–700

Table 2 Chemical composition of AISI 1045 steel used in this study (wt.%)

C	Si	Mn	P	S
0.45	0.20	0.55	0.011	0.025

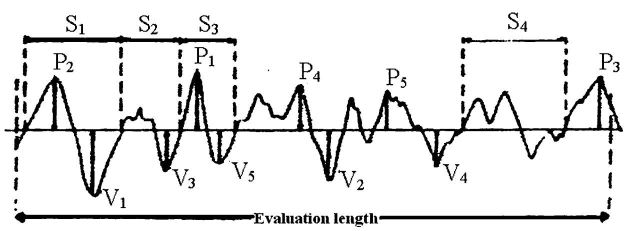

Fig. 1 Parameters for calculating R_z

Roughness (R_q), Skewness (R_{sk}), the maximum distance between peak and dip (R_{max}), and 10-point height roughness (R_z)) of samples were measured by Hommel Wercke T8000 surface profilometer and compared with the same properties before heat treatment. It should be mentioned that the surface characteristics of the specimens before heat treatment were almost the same. In order to verify R_z value, as an example, 10 regions in a specific length of surface profile as shown in Fig. 1 (5 highest peaks and 5 deepest peaks) were chosen and their averages were calculated according to Eq 1. In this equation, P and V stand for peak height and depth of dip, respectively (Ref 6). The methods of calculating other parameters have been shown in references (Ref 6, 7).

$$R_z = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + V_1 + V_2 + V_3 + V_4 + V_5}{10} \quad \text{(Eq 1)}$$

After heat treatment, samples for hardness measurements were washed in water solution containing 1.5% sodium nitride and 0.3% sodium carbonate to prevent rusting and hardness measurement was done at least three times for each surface according to the Rockwell C method.

Metallographic samples were prepared to reveal the surface microstructure of the heat treated samples with different quenching conditions. These microstructures were studied at different magnifications using the scanning electron microscope (SEM) CamScan MV2300.

Table 3 The effects of different quenchants on hardness values

	Quenchant		
Mechanical properties	Salt bath + 5 wt.% water at 205 °C	Salt bath at 205 °C	Stationary oil at room temperature
Surface hardness (HRC)	61 ± 1	60 ± 1	60 ± 1

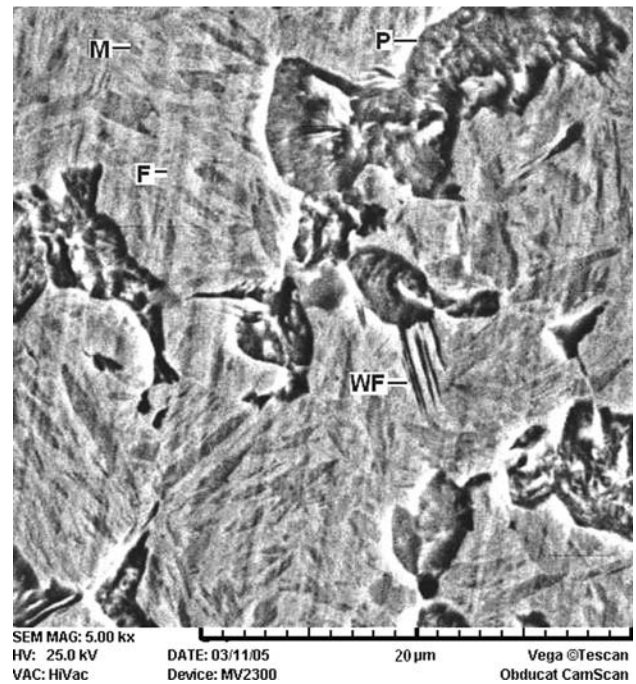

Fig. 2 Surface microstructure of 1045 sample quenched in stationary oil at room temperature. Microstructure consists of martensite (M), pearlite (P), some ferrite (F), and widmanstatten ferrite (WF)

3. Results and Discussion

3.1 Surface Hardness and Microstructure

Average surface hardness data of specimens in the quenched condition is given in Table 3. It can be observed that the surface hardness of all samples is almost equal. The microstructures of these samples are shown in Fig. 2-4. It can be seen in Fig. 2 that the microstructure of the oil quenched sample consists of martensite, pearlite, some ferrite, and widmanstatten ferrite. Figure 3 shows that the microstructure of 205 °C salt-hardened sample consists of pearlite and some dispersion of upper bainite in the martensitic matrix. The surface microstructure of the specimen quenched in 205 °C salt bath with 5% water is martensite and some bainite and pearlite (Fig. 4).

It was reported that the H-factor (severity of quench) for 205 °C alkaline bath with the addition of 5% water was calculated to be 0.4. H-factors for 205 °C salt bath and unagitated room temperature oil were 0.3 and 0.25, respectively (Ref 8). Therefore, both hot salt quenchants have higher quenching ability than oil. As expected, quenching in water

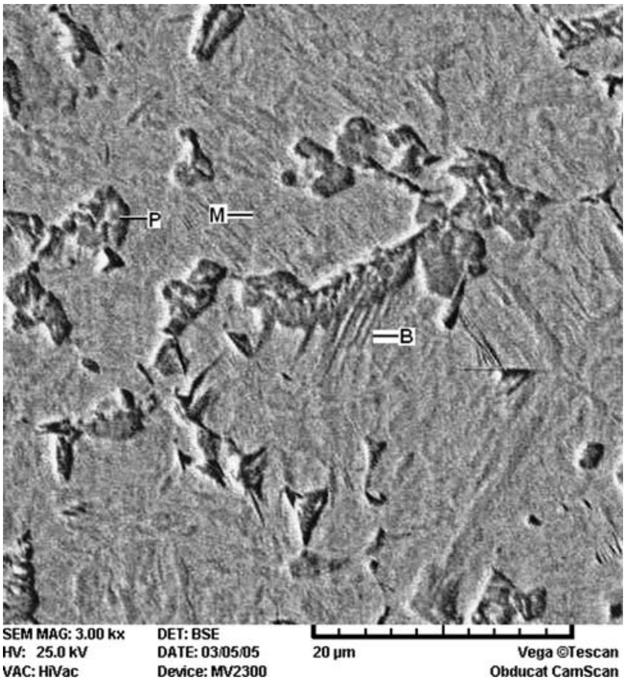

Fig. 3 Surface microstructure of 1045 sample quenched in salt bath at 205 °C. Microstructure consists of martensite (M), pearlite (P), and some bainite (B)

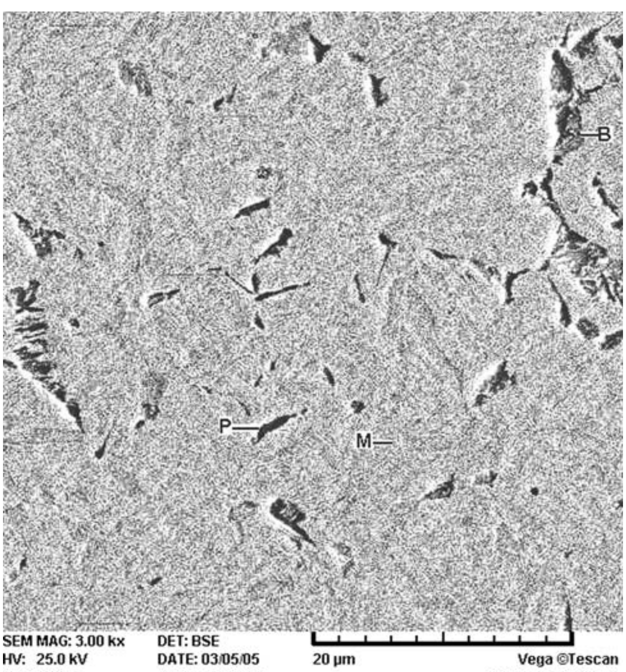

Fig. 4 Surface microstructure of 1045 sample quenched in salt bath at 205 °C including 5 wt.% water. Microstructure consists of martensite (M), some bainite (B), and perlite (P)

containing salt bath resulted in the formation of only a little amount of bainite in the matrix of martensite. The H-factors of 205 °C salt bath are higher those that of oil. Therefore, the sample has been quenched quick enough to reach the bainite zone. The amounts of ferrite and pearlite phases in the microstructure of salt bath quenched samples are less than those of oil.

Table 4 Roughness parameters of oil quenched specimen

	R_a, µm	R_q, µm	R_{sk}	R_{max}, µm	R_z, µm
Before treatment	0.14	0.18	0.347	1.28	0.90
Quenched in oil	3.79	4.98	1.027	28.36	26.86

Table 5 Roughness parameters of salt bath quenched specimen

	R_a, µm	R_q, µm	R_{sk}	R_{max}, µm	R_z, µm
Before treatment	0.11	0.14	0.601	1.65	1.20
Quenched in oil	1.15	1.48	−0.201	11.00	9.55

Table 6 Roughness parameters of specimen quenched in salt bath with addition of water

	R_a, µm	R_q, µm	R_{sk}	R_{max}, µm	R_z, µm
Before treatment	0.13	0.16	0.090	1.13	0.97
Quenched in oil	1.71	2.20	−0.34	15.01	12.13

3.2 Surface Roughness

Surface parameters resulted from roughness experiments of specimens are given in Table 4-6. It is shown that compared to non-treated samples, R_a value (average roughness) of salt bath and oil quenched specimens increased by about 1.04 and 3.65 µm, respectively. It is concluded that in comparison with salt bath quenched specimen, the surface roughness of oil quenched one has increased after heat treatment (Ref 7, 9, 10). This is due to the formation of high amount of surface oxidation, which occurs during quenching in oil. The salt bath quenched specimen, however, is protected by an alkaline layer after quenching that results in less oxidation when compared in terms of the thickness of the oxide layers.

After heat treatment, R_q parameter (root mean square roughness) of the oil quenched specimen had increased by 4.8 µm. The increase of R_q for salt bath and water containing salt bath was 1.34 and 2 µm, respectively. The results of this R_q values are in agreement with those of R_a values, i.e., the surface roughness of salt bath quenched samples is less than the oil ones.

It can be seen from Table 4-6 that after heat treatment, the R_z parameter (10-point mean roughness depth) of the oil quenched specimen has increased by about 26 µm. The increase for salt bath and water containing salt bath quenched specimens is about 8.35 and 11.16 µm, respectively. The measured roughness values also demonstrate the presence of oxide layer in the surface of the oil quenched specimen. The values also show that adding 5 wt.% water to the salt bath increased the surface roughness of samples slightly. This is probably due to the higher severity of quenching in water containing salt bath and more shearing during the martensitic transformation in this bath.

It is shown that the R_{sk} parameter (roughness skewness) for the surface of the oil quenched sample is positive, while this value for both salt baths is negative. R_{sk} verifies the distribution manner of peaks to dips in the surface of samples (Ref 7, 9, 10). The negative parameter indicates that the amount of peaks is less than dips. Therefore, for making balance in the average surface area, the peaks tend to be flat. Increase in wear and fatigue resistance can be expected in these specimens in comparison with the oil quenched specimens with positive R_{sk} values.

According to the Table 4-6, the R_{max} parameter, which indicates the maximum distance between a peak and dip in the specimen surface has increased by 27 μm after quenching in oil. This increase for salt bath and water containing salt bath quenched specimens is 9.5 and 14 μm, respectively. These values indicate that the distance between peaks and dips in the oil quenched specimen is higher than that of other baths. These results clearly show that the surface roughness of the oil quenched samples is higher than both salt baths.

Bearing area curves of different quenched specimens are shown in Fig. 5-7. It can be observed that in the oil quenched sample, suitable bearing area (60%) was achieved after about 30 μm grinding, while this bearing area for salt bath and water containing bath was obtained after 7 and 13 μm grinding, respectively. Moreover, the distribution of peaks and dips in both salt bath mediums is better than oil.

Figures 8-10 illustrate the amplitude density functions of three quenched samples. It can be seen that the function of the oil quenched specimens is asymmetrical, but it is rather symmetric in both salt bath mediums. Figure 8 and Table 4 show that the skewness of the oil quenched sample is positive, but according to Fig. 9 and 10 and Table 5 and 6, the skewness of both salt bath quenched samples is negative. It is concluded that unlike salt bath specimens, the tip of the peak in the oil quenched one is sharp

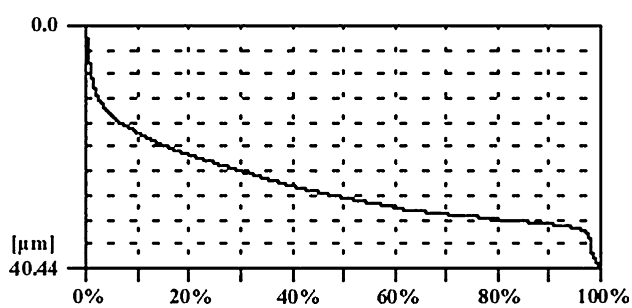

Fig. 5 Bearing area curve of stationary oil quenched specimen

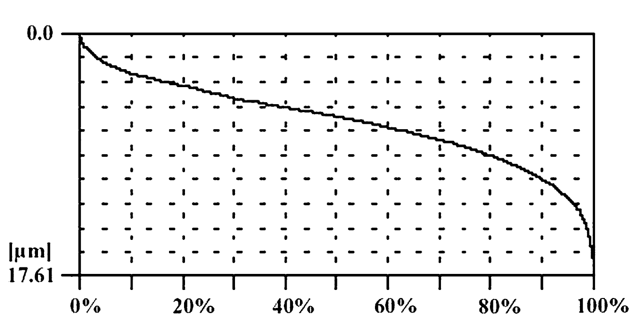

Fig. 6 Bearing area curve of 205 °C salt bath quenched specimen

(Ref 7, 9, 10). Therefore, as indicated before, lubrication properties of salt bath samples are better than those of oil one.

Figures 11-13 show the surface profile in the form of roughness and waviness on the length of 15 mm in the sample

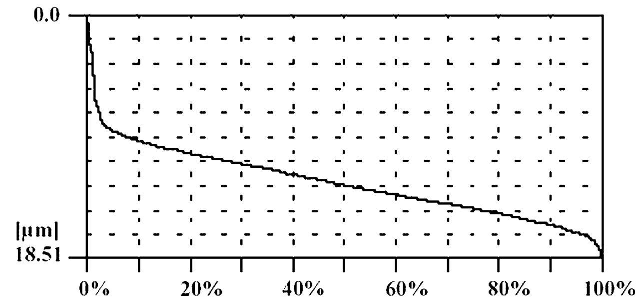

Fig. 7 Bearing area curve of 205 °C salt bath quenched specimen containing 5 wt.% water

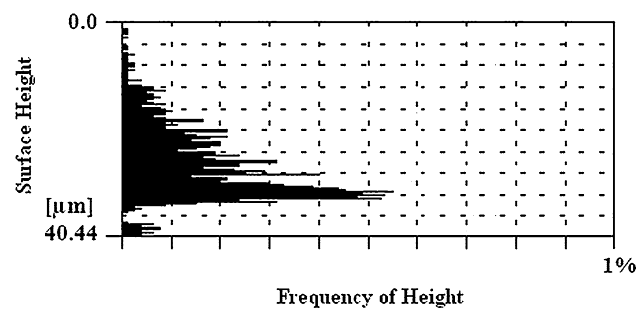

Fig. 8 Scope distribution function of oil quenched specimen

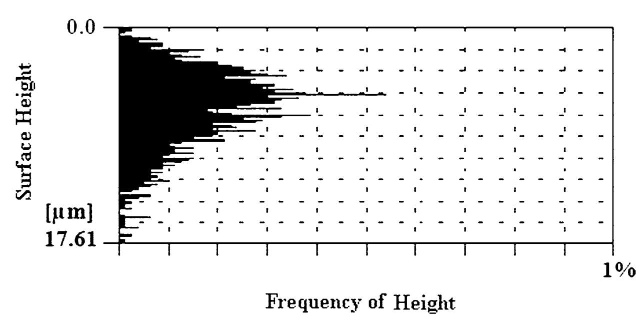

Fig. 9 Scope distribution function of 205 °C salt bath quenched specimen

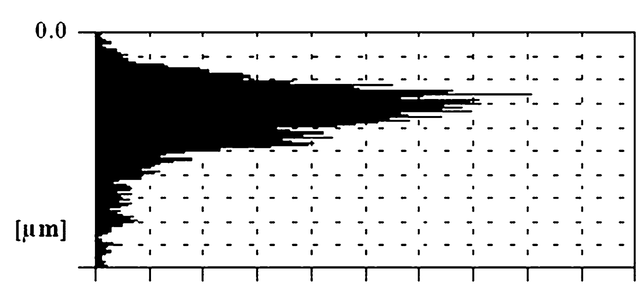

Fig. 10 Scope distribution function of 205 °C salt bath quenched specimen containing 5 wt.% water

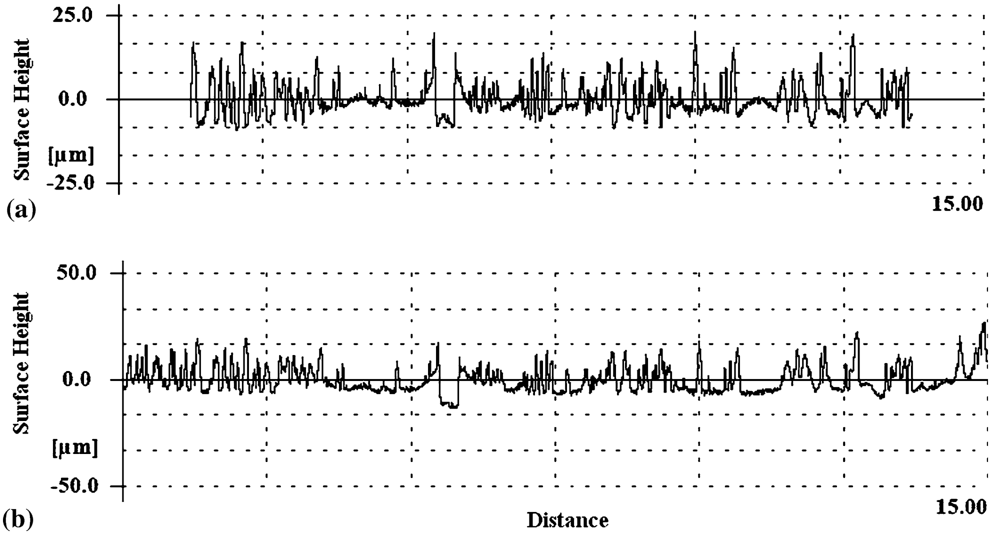

Fig. 11 Surface profile of quenched specimen in stationary oil (a) Roughness profile, (b) waviness profile

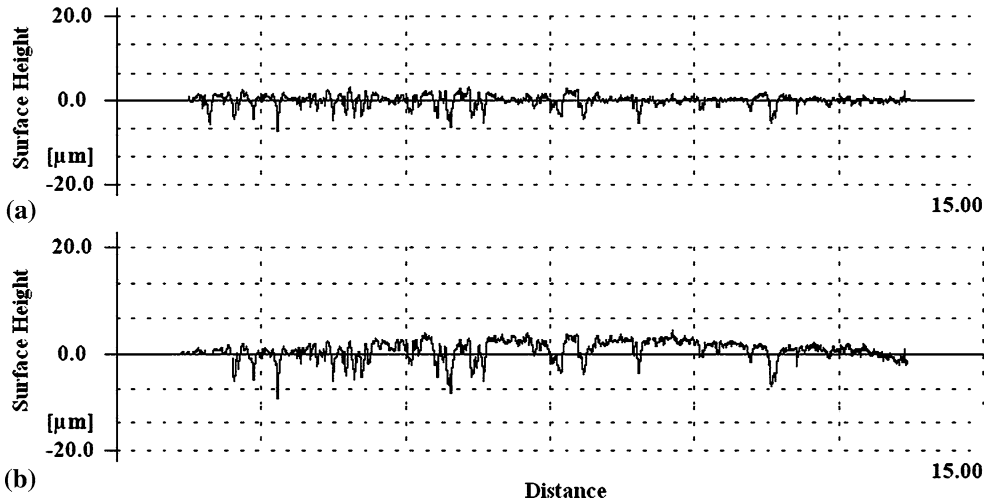

Fig. 12 Surface profile of quenched specimen in alkaline molten salt bath. (a) Roughness profile, (b) waviness profile

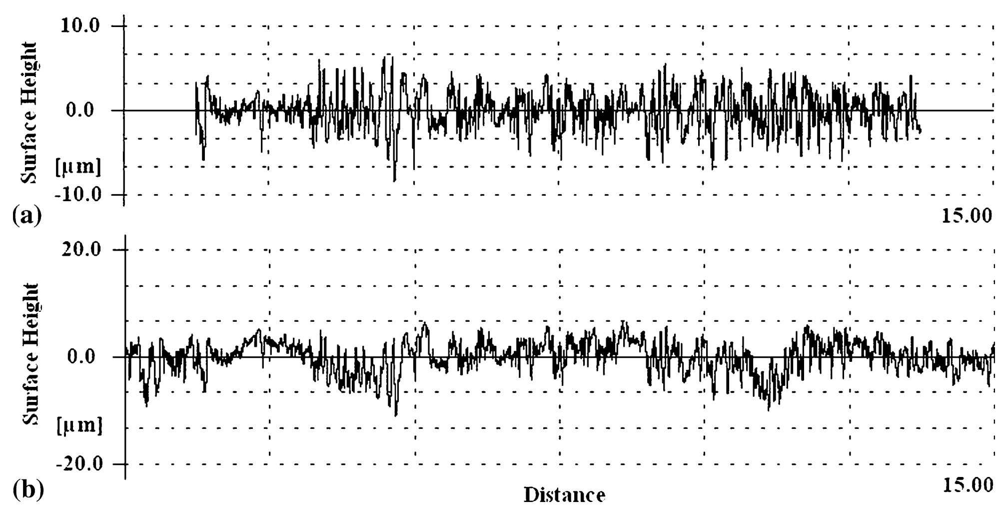

Fig. 13 Surface profile of quenched specimen in alkaline molten salt bath containing 5 wt.% water (a) Roughness profile, (b) waviness profile

surface. It can be depicted from these figures that there is a good agreement between the results shown in these Figures and the data given in Table 4-6, because waviness and roughness curves indicate that the distribution between peaks and dips in salt bath quenched specimens is more monotonous than the oil ones.

4. Conclusions

From the results of quenching AISI 1045 steel in hot alkaline salts with and without the addition of water and also oil quenching, the following conclusions can be made:

1. The surface hardness of AISI 1045 steel quenched in alkaline salt baths is almost equal to the oil quenched specimen.
2. The surface of the 205 °C salt bath quenched specimens containing 5 wt.% water has a microstructure containing some bainite in a martensitic matrix, while in the oil quenched specimen, the microstructure contains ferrite, pearlite, and widmansttaten ferrite in the martensite matrix. The microstructure of the 205 °C salt bath quenched specimens contains low amount of pearlite & bainite in a matrix of martensite.
3. Surface roughness resulting from quenching specimens in both water containing & water-free alkaline bath is less than that of oil quenched samples.
4. Less grinding is needed to achieve suitable bearing area (60%) in both salt bath quenched specimens in comparison to oil quenched samples. Moreover, the distribution of peaks and dips in the surface of samples quenched in both water & water free salt bath mediums is more desirable than oil quenched samples.
5. The tip of peaks in the surface of specimens quenched in both water and water free alkaline baths is round, while the tip in oil quenched specimens is sharp. This phenomenon results in better lubrication properties of salt bath treated samples. Also, the wear and mechanical properties of parts may improve due to salt baths quenching.

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