Effect on hardness and distortion by replacing quenching oils with aqueous polymer quenchants

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In recent years, it is required to improve productivity and reduce environmental load in the heat treatment process. Since aqueous polymer quenchants pose little danger of fire, it is possible to unify production lines with pre- and post-processes, which is expected to improve productivity. In addition, it is expected to reduce CO_2 emissions. On the other hand, aqueous polymer quenchants have a longer vapor blanket stage length and a faster cooling rate near the martensite transformation point than quenching oils, so there are concerns about changes in hardness, quench cracks, and increased distortion. In this study, we developed aqueous polymer quenchants with oil-like cooling properties and investigated the effect on the quenching quality with conventional aqueous polymer quenchants. The hardness and distortion of conventional aqueous polymer quenchants, developed aqueous polymer quenchants, water and quench oils were investigated, and examined whether the developed aqueous polymer quenchants could improve the hardness and distortion. As a result of quenching round bars of different materials, the developed aqueous polymer quenchants has the same hardness as oil regardless of the material, while the conventional aqueous polymer quenchants have the same hardness for chromium molybdenum steel , but lower hardness for carbon steel. It is considered that the developed aqueous polymer quenchants did not decrease in hardness because the vapor blanket stage length was shortened, so cooling proceeded without passing through the pearlite nose. In the quenching of C-type chromium molybdenum steel specimens, the distortion change of the developed aqueous polymer quenchants were as small as that of the quenching oils compared to the conventional aqueous polymer quenchants. Visualization and multi-point cooling performance evaluation experiments confirmed that the aqueous polymer quenchants had less uneven cooling than the conventional one. It is considered that the shortening of the vapor blanket stage length suppressed uneven cooling and reduced distortion.

Keywords: *quenching oils, water-solubilization, aqueous polymer quenchants, distortion*

1. Introduction

The heat treatment process consumes a lot of energy for heating and often emits CO_2 due to atmospheric control. CO_2 reduction is a issue for realizing carbon neutrality and achieving Sustainable Development Goals(SDGs). In addition to environmental conservation, it is necessary to work on improving production efficiency to achieve the SDGs, and various efforts are made by each company. As a quenching oils approach that can contribute to improving production efficiency and reducing CO_2 emissions, shortening the carburizing time by high cooling and reducing distortion variation by shortening the characteristic time have been reported[1)]. However, quenching oils pose a risk of fire, making it difficult to inline pre- and post-processes, which can hinder further improvements in production efficiency. If quenching oils can replace with aqueous polymer quenchants, it is thought that not only productivity can be improved, but also CO_2 emissions during quenchants production can be reduced.

On the other hand, aqueous polymer quenchants have a longer vapor blanket stage length and a faster cooling rate near the martensite transformation point than quenching oils, so there are concerns about changes in hardness, quench cracks, and increased distortion. In this study, we developed aqueous polymer quenchants with oil-like cooling properties and investigated the effect on the quenching quality with conventional aqueous polymer quenchants.

2. Experiment

2.1 Cooling performance

In Japan, the JIS K 2242 standard B method is commonly applied when evaluating cooling performance of polymer quenchants. Since the cooling rate from the martensitic transformation start temperature to the finish temperature is important as an index of quench cracking, the cooling rate from 400 to 200°C was selected as an evaluation item because of the type of steel material. In addition, if the vapor blanket stage is long, the microstructure becomes pearlite instead of martensite. vapor blanket stage length were also evaluated. The polymer quenchants and water were evaluated at a liquid temperature of 30°C without stirring, and the quenching oils was evaluated at an oil temperature of 80°C and 50 cm/s.

2.2 Quenching hardness of round bar

Evaluation of Quenching hardness was evaluated by using round bar made by JIS S45C(Carbon steel) and SCM435(Chromium molybdenum steel) which has 30 mm diameter and 30 mm height. The round bar was heated at 850°C for 60 minutes in a nitrogen atmosphere and then immersed in oil at an oil temperature of 80°C for 20 minutes, or in polymer quenchants and water at a liquid temperature of 30°C for 20 minutes. The hardness was evaluated by Rockwell hardness tester at intervals of 2 mm after cutting the center of the test piece(U-curve).

2.3 Quenching crack and distortion of C ring

Evaluation of quenching crack and distortion was evaluated by using C ring made by JIS SCM435(Chromium molybdenum steel)(Figure 1). The C ring was heated at 850°C for 60 minutes in a nitrogen atmosphere and then immersed in oil at an oil temperature of 80°C for 20 minutes, or in polymer quenchants and water at a liquid temperature of 30°C for 20 minutes. The crack was evaluated by a penetrant testing and distortion was evaluated by the amount of change in notch width before and after quenching. The distortion variation was evaluated by the difference between the maximum distortion value and the minimum distortion value when quenching was performed three times. After cutting the test piece in half, the hardness of the central portion was evaluated using rockwell hardness tester.

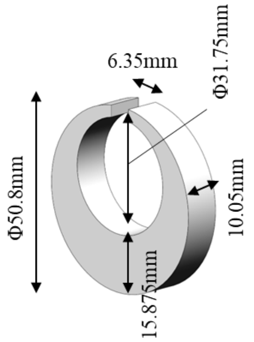

Figure 1. Dimensions of the C-ring

2.4 Cooling unevenness during quenching

Evaluation of temperature unevenness during quenching was evaluated by using round rod made by JIS SUS303(Stainless steel) which has 18mm diameter and 50mm height. Two thermocouples were mounted on round rod at 3 mm (bottom) and 25 mm (center) from bottom. The changes in temperature of round rod during quenching were measured at 1mm depth from surface. The round rod with two thermocouples was heated to 850℃ in a nitrogen atmosphere, and then quenched in quenching oils at 80℃ or polymer quenchants at 40℃. The temperature unevenness (Δt) was calculated by subtraction temperature of bottom from center.

3. Results

3.1 Cooling performance

Figure 2 shows the cooling curves for each quenchants, and Table 1 shows the characteristic time and 400-200℃ cooling rates obtained from the curves. The developed polymer quenchants have a shorter vapor blanket stage length and slower 400-200℃ cooling rate than the conventional polymer quenchants, indicating that the cooling properties are closer to high cooling oil.

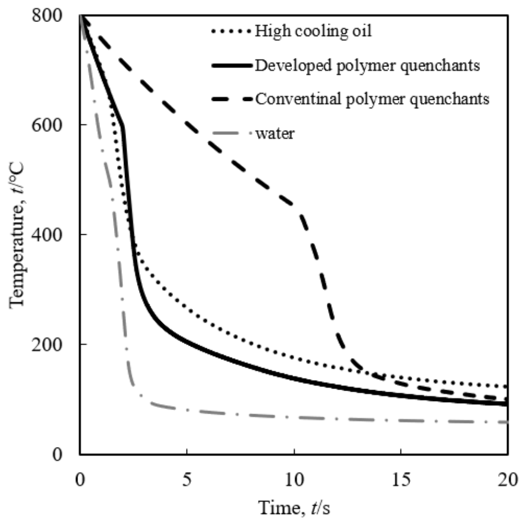

Figure 2. cooling curves for each quenchants

Table 1. cooling performance for each quenchants

Cooling performance	High cooling oil	Developed	Conventional	Water
		polymer quenchant (concentration：25wt%)		
vapor blanket stage length t/s	1.6	2.0	10.6	0.3
400-200 ℃ cooling rate ℃ s^{-1}	40	70	130	435

3.2 Quenching hardness of round bar

Figure 3 shows the hardness evaluation results of JIS S45C(Carbon steel) round bars quenched with each quenchants, and Figure 4 shows the hardness results of JIS SCM435(Chromium molybdenum steel) round bars quenched with each quenchants. The hardness of JIS SCM435 (Chromium molybdenum steel) was the highest when it was quenched with water, and the same level of hardness was obtained with other quenchants. On the other hand, the hardness of S45C was the highest when it was quenched with water, followed by high cooling oil and the developed polymer quenchants at the same level, and the conventional polymer quenchants had the lowest hardness. In the conventional polymer quenchants, cooling progressed while the ferrite and pearlite noses were affected, and it is thought that the hardness decreased because there were many structures that could not be transformed into martensite.

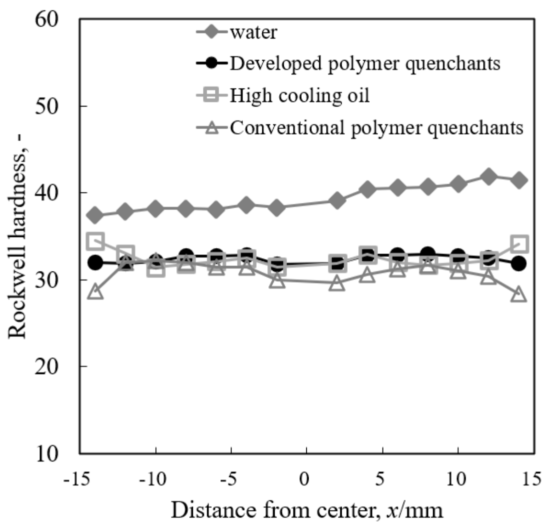

Figure 3. Hardness of JIS S45C(Carbon steel) round bars

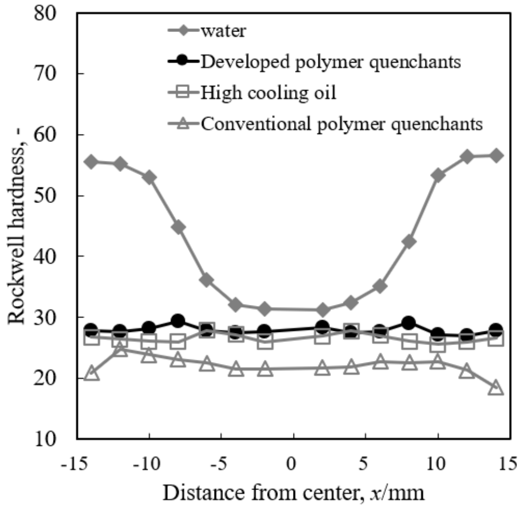

Figure 4. Hardness of JIS SCM435(Chromium molybdenum steel) round bars

3.3 Quenching crack and distortion of C ring

Table 2 shows the results of quench cracking and hardness of each quenchants. Water was the hardest and resulted in the occurrence of cracks. This is thought to be due to the rapid 400-200 ℃ cooling rate. The other oils had no cracks and had similar hardness.

Table 2. cooling performance for each quenchants

Cooling performance	High cooling oil	Developed	Conventional	Water
		polymer quenchant (concentration:25wt%)		
400-200 ℃ cooling rate ℃ s^{-1}	40	70	130	435
Rockwell hardness	55	55	57	58
Crack	 No crack			 With Crack

Figure 5 shows the change in notch width before and after quenching. Compared to the conventional polymer quenchants and water, the developed polymer quenchants reduced distortion variation, resulting in quenching quality equivalent to that of oil.

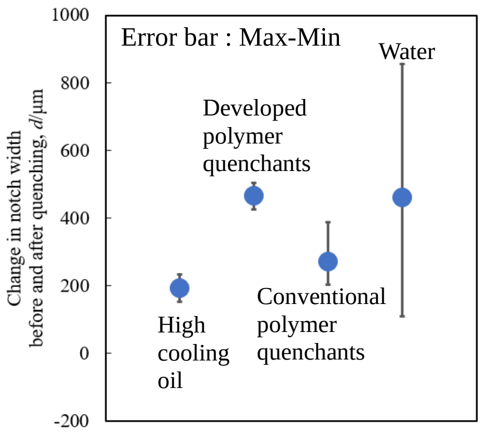

Figure5. Change in notch width before and after quenching.

4. Discussion

4.1 Cooling unevenness during quenching

In order to analyze the factors that reduced the distortion variation of the developed polymer quenchants compared to the conventional polymer quenchants, the cooling unevenness was evaluated using a round bar. Figure 6 shows the evaluation results of uneven cooling of the developed polymer quenchants and the conventional polymer quenchants. The developed polymer quenchants have less temperature unevenness between 400-200°C compared to the conventional polymer quenchants. It is considered that the distortion variation was reduced because the temperature variation in the martensitic transformation region of 400-200°C was reduced.

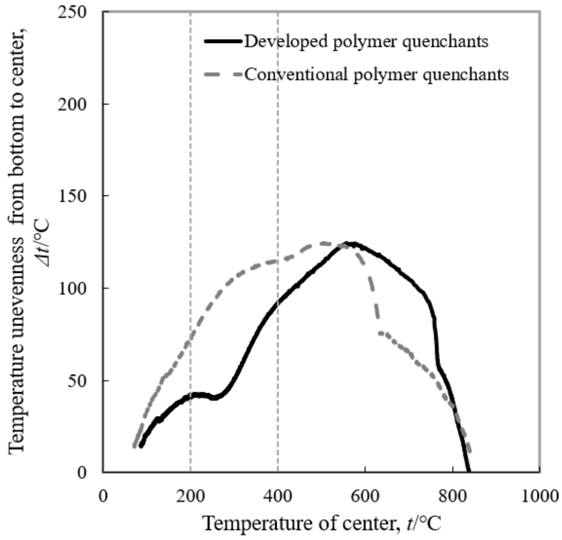

Figure 6. Cooling unevenness between temperature in the central part and temperature in the bottom part

5.Conclusion

(1) We have developed an aqueous polymer quenchants with a cooling property similar to that of oil.

(2) The developed polymer quenchants has the same hardness as oil regardless of the material, while the conventional polymer quenchants have the same hardness for chromium molybdenum steel, but lower hardness for carbon steel.

(3) Compared to the conventional polymer quenchants and water, the developed polymer quenchants reduced distortion variation, resulting in quenching quality equivalent to that of oil.

(4) The developed polymer quenchants has less temperature unevenness between 400 and 200°C compared to the conventional polymer quenchants. It is considered that the distortion variation was reduced because the temperature variation in the martensitic transformation region of 400-200°C was reduced.

6. References

1)K. Ichitani: Journal of The Japan Society for Heat Treatment. 62. 5 (2022) 209-213.