Characteristic of Quenching Refrigerant for Heat Treatment Deformation Control of SM45C Steel

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This study deals with the characteristic of quenching refrigerant for heat treatment deformation control of SM45C steel. Heat-treatment deformation must be controlled for the progress of production parts for landing gear. Most of deformation is occurred on inconsistent cooling. The inconsistent cooling is caused by a property of quenching refrigerant. When a heated metal is deposited in the quenching refrigerant, the cooling speed is so slow in early period of cooling because of a steam-curtain. After additional cooling, the steam-curtain is destroyed. In this progress, the cooling speed is very fast. The object of this study is to control the deformation of heat-treatment for landing gear by improving the conditions of quenching. The cooling curves and cooling rates of water, oil and polymer solution are obtained and illustrated. From the characteristics of the quenching refrigerant, the effects of heat-treatments on thermal deformation and fatigue strength are also investigated.

Key Words : Heat-Treatment Deformation (Circularity, Straightness), Quenching Refrigerant, Conditions of Quenching, Fatigue Strength

1. Introduction

The landing gear for the aircraft is a highly valued product as well as one of the most important mechanical parts. Most crucial in the manufacture of landing gears are heat-treatment and surface treatment processes. Lisic devised an apparatus that can systematically assess quenching solution (Lisic, B., 1978), and Beck drew the cooling curves of silver and steel test piece in order to examine cooling capacities of various hardening oils (Beck, G. et al., 1975). Ueyma & Kim elucidated heat deformation based finite element method (T. Ueyama etc., 1989, H. Kim et al., 1993) and Lee studied the microstructure upon heat treatments (S. Lee et al., 2000) but they failed to identifye the causes of deformation by heat-treatment.

Presently, deformation due to heat-treatment accounts for faulty mechanical parts. In this regards, intensive studies should be made to suggest better ways of controlling heat deformation in mechanical part manufacturing industries.

Aircraft landing gears are largely made of 4240 steel and 300M steel (S. Lee, 1993, J. Song et al., 1999). These are among the representative high tension steels, which gain high strength through the formation of martensite and tempering. Thus oil quenching is usually applied to the steel with far higher hardening capacity due to the addition of alloy elements. In the case of large parts such as aircraft landing gears, however, heat-treatment deformation tends to occur owing to their large sizes and inconsistent cooling. Because mechanical correction of heat-treatment deformation is not allowed in the manufacture of landing gears, the occurrence of heat deformation at the last process of heat-treatment process means faulty

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and useless products. Therefore exact control of heat-treatment deformation is indispensable in the manufacture of landing gears.

Most of the heat deformation is attributed to inconsistent cooling of the mechanical parts. While some cases of inconsistent cooling may be due to the shapes of the parts, a more fundamental factor should be found in the characteristics of quenching cooling solution. At the early cooling stage, heated metals, which are drowned in quenching solution, cool down very slowly due to the steam-curtain formed on the surface. At later cooling stages, the steam-curtain is destroyed and cooling rate increases greatly as the metals are cooled down by evaporation heat of the cooling material. When water and oil are used together as a cooling solution the destruction of steam-curtain occurs locally, which results in inconsistent cooling rate and subsequent deformation. Therefore, in order to control heat-treatment deformation due to inconsistent cooling, it is essential to employ a cooling solution that can ensure uniform destruction of steam-curtain on the whole surfaces of the mechanical parts. Drowning the parts in polymer solution may be recommended as an alternative to make possible the uniform destruction of steam-curtain on the whole surfaces, thereby effectively controlling heat-treatment deformation due to inconsistent cooling.

The purpose of this study is to develop a better method of controlling heat-treatment deformation in aircraft landing gears by improving quenching conditions. The cooling curves, cooling rates, and quenching characteristics of the three cooling solutions(water, oil and polymer solution) obtained and illustrated. From the characteristics of the quenching refrigerant, the effects of heat-treatments on thermal deformation and fatigue strength are also investigated.

2. Test Pieces and Experimental Method

2.1 Specifications of test pieces

This study employed SM45C as experimental test pieces whose chemical compositions are presented in Table 1. For the convenience standard test pieces(No. 10) were used, because the complicated shape of the landing gear makes it cumbersome for the experiment. The shape of the standard test piece is shown in Fig. 1.

Table 1 Chemical compositions of SM45

SM45S	C	Si	Mn	P	S	Ni	Cr	Cu
Range	0.42~ 0.48	0.15~ 0.35	0.60~ 0.90	≤ 0.03	≤ 0.035	≤ 0.25	≤ 0.25	≤ 0.20
Measured	0.44	0.28	0.73	0.026	0.019	0.12	0.20	0.16

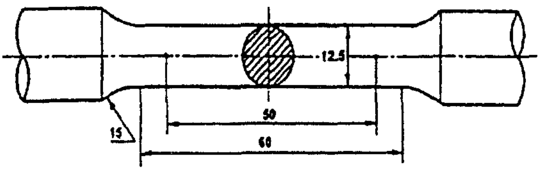


Fig. 1 Shape of standard test piece

A SM45C cylinder(18mm in diameter) was cut down into small pieces, and a center hole was made on each piece to process it into a test piece on a programmed CNC lathe. Each test piece was grounded by cylindrical grinder to obtain zero circularity and straightness.

2.2 Experimental method for characteristic of refrigerant

PAG(polyalkylene glycols) was adopted as the cooling solution for the experiment, while employing water and oil as comparative cooling solutions. Quenchotest(manufactured IVF) was used to measure cooling rate; the diagram of cooling rate measurement apparatus is presented in Fig. 2. The principle of measuring cooling rate on this apparatus is that when the probe is quenched in bath after being heated to 845°C in furnace, a thermocouple in the probe detects temperature and sends the signal to recorder, which transmit the data to a computer connected to it.

To measure variation in a cooling rate of cooling solution, a fixed agitation speed of 2.36m/s was applied to the polymer solution while varying concentration to 15% and 20% and temperature to 20°C, 40°C, and 60°C. Since water has no variations in concentration the fixed agitation speed was 2.36m/s employed to water, with varing temperature to 20°C, 40°C, and 60°C. In the case of oil, temperature was varied to 20°C, 40°C, 60°C and 80°C.

The optimal heat-treatment condition obtained in the above experiment was adopted for heat treating the SM45C steel test pieces; after the heat-treatment, the test pieces were fastened and evolved on the cylindrical grinder to measure their circularity with a dial indicator, and the table of the grinder was conveyed to measure straightness.

The heat-treatment process is presented in Fig. 3. The test pieces underwent one hour of austenizing, then quenching, and one hour of tempering treatment in 425°C. All the heating treatment procedures were carried out under ambient Argon gas to prevent oxidation.

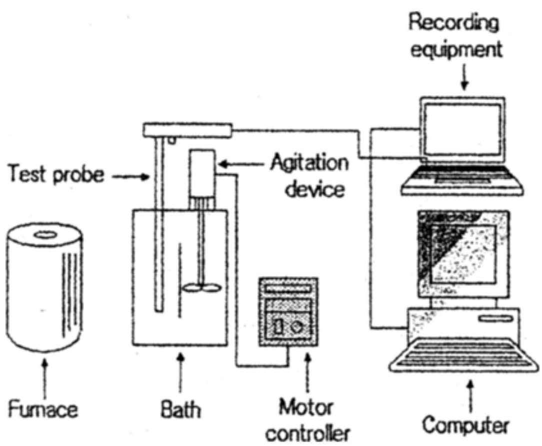


Fig. 2 Apparatus for measuring cooling rate

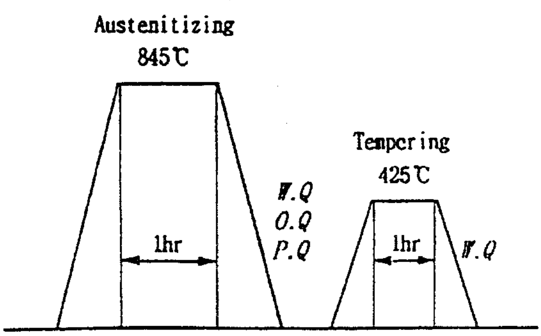


Fig. 3 Schematic diagrams of heat-treatment

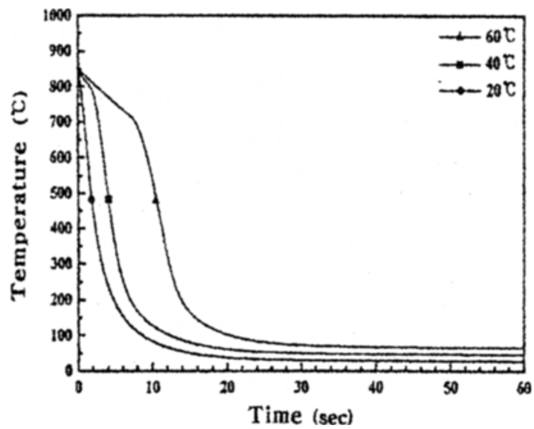
3. Characteristics of Cooling Solutions

3.1 Water

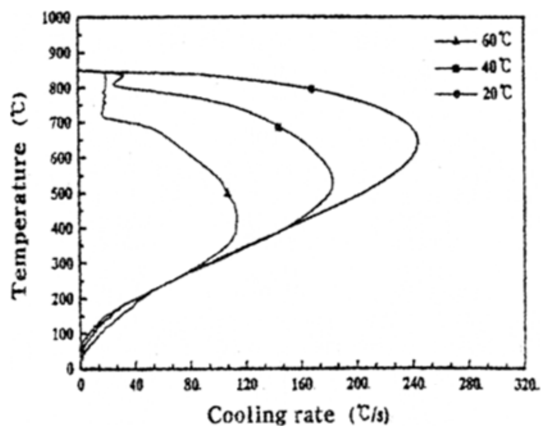
Fig. 4(a) and (b) present temperature-time cooling curve and differential cooling rate curve, obtained when the Ni base super alloy heated to 845°C was quenched in the cooling solution fixed at 2.36m/s. Almost no steam-curtain was observed when the cooling solution was at 20°C, but with the temperature increasing from 40°C to 60°C, the steam-curtain increased.

3.2 Polymer Solution

Generally speaking, two major factors having the greatest effect on the heat-treatment defor-

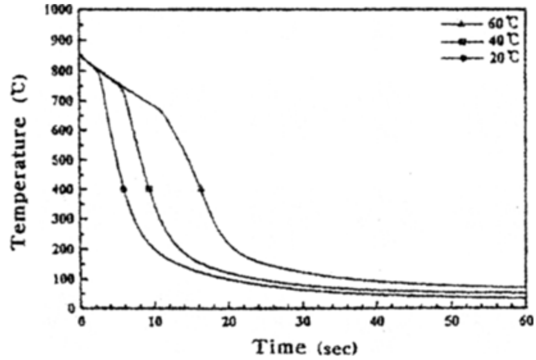


(a) Temperature-time cooling curve

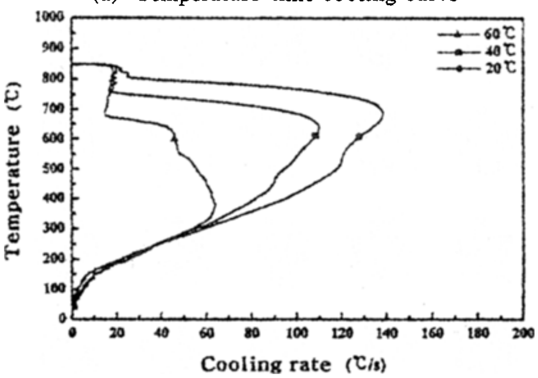


(b) Differential cooling rate curve

Fig. 4 The quenching characteristics of water

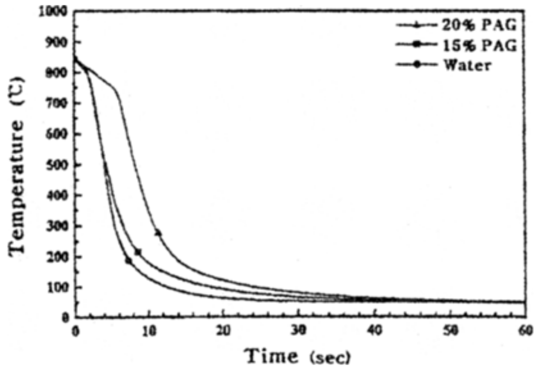


(a) Temperature-time cooling curve

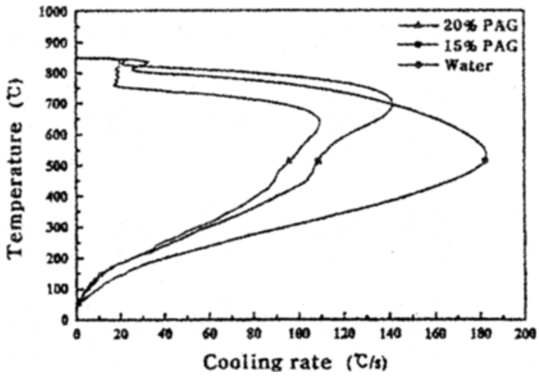


(b) Differential cooling rate curve

Fig. 5 The quenching characteristics of polymer solution (Concentration=15%)



(a) Temperature-time cooling curve



(b) Differential cooling rate curve

Fig. 6 The quenching characteristics of polymer solution (Temp.=20°C)

mation in manufacturing materials are temperature and concentration. The temperature of the polymer solution was varied to observe temperature effect.

Fig. 5(a) and (b) show the temperature-time cooling curve and cooling rate curve, respectively. Temperature increase from 20°C to 40°C showed a slight increase in steam coating stage, but significantly greater increase was observed at 60°C. It may be because heating polymer solution over 60°C may lead to its separation from water, resulting in lowered cooling capacity. Thus this study set the optimal temperature of the cooling materials as 20°C.

The temperature of the cooling solution was fixed at 20°C and the concentration was varied so as to investigate its effect on cooling rate, which is shown in Fig. 6(a) and (b), also including the curves when water was selected as a cooling solution.

As shown in Fig. 6(a), steam-curtain stage showed significantly great increase when the concentration of polymer solution was at 20%. Fig. 6(b) indicates that at the concentration of 15% maximum cooling rate was greater than at 20% but lower than when water was used. Cooling rate was found to be lowered at 400°C, around the temperature at which Martensite transformation of steel materials starts to occur. In order to maximize hardening effect and to minimize heat-treatment deformation, steam-curtain stage should be shortened and cooling solution with slower cooling rate at air stage should be selected.

In this regard, we can consider 15% of 20°C polymer solution as the optimal concentration.

3.3 Oil

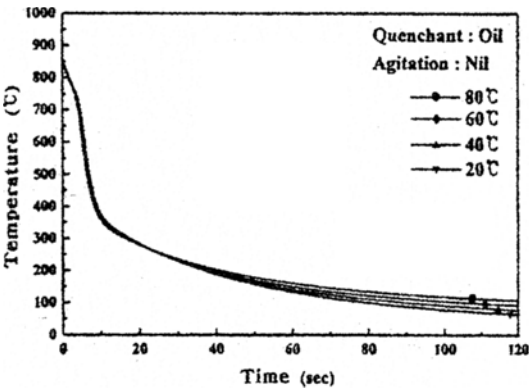
Fig. 7(a) shows measurements of oil temperature with time in heat-treatment. The figure indicates that at the initial stage, oil showed similar cooling characteristics at all the temperatures, but 80°C oil led to slightly better cooling performance. This may be because at this temperature the oil has better fluidity at temperature higher than the normal temperature and thus tends to enhance the cooling rate. In particular, 80°C oil cools down more slowly than other cooling solution at temperatures less than 300°C. Fig. 7(b) suggests that 80°C oil may be the optimal condition because at this temperature oil shows the highest cooling rate.

It was found that water showed the highest cooling rate, while that of oil was the lowest. Water and polymer solution cooling rates were highest at 680°C and 590°C, respectively. Polymer solution eliminated steam-curtain all at once and thus could remove the steam-curtain occurring in water-cooling, and it also took less time in reaching the maximum cooling rate than water cooling.

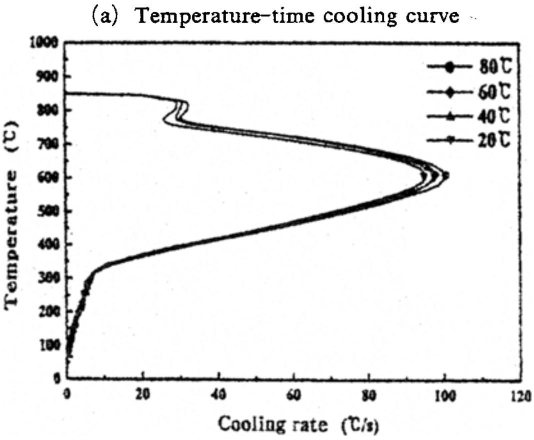
4. Heat Deformation and Surface Character

4.1 Measurements of heat deformation and discussion

Prior to heat-treatment, test pieces were ground so that their circularity and straightness (J. Song et al., 1999) were equally zero. After heat-treatment, test pieces were fastened on the cylindrical grinder to measure circularity with the dial indicator; their straightness was measured by grinding the table. Test pieces were heat treated in 15% of 20°C polymer solution, 80°C oil, and 20°C water at agitation speed of 2.36m/s before measuring circularity and straightness, which are shown in Figs. 8 and 9. When water was employed as a cooling solution, it caused the



(a) Temperature-time cooling curve



(b) Differential cooling rate curve

Fig. 7 The quenching characteristic of oil

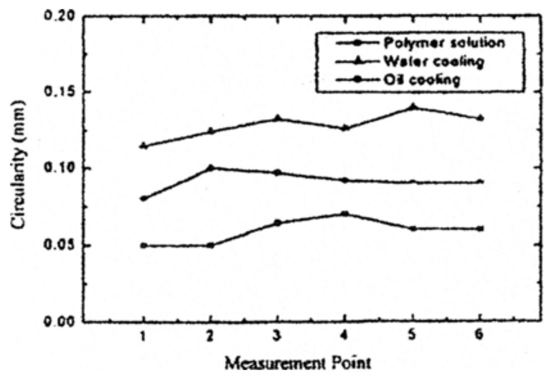


Fig. 8 Circularity of standard test piece

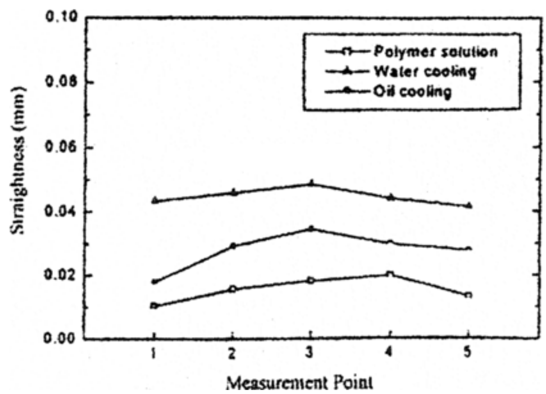


Fig. 9 Straightness of standard test piece

greatest heat deformation because steam-curtain surrounding the test pieces broke away, which led to inconsistent cooling, and because cooling rate is high even at 400°C, around the temperature of Martensite transformation. As shown in Figs. 8 and 9, circularity and straightness were great in the order of polymer solution, oil and water, and 15% of 20°C polymer solution produced the lowest circularity and straightness.

4.2 Measurements of Rockwell hardness and discussion

Figure 10 shows the Rockwell hardness measurements of test piece that were heat-treated in the cooling solution of water, oil, and polymer solution.

It was found that there was no significantly great difference in Rockwell hardness between the cooling solutions; the test pieces treated in water showed the highest hardness.

4.3 Metallography of heat treated test pieces

The metal microscope(Nikon EPIPHOT 200) was employed to observe the metallography. Test pieces were cut down into smaller pieces, mounted and grounded, eroded in a mixture of 5ml nitric acid and 100ml ethyl alcohol, washed away in running water, dried with a blow dryer to avoid staining, and observed under the meal microscope.

The observation spots were on the surface of the test pieces, and the metallographic pictures are presented in Fig. 11. As shown in Fig. 11, Martensitic texture was observed on water quen-

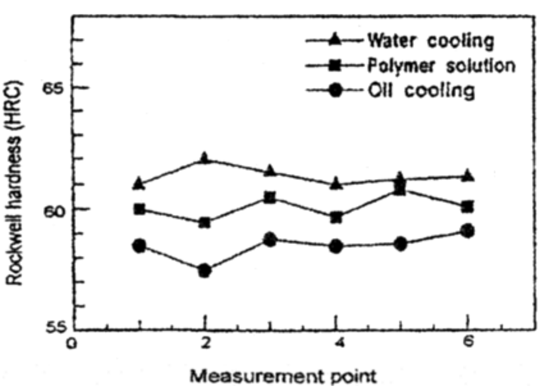
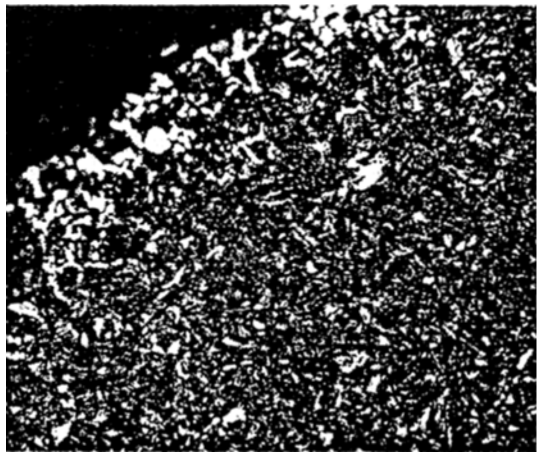
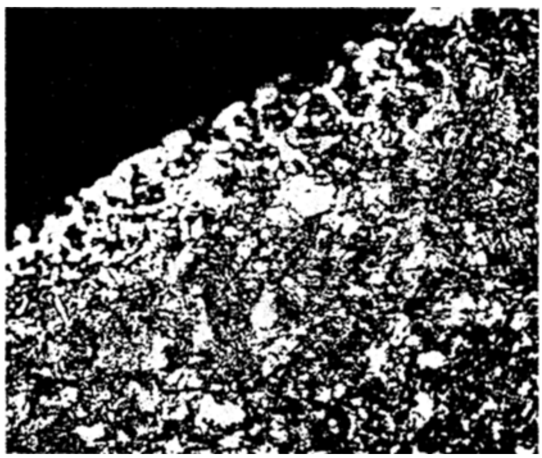


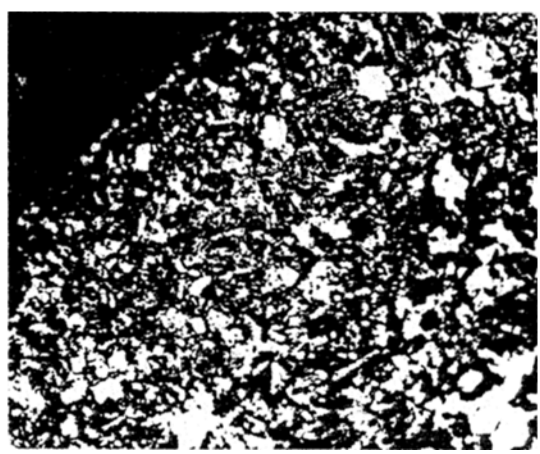
Fig. 10 Rockwell hardness distribution of standard test piece



(a) Water quenching (50X)



(b) Polymer solution (50X)



(c) Oil quenching (50X)

Fig. 11 Metallography of surface

ching, Vernite texture on polymer solution, and Pearlite texture on oil quenching.

5. Fatigue Test

Figure 12 shows the picture of rotation bending test(4 point bending fatigue of Ono's method) apparatus. Test piece a is fixed to axis b and driven by motor d on flexible axis c. Axis b is supported by 4 ball bearings in bearing box f. Bearing box f is fixed to test piece supporter h through knife edge g which is supported by the outer axis. The two inner axis transmit load via knife edge i to heavy weight j. Constant bending moment is applied to between i and i. K is the rotation counter gauge, and m is a point of contact at auto-stop that block the circuit and activates solenoid valve in order to open the power circuit of motor d in case a test piece breakage. N is the balancing weight that adjusts exactly the position with zero bending moment when the balancing weight is not applied as heavy weight. When a test piece is fixed, rotated and given target weight, the test piece is affected by fixed bending moment on the space, bending stress is applied to a spot of test piece surface. The bending moment M applied to the test piece is obtained by:

$$M=(P/2)a \qquad (1)$$

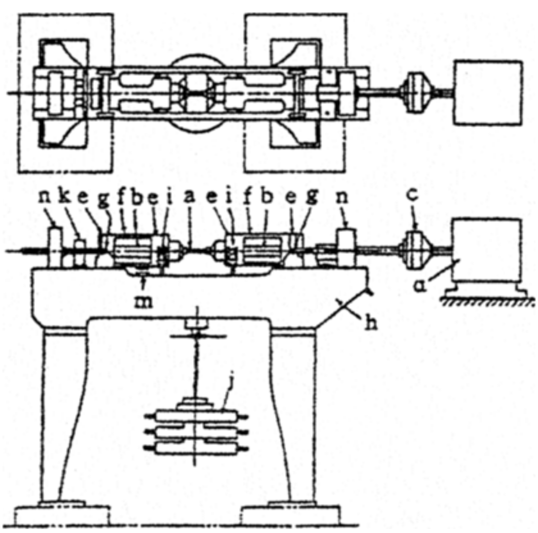


Fig. 12 Rotational bending fatigue test

Where P refers to balancing weight and a refers to the distance between half side of knife edges, and when this bending moment is applied all over the test piece, bending stress σ is obtained by:

$$\sigma=32M/\pi d^3 \qquad (2)$$

Where d refers to the diameter of test part. Evolution speed can be in the range of 1,500 to 6,000per minute, but 3,000per minute is usually adopted. Table 2 presents the major specifications of rotational bending fatigue tester.

Ono's method rotational bending fatigue tester was employed to perform fatigue tests on test pieces with no heat-treatment and on test pieces heat treated in water, oil, and polymer solution, and the S-N curve based on the obtained results was presented in Fig. 13.

The fatigue strength of each test piece was calculated by the formulation $\sigma_u=S_0+\Delta d$ of

Table 2 Specification of rotational bending fatigue tester

MODEL	DYD-150B
Bending moment	20Kg-m
R.P.M	3000
Mechanical counter	10^7
Length of loading lever	250mm
Loading weight	160Kg·f
Dimension (W ×D×H)	1650×350×930
Weight	250Kg

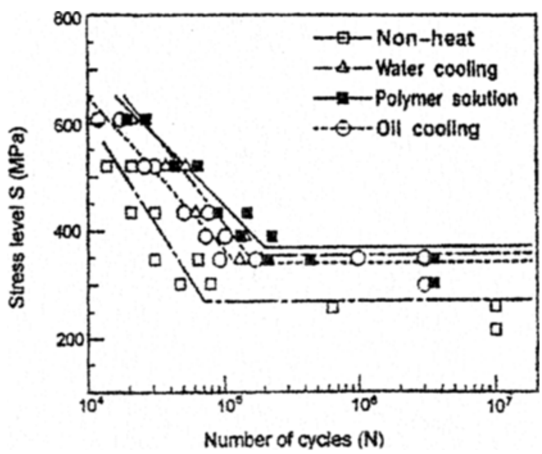


Fig. 13 S-N curves of test pieces

staircase method. Where S_0 refers to stress level value at the starting point of the test, and d refers to the interval of stress level values. Coefficient Δ is calculated as the ratio of stress level value interval(d), fatigue strength, and standard deviation(σ).

The fatigue strength of each test piece was calculated as the mean value of five tests. It was found that fatigue strengths were 271MPa for the test piece with no heat-treatment, 324MPa for oil solution, 356MPa for water, and 377MPa for polymer solution.

Heat-treatment effect obtained in the test was found to be between 26% and 39%, and polymer solution led to greater fatigue strength than any other cooling solution.

6. Conclusion

The results of this study are as follows:

(1) The optimal quenching conditions of cooling solution were 20°C for water, 15% concentration and 20°C for polymer solution, and 80°C for oil.

(2) Circularity and straightness were great in order of polymer solution, oil and water, and 15 %, 20°C polymer solution produced the lowest heat deformation in the test pieces.

(3) Hardness measurements indicated that test piece hardness was high in order of oil, polymer solution, and water.

(4) Fatigue test result suggested that heat-treatment improved fatigue strength by 26-39%, with polymer solution producing 6-10% higher fatigue strength than other cooling solutions.

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