Effects of Post-heating and Eleetro-polishing on Fatigue Strengths of 70:30 Brass and Eleetrolytic Copper Specimens

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NOTES

Effects of Post-heating and Electro-polishing on Fatigue Strengths of 70:30 Brass and Electrolytic Copper Specimens*

By Tsunemi URYU

1. Introduction. In the former paper[1)] we have reported that the fatigue strengths of plain specimens, i. e., specimens without notch, of various kinds of carbon steels decreased by 10～20%, if the specimens were annealed at a temperature above their recrystallization temperature after their surfaces were finished, as compared with those of specimens without such annealing.

As to the cause of such detrimental effect of post-annealing, we have considered the notch-effects of hair cracks, which would start from slag inclusions in steels located near the surface of the specimen as a result of turning or polishing the specimen. Of course, the strain-hardened layer, which will strengthen the specimen for fatigue, is also formed near the surface of the specimen due to such machining. Therefore, if the specimen is so post-annealed that such strain-hardened surface layer is relieved, the notch-effects of hair cracks remain in the specimen and cause the lowering of its fatigue strength. While, in the not post-annealed specimen, the notch-effects of hair cracks will be cancelled by the strengthening action of the strain-hardened surface layer mentioned above, so that the lowering of the fatigue strength of the not post-annealed specimen will be very little.

However, even if such hair cracks will not start from non-metallic inclusions during the surface finish, such detrimental effect of post-annealing as mentioned above can be caused also by the fact that the notch-effects of inclusions on or just below the surface of the specimen are larger than those of inclusions far below the surface. Now, Fig. 1 is useful to think of such larger notch-effect of a inclusion located near the surface, if we suppose that the inclusion acts as a circular hole in the plate. The stress concentration factors α_A and α_B *vs.*

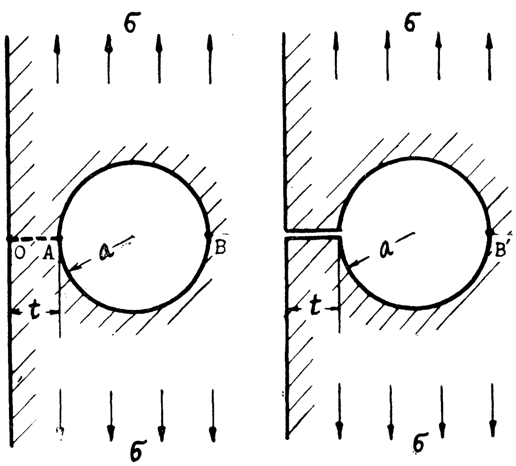

Fig. 1. Semi-infinite plate with a circular hole located near the straight edge and under tension parallel to the edge.

* Read before the 30th General Meeting (Tokyo) of Japan Soc. Mech. Engs., April 2, 1953.

1) T. Isibasi, T. Uryu, "Effects of slag inclusions in carbon steels on their fatigue strength," Rep. Res. Inst. App. Mech., Kyushu Univ., I, 1952, p. 107.

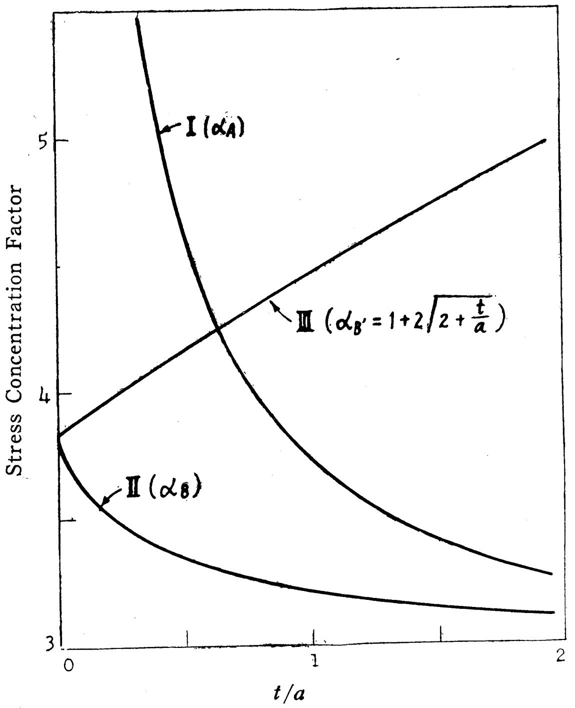

Fig. 2. Stress concentration factors *vs.* t/a at the points A, B and B′ in Fig. 1(a) and (b).

t/a at the points A and B in Fig. 1(a) are shown with the curves I and II in Fig. 2, respectively.[2] So far as t/a is small, both α_A and α_B are considerably larger than 3, i.e. the stress concentration factor of the hole far from the edge. In such case the first fatigue crack will presumably start from the point A to O, consequently the hole becomes an outside notch when the part AO is cracked (Fig. 1(b)). The stress concentration factor $\alpha_{B'}$ *vs.* t/a at the point B' in Fig. 1(b) is shown with the curve III in Fig. 2.[3] Therefore, the hole located at the place of $t=0.64\,a$ (at which $\alpha_A = \alpha_{B'} = 4.25$) will exert the most deleterious effect on the fatigue strength of that plate. J. B. Johnson's experiments (SAE X-4340 steel)[4] have given a evidence to this fact that the inclusions on or just below the surface of the specimen had higher notch-effects than those of the inclusions far below the surface.

From the above facts it can be considered that, if the material contains non-metallic inclusions as a stress-raiser, the thin strain-hardened surface layer of the same order of magnitude as the linear dimension of the inclusions, such as that formed due to turning or polishing the specimen, is much effective on the increase in the fatigue strength of the specimen, and, if such strain-hardened surface layer is softened by post-annealing the specimen, the notch-effects of inclusions, or hair cracks started from the inclusions during the surface finish, located near the surface give rise to the considerable decrease in the fatigue strength in comparision with that of the specimen without such annealing. Moreover, electro-polishing of the specimen, after the surface was mechanically polished, can be expected to have the same detrimental effect on the fatigue strength as that of post-annealing since the electro-polishing removes also the strain-hardened surface layer from the specimen.

For example, M. Hempel[5] has reported that both post-heating (at 500°C, 2 hr., in

[2] T. Udoguti, "Some examples of solutions in Two-dimensional problems of elasticity by bi-polar coordinates, part I. (A semi-infinite plate containing a circular hole)," Trans. Japan Soc. Mech. Engs., 13, 1947, No. 44, p. 17.

[3] H. Neuber, "Kerbspannungslehre," Julius Springer, Berlin, 1937.

[4] J. B. Johnson, "Magnaflux—what does it show?," S.A.E. Journal, 44, 1939, p. 59.

[5] M. Hempel, "Dauerfestigkeitsprüfungen und Werkstoffverhalten bei der Schwingungsbeanspruchung—1. Dauerversuche zur Schaffung von Berechnungsgrundlagen." Zeits. VDI, 94, 1952, s. 809.

vacuum) and electro-polishing (the thickness of surface removal, 0.01～0.03 mm) of carbon steel plain specimens lowered their fatigue strengths by about 15% of that of the specimens as mechanically polished. G. R. Gohn and S. M. Arnold's experiments[6] show that the surface work-hardening by polishing with No. 400 Aloxite paper increases the fatigue strengths of various beryllium-copper strips by 13～24% as compared with those of the strips as rolled.

In this study, to see the effect of electro-polishing as well as post-heating on the fatigue strengths of plain specimens of 70 : 30 brass and electrolytic copper, rotary bending tests were carried out. (The speed of stress repetitions was 2500～2700 rpm.).

2. Experiments on 70 : 30 brass. The 70 : 30 brass used has the following chemical composition; 69.7% Cu, 28.7% Zn, 0.03% Sn, trace of Pb. Its microphotograph is shown in Fig. 4, and its mechanical properties are shown in Table 1. Fatigue specimens (12 mm in dia.) were cut from a rolled plate of 18 mm in thickness, such that their longitudinal axes coincided with the rolling direction of the plate. All specimens were annealed, before turning, at 500° C for 1 hr. and cooled in the furnace. The surfaces of the specimens were finished with cotton flannel and fine carborundum powder after they were polished down to 0/5 emery paper.

Table 1. Mechanical properties of the materials used (Annealed state).

Material	Annealing	Yield strength (0.2% offset), kg/mm²	Tensile strength, kg/mm²	Elongation (gauge, 50 mm), %	Brinell hardness number
70 : 30 brass	500° C, 1 hr.	12.4	33.4	68.7	70
Electrolytic copper	450° C, 1 hr.	3.9	22.6	56.5	55

(*a*) *Effect of post-heating.* After the surface finish mentioned above, each of four groups of specimens was heated at each temperature of 200°, 300°, 400° and 500° C for 1 hr. and cooled in the furnace, held in a tight steel box packed closely with brass cutting chip.

The results of fatigue tests with the four groups of post-heated specimens and with specimens as mechanically polished are shown in Fig. 3 and in Table 2. These results obtained can be explained on the basis of the relation between the softening of strain-hardened surface layer and the post-heating temperature.[7] Since the recrystallization of cold-worked 70 : 30 brass takes place starting at about 225° C, the strain-hardened surface layer of specimens does not soften at 200° C (at which temperature the cold-worked brass rather hardens), so that the fatigue limit of the specimens post-heated at 200° C does not decrease. On the other hand, the degree of softening of the surface layer of specimens post-heated at 300～500° C increases with the rise of the heating temperature, so that the fatigue limits of such specimens decrease naturally with the rise of the heating temperature.

Some of the larger non-metallic inclusions observed in the present brass are shown in

[6] G. R. Gohn and S. M. Arnold, "The fatigue properties of beryllium-copper strip and their relation to other physical properties," Proc. ASTM, 46, 1946, p. 741.

[7] e.g., E. Davis and S. G. Temple, "Batch and continuous annealing of copper and copper alloy," Jour. Inst. Metals, 80, 1952, p. 287; B. L. Averbach, "Recovery and recrystallization in brass," Jour. Metals, Trans., 185, 1949, p. 491.

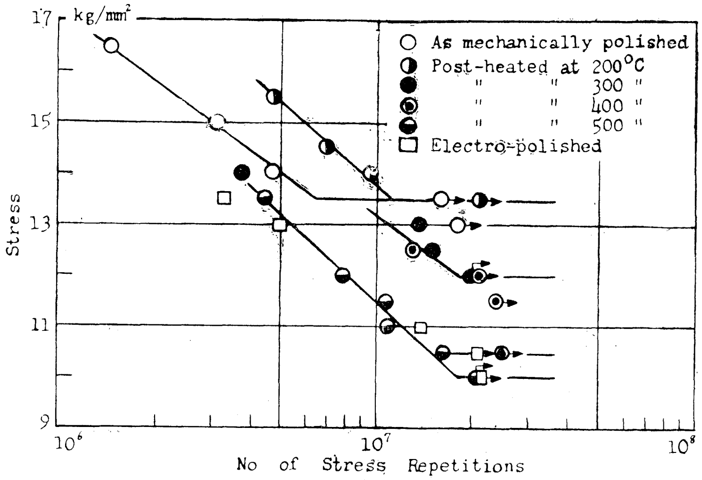

Fig. 3. S–N curves of plain specimens of 70 : 30 brass.

Table 2. Results of fatigue tests with 70:30 brass plain specimens.

Treatment after mechanical polishing		Fatigue limit, kg/mm^2	Ratio*
As made		13.5	—
Post-heated	200° C	13.5	1.00
	300 "	12.0	0.89
	400 "	12.0	0.89
	500 "	10.0	0.74
Electro-polished		10.5	0.78

* Ratio of the fatigue limit of treated specimens to that of specimens as made.

Fig. 5. The thickness of the strain-hardened surface layer of a specimen as mechanically polished was measured by means of *X*-ray diffraction photographs (Fig. 7(a)∼(f)), and the surface layer of about 0.05 mm in thickness was seen to be severely work-hardened. Therefore, such a thickness will be sufficient to strengthen the material around the inclusions located near the surface.

(*b*) *Effect of electro-polishing.* Then, a group of specimens which were electro-polished after their surfaces were mechanically finished in the same way as mentioned before was prepared. The conditions of electro-polishing were as follows: Electrolyte, 43% orthophosphoric acid in water; current density, 7 amp/dm^2; voltage, 2 volt; temperature, 15∼20° C. The thickness of the surface layer of each specimen removed due to electro-polishing was about 0.05 mm.

The results of fatigue tests of this group are shown also in Fig. 3 and in Table 2. It is reasonable that the fatigue limit of the electro-polished specimens is almost equal to that of the specimens post-annealed at 500° C.

3. Experiments on electrolytic copper. We consider that the presence of non-metallic inclusions as a stress-raiser in materials is essential to the decrease in the fatigue strength of post-annealed specimens. If the material has no non-metallic inclusions, such detrimental effect of post-annealing will be very little for that material.

To confirm this point of view, the electrolytic copper was examined because of its cleaner structure. Its mechanical properties and microphotograph are shown in Table 1 and in Fig. 6, respectively. Fatigue specimens (12 mm in dia.) were turned from round bars of about 18 mm in dia., which were, before turning, annealed at 450° C for 1 hr. and cooled in the furnace. The mechanical surface finish, post-annealing (at 450° C) and electro-polishing of the specimens were carried out in the same ways as in the case

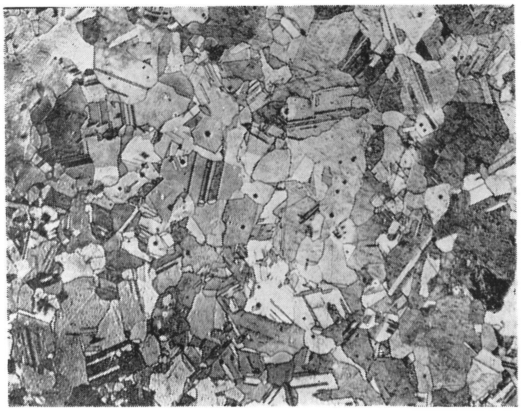

Fig. 4. Microphotograph of 70 : 30 brass (× 100).

Fig. 5. Some larger inclusions in 70:30 brass (× 100, unetched).

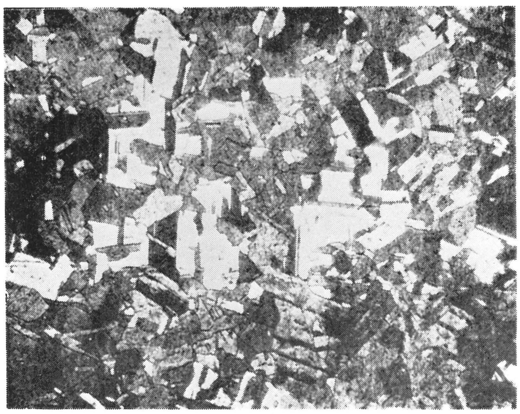

Fig. 6. Microphotograph of electrolytic copper (× 100).

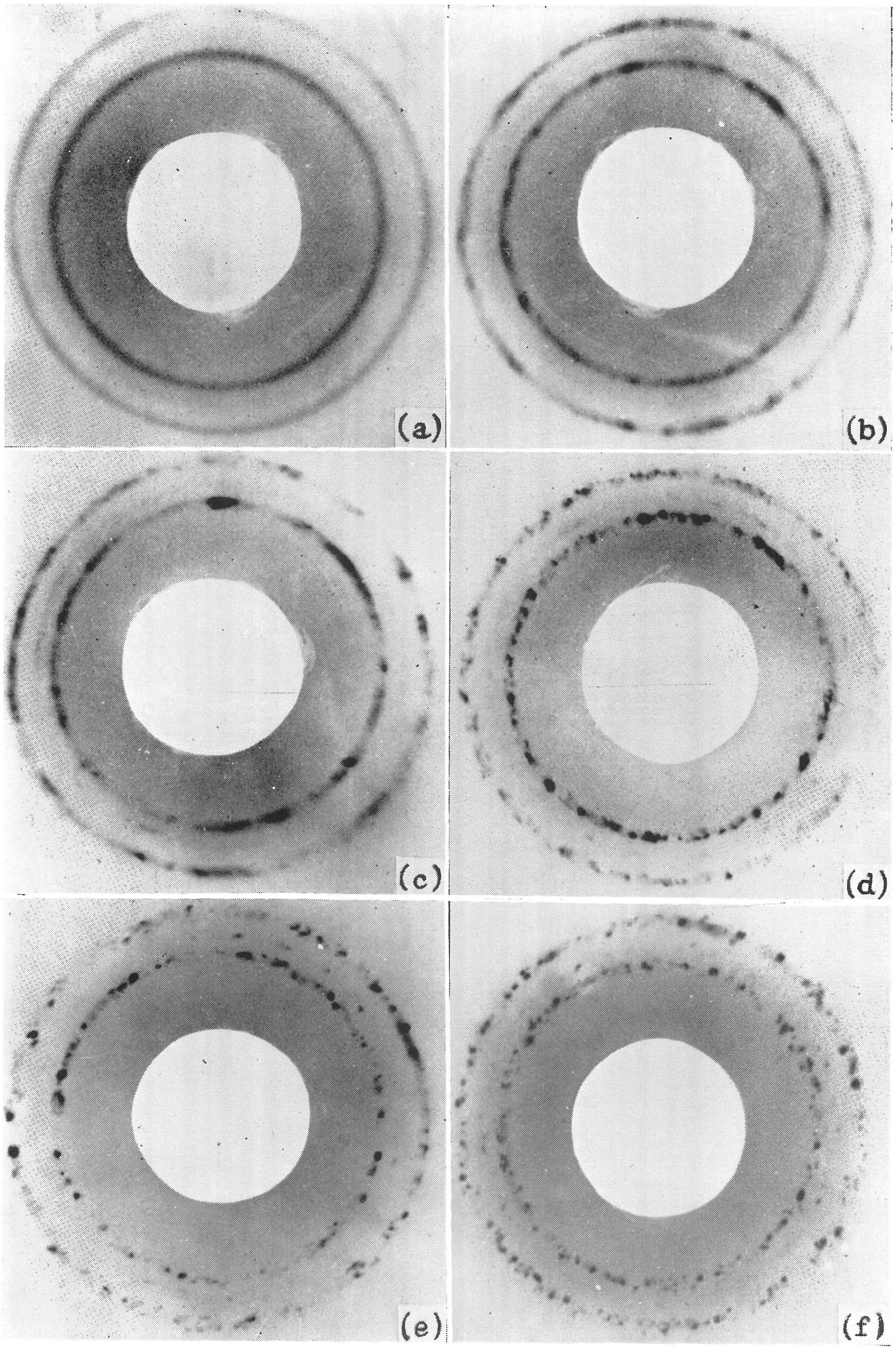

Fig. 7. X-ray diffraction photographs taken at the original and the successively etched surfaces of a mechanically polished plain specimen of 70:30 brass: (a) taken at the original surface; (b) taken after removing 0.025 mm from the original surface by etching; (c) after removing 0.05 mm; (d) after removing 0.08 mm; (e) after removing 0.10 mm; (f) after removing 0.16 mm.

of the brass specimens.

The results of fatigue tests of the specimens, as mechanically polished, post-annealed and electro-polished, are shown in Fig. 8 and in Table 3. As can be seen from these results, the detrimental effect of post-annealing as well as electro-polishing is very little as was expected.

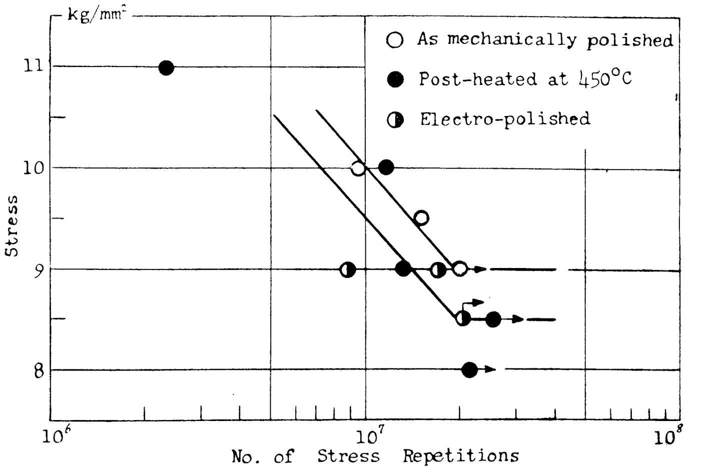

Fig. 8. S–N curves of plain specimens of electrolytic copper.

Table 3. Results of fatigue tests with electrolytic copper plain specimens.

Treatment after mechanical polishing	Fatigue limit, kg/mm²	Ratio*
As made	9.0	—
Post-annealed at 450°C	8.5	0.95
Electro-polished	8.5	0.95

* Ratio of the fatigue limit of treated specimens to that of specimens as made.

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