Influence of the Crystal Orientation and the Grain Size on the Flexing Property of Tough Pitch Copper

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ABSTRACT We researched the influence of the crystal orientation and the grain size on the flexing property of tough pitch copper (C1100). As a result of the Institute of Interconnecting and Packaging Electronic Circuits (IPC) bending tests under the same conditions, a sample oriented to a {001}<100> orientation (W-orientation) had a better life than a sample oriented to a {001}<110> orientation (NDW-orientation). As a result of a surface observation and an analysis after the tests, the surface of the sample oriented to a {001}<110> orientation (NDW-orientation) was confirmed to have a surface roughness and some cracks which was assumed to be the starting point of fracture, which is contrary to the sample oriented to a {001}<100> (W-orientation). In addition, in the case of a random orientation, it was clarified that the smaller the crystal grain size, the better the bending performance. In addition, in the case of a random orientation, it was clarified that the smaller the crystal grain size, the better the flexing property.

1. INTRODUCTION

Tough pitch copper (C1100) having a {001}<100> recrystallized texture is known for its excellent flexing property[1], and is used for flat cables, etc. To make the tough pitch copper, a cold working with a large area reduction is performed at first to sufficiently develop a β fiber rolled texture, and then a recrystallization heat treatment is performed, thereby obtaining a structure which is oriented to the W-orientation and coarsely developed.

The reasons for the excellent flexing property are; the W-orientation effectively contributes to the flexibility[2], the highly oriented texture that does not depend on the specific orientation leads to high flexibility[3, 4], regardless of the orientation accumulation itself, a remarkable coarsening of the crystal grains which occurs with the accumulation leads to high flexibility[5]. However, the degree of each impact is not clear. In this report, we researched the factors affecting the flexing life, especially in tough pitch copper with coarse W-orientation grains, and studied the crystal orientation, the crystal grain size and their interrelationship.

2. EXPERIMENTAL PROCEDURE

Rolled strip samples were mainly used for the research of a crystal orientation, and samples of rolled round wires, which are easy to control, were used for the experiment targeting a grain size. Table 1 shows the trial processes. No.1 are strip samples, and No.2 are rolled round wire samples.

Table 1 Processes of test pieces.

Sample number		Previous Process	Post Process	Sampling Derections
1: Strip	1-1	150 mmt→HR and CR (12 mmt) → HT (general)	CR (0.17 mmt)→HT (200℃, 2 h) →CR (0.035 mmt)→HT (200℃, 2 h)	0° (Longitudinal is parallel to LD)
	1-2		CR (0.45 mmt)→HT (200℃, 2 h) →CR (0.035 mmt)→HT (200℃, 2 h)	0°
	1-3		CR (0.035 mmt)→HT (200℃, 2 h)	0°
	1-4			22.5° (rotated on ND axis from 0°)
	1-5			45.5° (rotated on ND axis from 0°)
	1-6		CR (0.45 mmt)→HT (200℃, 2 h) →CR (0.035 mmt)→HT (700℃, 2 h)	0°
2: Drawing and rolling	2-1	9 mm ϕ→CD (0.22 mm ϕ)→ HT (general) → CR (0.035 mmt, 0.8 mmw) →RT	–	0°
	2-2		→HT (400℃, 2 h)	0°
	2-3		→HT (500℃, 2 h)	0°
	2-4		→HT (600℃, 2 h)	0°

HR: Hot Rolling CR: Cold Rolling CD: Cold Drawing HT: Heat Treatment RT: Recrystallization Treatment
mmt: millimeter thickness mmw: millimeter width LD: longitudinal direction ND: normal direction

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For sample No.1 (strip), a softening heat treatment was performed by general hot rolling and followed by cold rolling. Then, to produce recrystallized materials with different W-orientation ratios, they were subjected to a final cold rolling with the area reductions of 79, 92, and 97%, and the thickness was set to 35 μm. Finally, they were subjected to a recrystallization heat treatment. The test pieces cut out from the strips in the rolling direction were identified as samples No.1-1, No.1-2 and No.1-3. Furthermore, in order to obtain different orientations, strips were cut out at 22.5 degrees and 45 degrees in the rolling direction of the strips with an area reduction rate of 97%, and they were identified as samples No.1-4 and No.1-5, respectively. Figure 1 shows the relationship between the sampling directions of the strips and the samples oriented to the W-orientation (sample No.1-1 to sample No.1-3), the {001} <210> orientation (W/NDW-orientation) (sample No.1-4), and the NDW-orientation (sample No.1-5).

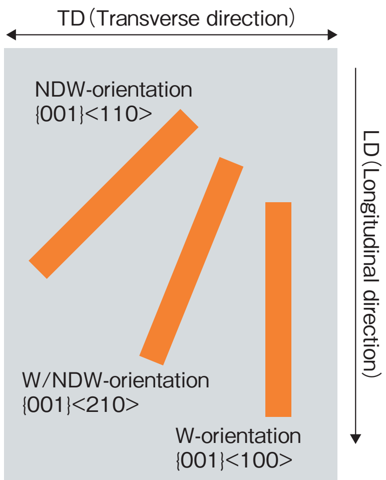


Figure 1 Relationship between the sampling directions and the oriented samples of the strips.

In order to suppress the orientation in the W-orientation, a cold rolling and a heat treatment with low area reductions were repeated, and finally, a recrystallization heat treatment was performed to make sample No.1-6. It was subjected to a high-temperature heat treatment to coarsen the recrystallized grains to match the mechanical properties of the samples No.1-3 to No.1-5 as much as possible.

For sample No.2 (rolled round wire), after drawing and annealing were repeated, the final rolling was performed to a thickness of 0.035 mm and a width of 0.8 mm, and finally, a recrystallization heat treatment was performed (sample No.2-1). After that, an additional heat treatment was performed at 400°C, 500°C, and 700°C to change the grain sizes (samples. No.2-2, No.2-3 and No.2-4, respectively).

The crystal orientations and the grain sizes of all samples were measured by the Electron BackScatter Diffraction (EBSD) method. The analysis was conducted by EDAX TSL's software, "Orientation Imaging Microscopy v5". The tolerance angle was set to 12.5 degrees in the orientation analysis. The grain sizes were the average values of the grain diameters on a transverse direction-normal direction (TD-ND) plane or a longitudinal direction-transverse direction (LD-TD) plane by the cutting method of the Inverse Pole Figure (IPF) map.

Tensile tests were performed on samples No.1-3, No.1-4, No.1-5, and No.1-6, but the width of the test pieces was 12.75 mm, which did not comply with JIS Z 2241.

The bending tests were performed using Ueshima Seisakusho's flexing tester, FT-2130 (the test method of this tester conforms to the standard of the Institute of Interconnecting and Packaging Electronic Circuits (IPC)) with 12.75 mm width and 120 mm length for sample No.1 and 0.8 mm width and 120 mm length for sample No.2. The test temperature was 85°C, and the test conditions were a bending radius of 6.3 mm and a stroke of ±13 mm.

The life until break was defined as the life, and each test piece was tested repetitively from N=1 to 4 for obtaining the average values. Figure 2 shows the simplified schematic of the flexion movement part.

The surfaces of the flexing test samples were observed with a scanning electron microscope (SEM), and the surface roughness was measured with a laser microscope (KEYECE VK8510).

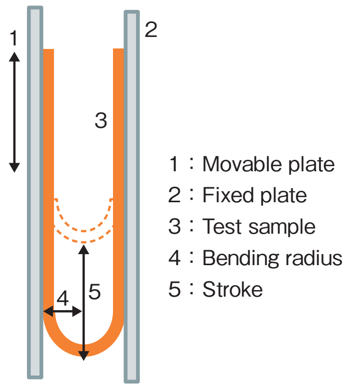


Figure 2 Simplified schematic of the flexion movement.

3. RESULT AND DISCUSSION

3.1 Effect of the Crystal Orientation on the Flexing Life of Recrystallized Heat Treatment Materials

Figure 3 shows the area fractions and the IPF maps of sample No.1 in the W-orientation.

The area fractions in the W-orientation were 48, 73, 97 and 19% in samples No.1-1, No.1-2, No.1-3 and No.1-6, respectively. In samples No.1-1, No.1-2 and No.1-3, it was confirmed that the higher the degree of orientation, the larger the proportion of coarse grains in which the W-orientation preferentially grew. It was also found that sample No.1-3 with 97% of the W-orientation had coarse grains of 100 to 300 μm on the LD plane and 30 to 100 μm on the TD plane. From these results, samples No.1-3, No.1-4, and No.1-5 have the strong W-orientation, the W/

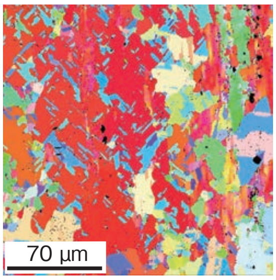
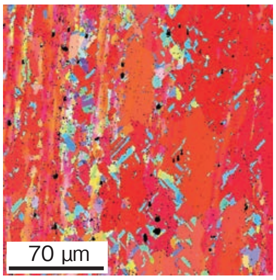
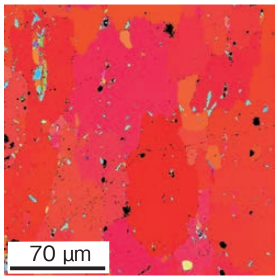
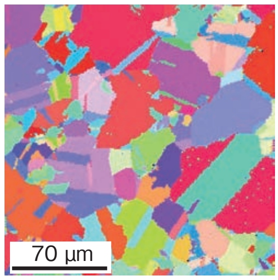
Sample Number	No.1-1	No.1-2	No.1-3	No.1-6
Area fraction of W-orientation {001}<100> (%)	48	73	97	19
IPF MAP				

Figure 3 Area fractions in the W-orientation and the IPF maps of the LD-TD plane of sample No.1.

NDW, and the NDW-orientation, respectively, whereas sample No. 1-6 has a weak orientation, that is, the orientation was random. The average grain size was about 50 µm.

Figure 4 shows the relationship between the flexing life and the area fraction of the W-orientation in samples No.1-1, No.1-2 and No.1-3. The life of sample No. 1 was 540,000 times, that of sample No.2 was 570,000 times, and that of sample No.1-3 was one million times or more (the test was terminated because it had not been broken when reaching one million times). The degree of orientation and the flexing life were not necessarily in a proportional relationship, and sample No.1-3, in which the W-orientation was most strongly oriented, showed a significantly longer life compared to others. From these results, it is assumed that there are other effects such as a crystal orientation or a grain size other than the W-orientation.

Table 2 shows the mechanical properties of samples No.1-3, No.1-4, No.1-5 and No.1-6. Comparing the samples, the difference in the strength was small but the difference in the elongation was large.

Figure 5 shows the flexing lives of samples No.1-3, No.1-4, No.1-5 and No.1-6.

The flexing life of the sample with the W-orientation (sample No.1-3) was 10 times and more than that of sample No.1-4 (W/NDW-orientation) and sample No.1-5

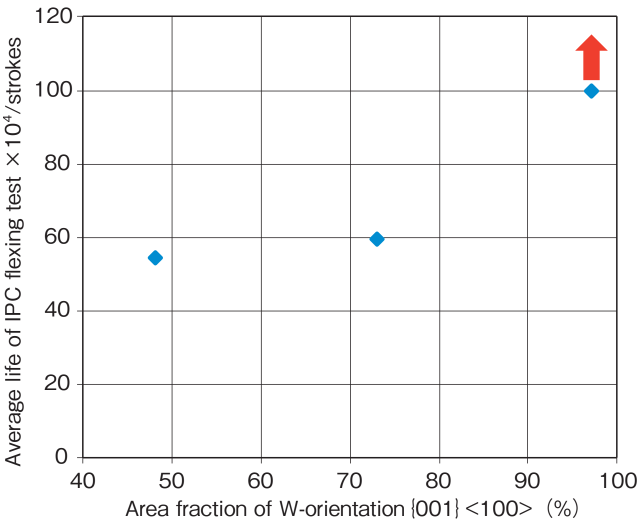


Figure 4 Relationship between the average life measured by the IPC flexing tests and the area fraction of the W-orientation {001}<100>(force-quit at 1.0×10^6 strokes).

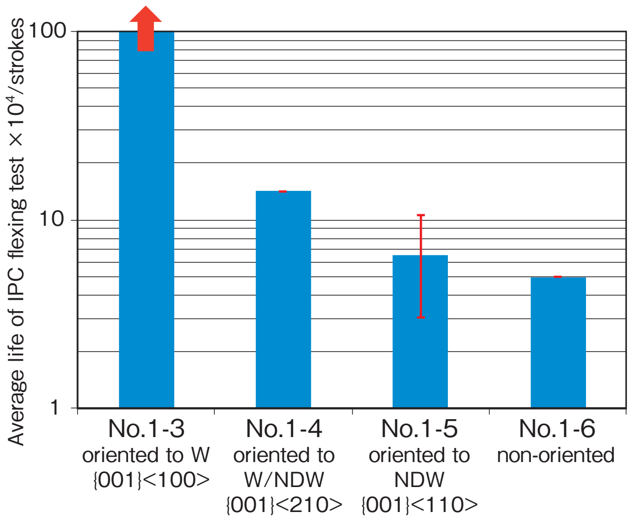


Figure 5 Average flexing lives measured by the IPC flexing tests on the differently oriented samples (force-quit at 1.0×10^6 strokes).

Table 2 Mechanical properties of sample No.1.

Sample Number	Oriented Crystal	Yield Strength / MPa	Tensile Strength / MPa	Elongation (%)
No.1-3	W-orientation {001}<100>	40	122	6
No.1-4	W/NDW-orientation {001}<210>	35	133	43
No.1-5	NDW-orientation {001}<110>	36	132	31
No.1-6	Non-oriented	43	143	12

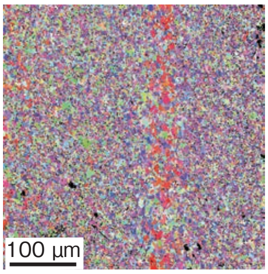
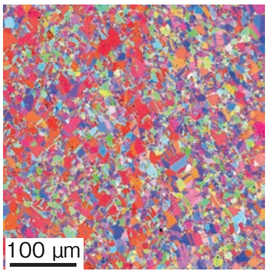
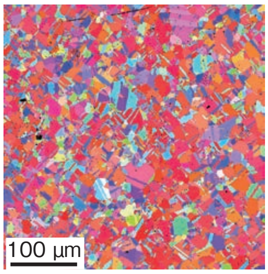
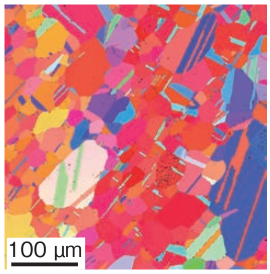
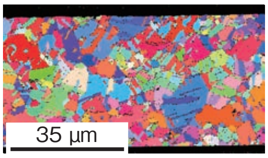
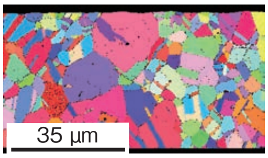
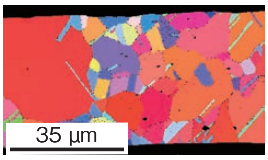
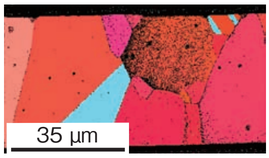
(NDW-orientation) (the test on sample No.1-3 was terminated during test). From this result, it is considered that the flexing life was greatly improved by the W-orientation, but the W/NDW and the NDW-orientations did not contribute to it. In other words, it is concluded that the flexing life depends on the high orientation of specific crystal grains (in this case, the W-orientation), and even if the grain size is coarse, it does not necessarily improve.

3.2 Effect of the Grain Size on the Flexing Life of Recrystallized Heat Treatment Materials

Figure 6 shows the IPF maps, the crystal orientations and the measurement results of the grain size (LD plane and TD plane) of sample No.2. The average grain sizes of the sample subjected to the recrystallization heat treatment alone and the ones with an additional heat treatment at 400°C, 500°C and 700°C for two hours were 4, 10, 18 and 35 µm, respectively. Also, as the average grain size increased, the orientation in the <100> direction tended to increase. However, as the degree of orientation (area fraction) in a specific orientation was much lower than that of samples No.1-3 to No.1-5, which were close to 100%, it was regarded as a random orientation.

Figure 7 shows the flexing life of sample No.2. As it can be seen from the figure, the flexing life was improved as the grain size became finer. When large grains were involved, it is considered that the flexing life was improved only in the case when the W-orientation was oriented as shown in Figure 4 within the range of the conditions of this test. From these results, it is considered that the coarse grain structure oriented to the W-orientation was reverified to be largely influenced by the crystal orientation.

(a)

Sample Number	No.2-1	No.2-2	No.2-3	No.2-4
Average grain size/µm (TD-ND)	4	10	18	35
IPF MAP (LD-TD)				
IPF MAP (TD-ND)				

(b)

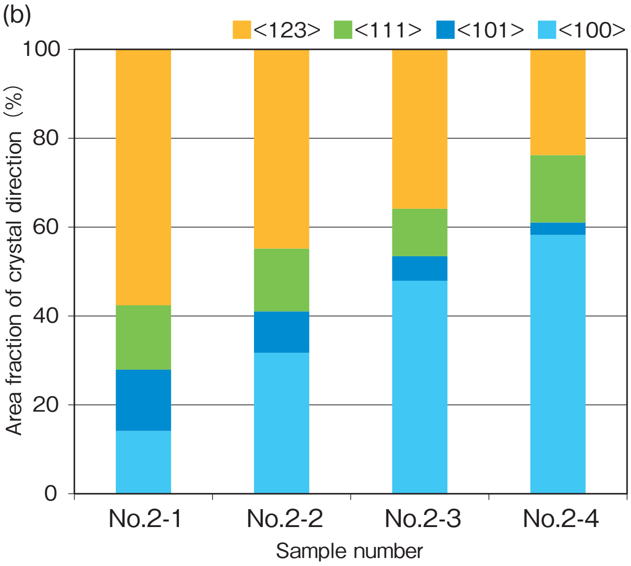


Figure 6 (a) Average grain sizes on the TD-ND plane and the IPF map on the LD-TD plane and the TD-ND plane of sample No.2.
(b) Crystal directions on the LD-TD plane of sample No.2.

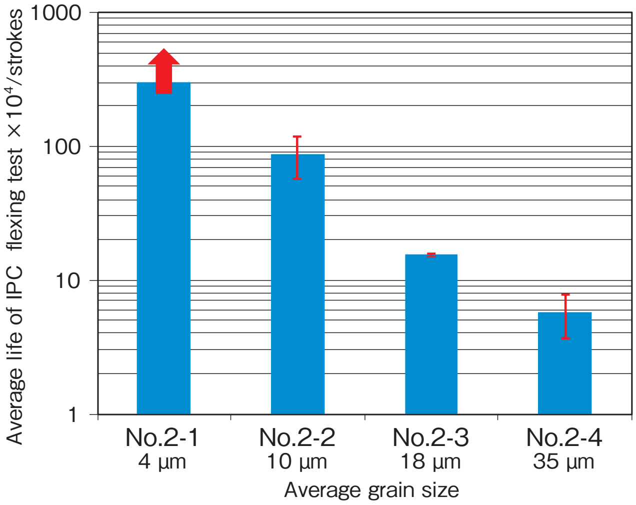


Figure 7 Average flexing lives of sample No. 2 after the IPC flexing tests (force-quit at 3.0×10^6 strokes).

3.3 Discussion

Figure 8 shows the SEM images of the surface of the samples after bending 200,000 times in samples No.1-1, No.1-2 and No.1-3. The growth of undulations on the surface layers was confirmed, and in connection with the Figure 2, the area was clearly larger as the orientation of the W-orientation was lower. Figure 9 shows the SEM images of the surface of the sample with the W-orientation (after bending 200,000 times) and the sample with the NDW-orientation (after bending 90,000 times, which was the breaking point) to consider the effect of the crystal orientation. When the NDW-orientation was oriented, a microscopic surface roughness was observed on the entire surface, but when the W-orientation was oriented, the surface roughness was minor.

From these results, it is considered that a crystal orientation had a large effect on the plastic deformation behavior during bending. This roughness on the surface is assumed to be due to a extrusion and an intrusion of the slip surface formed by a slip of the crystal, and it is also assumed that the differences in the relative relationship between the stress and the crystal direction, such as the number of main slip directions considered to be active in the stress direction or the Young's modulus, had an effect.

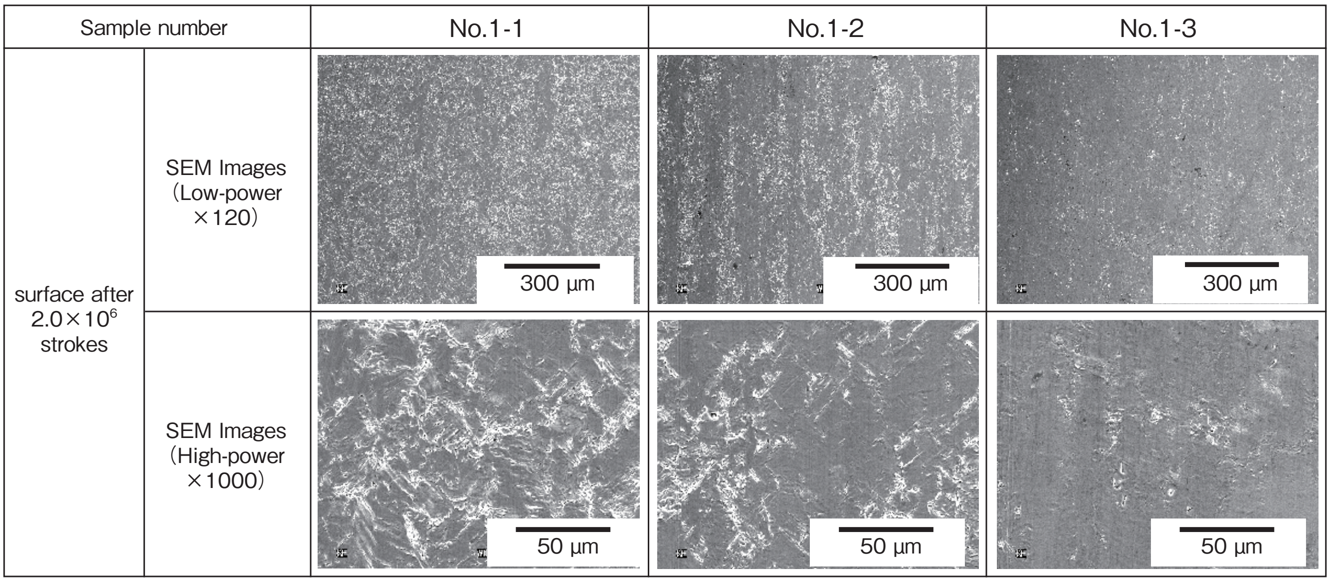


Figure 8　SEM images of the surface of samples No.1-1, No.1-2 and No.1-3 after the IPC flexing tests.

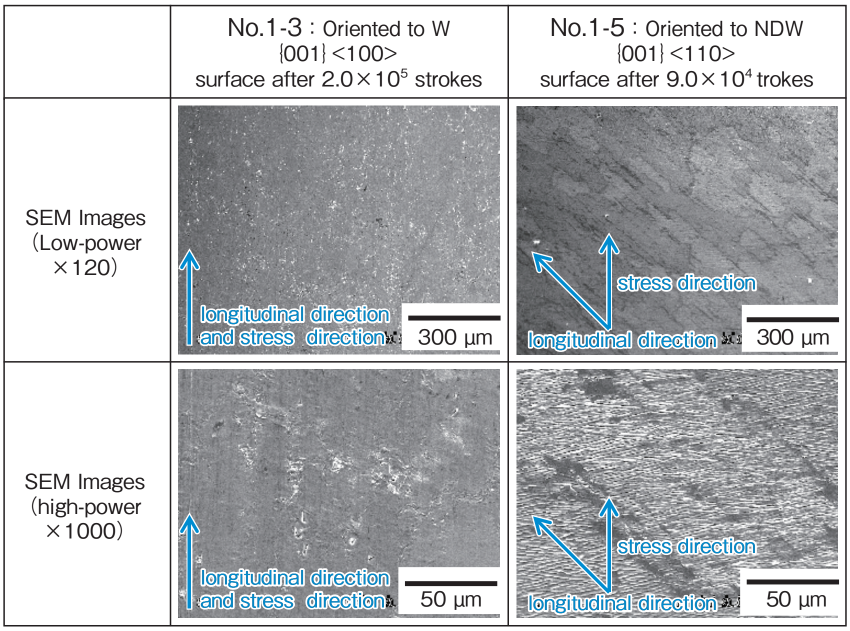


Figure 9　SEM images of the surface of samples No.1-3 and No.1-5 after the IPC flexing tests.

Figure 10 shows the surface roughness of the samples measured by a laser microscope. It can be seen that when the W-orientation was oriented, the surface became relatively flat, but when the NDW-orientation was oriented, the unevenness was remarkably formed. Figure 11 shows the surface appearance of a sample in which the NDW-orientation was oriented. Since the cracks observed on the surface were along the valleys of the irregularities, it is considered that the stress concentration might have increased in the concave portions of the valleys to generate cracks, which is considered to be one of the focuses of the destruction process.

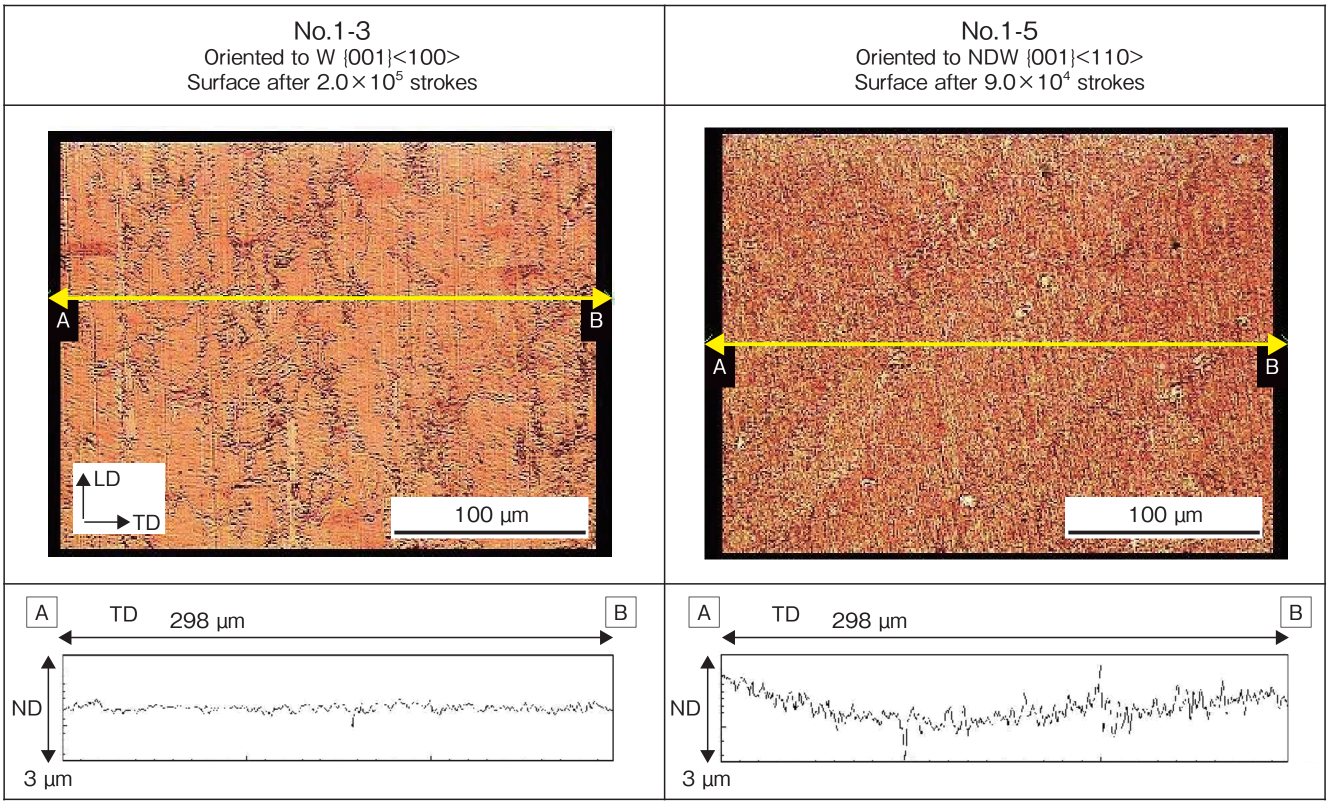


Figure 10 Roughness on the surfaces of samples No.1-3 and No.1-5 after the IPC flexing tests.

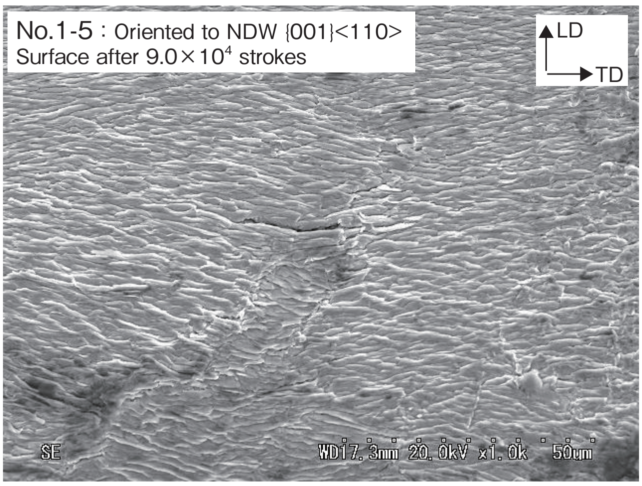


Figure 11 SEM image of a surface crack of sample No.1-5 after the IPC flexing tests.

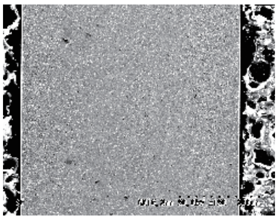
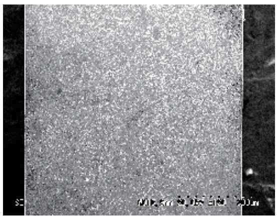
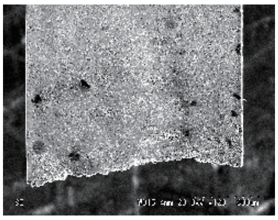
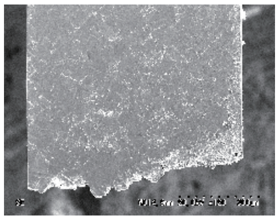
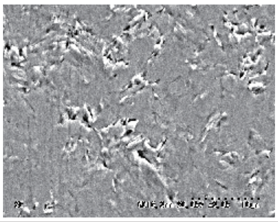
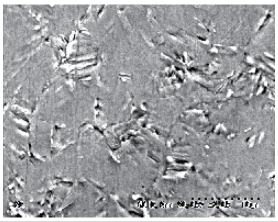
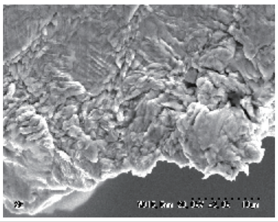
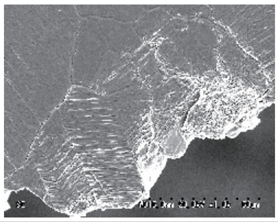
sample Number	No.2-1	No.2-2	No.2-3	No.2-4
Average Grain Size/μm	4	10	18	35
strokes	2.0×10^5	2.0×10^5	1.5×10^5	6.0×10^4
SEM Images (Low-power ×120)				
SEM Images (High-power × 1000 or ×3000)				

Figure 12 SEM images of the surfaces of sample No.2 after the IPC flexing tests.

Figure 12 shows surface SEM images of sample No.2 having relatively random crystal orientations and different grain sizes after bending 200,000 times or the ones fractured before that. In sample No.2-1, which has fine crystal grains, the growth of surface roughness due to crystal slip across the grain boundaries was suppressed, and the generation range was also narrow. This is considered to be the reason for the longer life.

In this study, the surface state changed depending on the crystal orientation in the surface layer, and the cracks that were likely to have been affected by the change were generated. However, the change in the underlying structure is unknown, and further investigation is needed.

This study is focused on the relationship between the crystal orientation, the grain size and the flexing life. However, the effects of the degree of crystal orientation and the characteristics of the grain boundaries associated with them, or the shape of the crystal grains (such as the aspect ratio, etc.) were not considered. Therefore, we will work on it as a future issue.

4. CONCLUSION

We investigated the dependence of a crystal orientation and a grain size on the flexing life of tough pitch copper and obtained the following conclusions.

(1) The flexing life is longer in the sample oriented in the {001}<100> orientation (W-orientation) than in the sample oriented in other than the {001} <100> orientation (W-orientation). That is, the flexing life do not necessarily improve only by the coarsening of the crystal grains, but the orientation in a specific orientation contributes strongly.

(2) When the crystal grains are randomly oriented, the flexing life tends to be longer as the crystal grain size is finer.

(3) When the flexing life is excellent, the undulation growth on the surface after the test is minor, but when the flexing life is inferior, the undulation growth is remarkable. This suggests that the difference in the crystal orientation affects each phenomenon. This is caused by the extrusion and the intrusion on the surface due to the crystal slip caused by bending, and it is considered that it eventually becomes the starting point of a crack.

In the future, to investigate the detailed mechanism, the influence of the state of the roughened substructure, of the coincidence boundary caused by the degree of crystal orientation or the grain shape, and of the grain shape (aspect ratio, etc.) will be investigated.

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