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# Change of hardness of copper sheet by spliting process

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**Abstract**

Jointed products such as bus bars of automobiles have been manufactured up to date copper and aluminum by welding or screw fastening. This process causes high cost and low productivity because many process steps and skilled working are needed. As a new technology to solve these problems, splitting process (Warisaki®) technology has been developed. By combining Warisaki® process and crumping technologies, those products can be manufactured with low cost and high productivity in a line. This Warisaki® technology can be extended into the fields such as aircrafts and environmental energy devices, etc., not limited to automobiles. The purpose of this study is to obtain fundamental knowledge on local mechanical property change by Warisaki® process and by some additional deformation processes. Copper specimens (C1100 P-1/4H) with 3mm thickness were split into a pair of branches with 1.5 mm thickness and the splitting blade was run with some split steps of 1, 4 and 6 mm, and the tip angles were enlarged to 90 and 180 degrees by the secondary bending process. Vickers and dynamic hardnesses of split specimens were measured and the microstructures were observed. As the results, the hardness became about 1.3 times of that in the as-received material by work hardening in the split branches and near the split tip. Marked plastic flow was observed adjacent to the split surface. It was concluded that no crack initiates at the split tip even after increase of the split step and enlargement of the tip.

*Keywords*: Splitting process; Warisaki®; Copper; Hardness; Microstructure; Work hardening; Crack; Plastic flow

## 1. Introduction

Bus bar is an electric terminal of the electric circuits of automobiles, and the cost down and the lightweight are required strongly with having electric contact reliability. Jointed products such as bus bars of automobiles have

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been manufactured up to date copper and aluminum by welding or screw fastening. This process causes high cost and low productivity because many process steps and skilled working are needed. As a new technology to solve these problems, splitting process (Warisaki® [1]) technology has been developed. The Warisaki® technology is a processing technology which splits the end of a metal plate or a metal bar to two or more branches by a press machine equipped with the splitting blade. By combining Warisaki® process and crumping technologies, those products can be manufactured with low cost and high productivity in a line. This Warisaki® technology can be extended into the fields such as aircrafts and environmental energy devices, etc., not limited to automobiles.

The purpose of this study is to obtain fundamental knowledge on local mechanical property change by Warisaki® process and by some additional deformation processes. Copper specimens (C1100 P-1/4H) with 3mm thickness are split into a pair of branches with 1.5 mm thickness and the splitting blade is run with some split steps of 1, 4 and 6 mm. Vickers and dynamic hardnesses of split specimens are measured and the microstructures are observed.

## 2. Experimental method

### *2.1. Splitting process*

A tough pitch copper sheet of 10 mm in width, 45 mm in length and 3 mm in thickness (C1100 P-1/4H [2]) is split by a press machine equipped with the splitting blade. The splitting blade is run with some split steps of 1, 4 and 6 mm and the thickness of specimen is split into a pair of branches with 1.5 mm thickness [1]. And a secondary bending process which enlarges the tip of the split branch portion to 90 and 180 degrees is performed.

After that, specimens for hardness tests are cut about lower 15 mm from the split tip, embedded to resin, polished on the surface and supplied for hardness tests.

### *2.2. Vickers hardness test*

Vickers hardness ($H_{V0.3}$ [3]) is measured under a condition of a test load of 300 g and a holding time of 15 s by using the Akashi Vickers hardness tester (AVK-C1).

Positions of the hardness tests for split copper specimens are shown in Fig. 1. The hardness is measured in wide range from the split area (19 mm) to the unsplit area (7 mm) with about 1 mm interval, and measured at the three positions of 0.5 mm inner side from the outer surface as shown in ①, the center of the split branch as shown in ②, and about 0.5 mm from the split surface as shown in ③ parallel to the splitting direction.

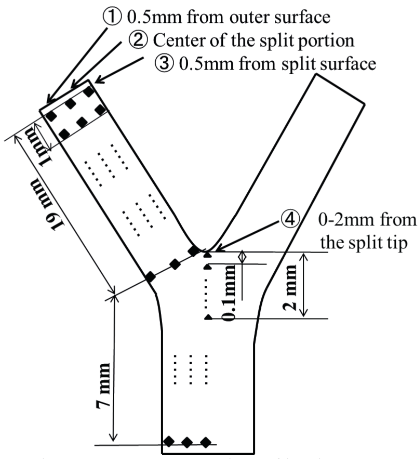


Fig. 1. Measurement points of hardness tests.

### 2.3. Dynamic hardness test

In order to evaluate mechanical properties (hardness, etc.) in a very small area, dynamic hardness [4] are measured by using the Shimazu dynamic ultra-microhardness tester (DUH-W201).

Dynamic hardness is a hardness which pushes an indenter on the specimen with ultra-micro load and is computed from the continuous data of a load and a depth of indenter, no need to observe the mark of indenter. The hardness can evaluate mechanical properties including a part of elastic recovery. In this research, the detailed hardness distribution (dynamic hardness $D_{h0.03}$) from the split tip to 2 mm as shown in Fig. 1④ is evaluated under a condition of a test load of 30 g and a holding time of 1 s. And the measurement interval is 0.1 mm.

The dynamic hardness $D_h$ is shown by the following equation(4).

$$D_h=\alpha L／h^2, \tag{1}$$

where L and h are a test load and a depth of a indenter respectively, and $\alpha$ is a constant ( 3.8584) of a triangular pyramid indenter.

### 2.4. Microscopy

Microstructures of copper specimens before and after the splitting process are observed in detail by using an optical microscope. The split specimens are embedded to resin and are buffed the surfaces for the optical microscopy.

## 3. Experimental results and discussions

### 3.1. Results of Vickers hardness test

Distribution of Vickers hardness $H_{V0.3}$ of copper specimens which are measured parallel to the splitting direction are shown in Fig. 2(a) - (c) corresponding to some split steps of 1, 4, and 6 mm respectively. The greatest Vickers hardness of the split area shows about 1.3 times of that in the as-received material. Increase of this hardness is based on work hardening accompanying plastic deformation, and is equivalent to C1100 P-H [2] of tough pitch copper. It is necessary to mind at the time of a secondary process. If it is H grade, it is a range in which a secondary plastic process is possible. The hardnesses in 0.5 mm from the split surface, a center part and that in 0.5 mm from an outer surface of a specimen are almost equivalent, and the mechanical properties are considered not to vary in the width direction. The hardness of the starting point of split area is a little smaller, and the hardnesses in the split area and near the split tip show almost equal. The mechanical properties after the splitting process are considered to be also almost equivalent.

### 3.2. Results of dynamic hardness test

Distribution of dynamic hardness $D_{h0.03}$ which is measured in the range from the split tip to 2 mm is shown in Fig. 3. The dynamic hardness of the split tip becomes very hard by work hardening accompanying plastic deformation, and it is falling gradually to unsplit area. The hardness of the split tip shows from 1.23 to 1.47 times of that in the unsplit area at 2 mm distance. And the hardness near the tip tends to increase a little with increasing of the split step, and the hardness at 2 mm distance from the tip is almost equivalent.

This dynamic hardness shows the smaller value about twenty percent with the above-mentioned Vickers hardness. This reason is for the loading capacity of a dynamic hardness test. The dynamic hardness means the characteristic of the material surface since it is smaller figure than a Vickers hardness test loading capacity. It is subject to more influence of the quality of a material surface. However, the tendency is the same and the more detailed hardness distribution can be measured near the split tip by dynamic hardness test.

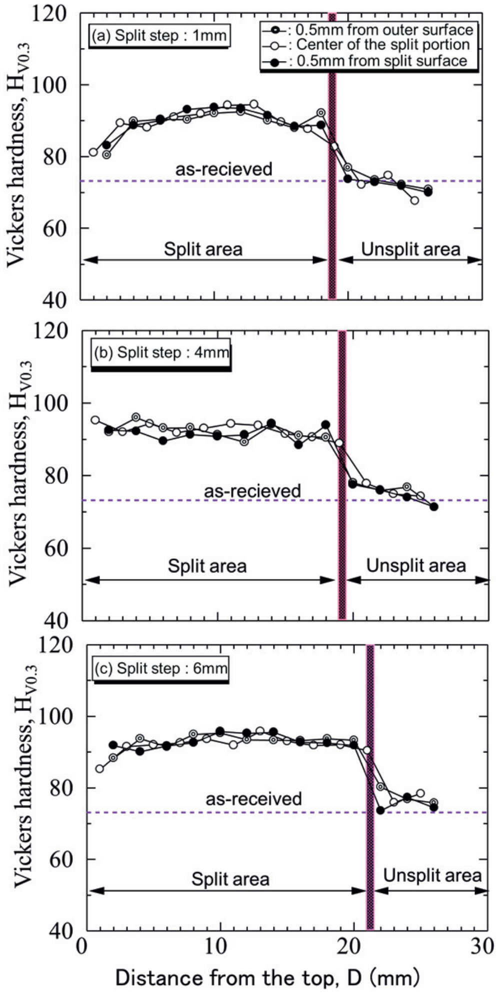



Fig. 2. Vickers hardness at locations indicated in Fig. 1①-③.

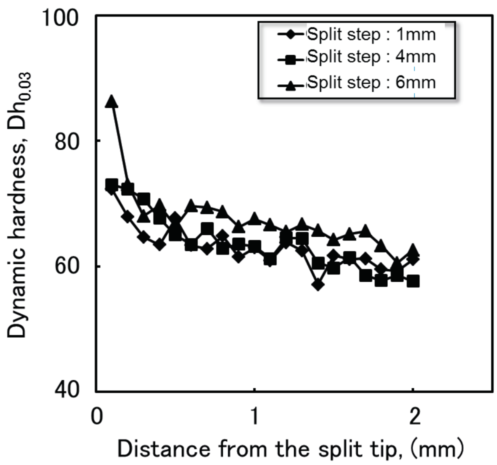



Fig. 3. Dynamic hardness at locations indicated in Fig. 1④.

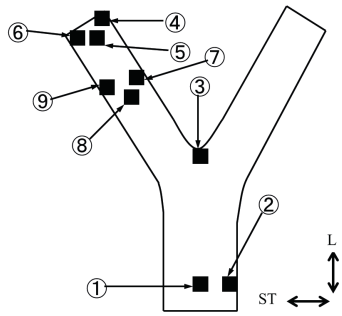



Fig. 4. Observed locations in the optical microscopy.

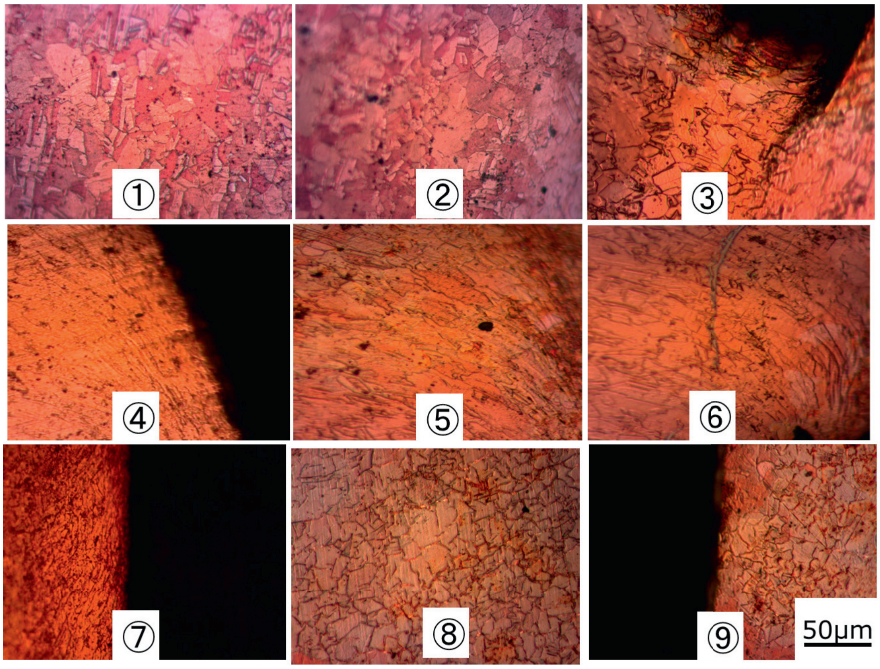
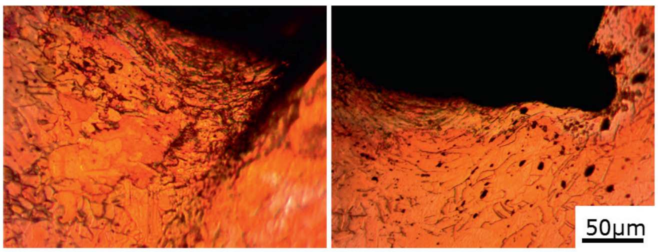



Fig. 5. Microstructures of the specimen at the locations indicated in Fig. 4.




(a) Tip angle : 90° (b) Tip angle : 180°

Fig. 6. Microstructures near the split tip for different tip angles.

*3.3. Microscopy observation*

The observation points of an optical microscope of a split specimen with a split angle of 30 degrees and a split step of 1 mm are shown in Fig. 4 as an example, and longitudinal (L) and short transverse (ST) directions of the specimen are indicated in this figure. The microstructure photographs corresponding to those positions are shown in Fig. 5. The unsplit areas of ① and ② show the same organization, and the diameter of a mean crystal grain is about 20 μm. The compressive plastic deformation according to pushing of the splitting blade is observed at the split tip as shown in ③. And then, the black range which is visible at the split tip is not a crack so that it may mention later, and the indented part by the perpendicular shrinking is looked in black when the split blanches are extended by the secondary bending. Since the big plastic flow is observed near the split surface of ④, hardness of the split surface is suggested to have further hardened. The plastic flow of a copper crystal grain is observed in the split side of ⑤, and the plastic flow of a crystal grain is seldom seen near the outside surface of ⑥. The plastic flow of a crystal grain is observed near the split surface of ⑦ and is little observed in the middle part of ⑧ and the outside surface of ⑨.

The tip angle is enlarged to 90 and 180 degrees after the splitting process, and the optical microscope photograph of the tip is shown in Fig. 6. When the black range at the tip is observed in detail, it is not a crack and not a propagation in spite of being extended into flatness (180 degrees) as shown in (b). It is shown that there is neither crack initiation nor crack propagation and a good splitting process can be realized.

*4. Conclusions*

In order to obtain the fundamental knowledge about splitting process for the products of automobiles which have low cost and high productivity, etc., the splitting process and a secondary bending to the copper sheet were performed in this research. And the influence on the local hardness and the microstructure were evaluated. The obtained results are summarized and are shown below.

(1) Vickers hardness of the split area became large about 1.3 times of that in the as-received material. Increase of this hardness was a range in which secondary process was possible.
(2) By dynamic hardness near the split tip, work hardening was measured in detail and decreased gradually along to the unsplit area. The increase of the hardness by the work hardening was equivalent to increase of the above-mentioned Vickers hardness.
(3) From microstructure observation of the split area, remarkable plastic flow was shown near the split surface.
(4) The indented part by the perpendicular shrinking was looked near the split tip when the split blanches were extended by the secondary bending. However, good splitting process and secondary process which did not have crack initiation and crack propagation was concluded to be able to realize.

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