

Welding Methods and Forming Characteristics of Tailored Blanks (TBs)

Yasunobu MIYAZAKI*¹
Yukihisa KURIYAMA*¹

Koji HASHIMOTO*¹
Junichi KOBAYASHI*²

Abstract

Recently, tailored blanks (TBs) are widely used for automobile body parts. This paper mentions the characteristics of TBs themselves and discusses not only welding methods as the manufacturing process of TBs but also forming characteristics of TBs. After outlining the methods of welding process, the laser welding was focused on as a typical welding method for TBs. And the feature of the welded portion, weld defects and the influence of wavelength on welding were explained in detail. The fracture of TBs at forming process is classified into two phenomena, namely “strain rule”, breakage determined by strain, and “stress rule”, breakage determined by stress, and forming failures of actual autobody parts are discussed based on these two phenomena. Forming failures discussed in this paper are as follows: the fracture at base material of TBs consisting of several pieces of sheet with different quality or different thickness, the arrangement of weld bead in connection with the direction of material flow-in, the fracture at deep drawing, the fracture at stretch flanging, and the fracture caused by weld defect at the beginning and the ending of weld.

1. Introduction

If the development of industrial technology is construed as one of the currents of the times independent of a nation, society or humans, the original source of tailored blanks can be dated back to the conceptual patent in 1961¹⁾. In 1967 a side panel was manufactured by TIG welding, an event that may be considered as the first cry of this technique. This technique which once seemed to cease to exist was revived when Japanese and European automakers employed it around 1985 for the manufacture of side panels and floor panels. This opened a way toward the beginning of brisk development. This paper outlines tailored blanks, details their welding methods and formability, and refers to their future prospects.

2. What is Tailored Blank (TB)?

An auto body is required to have various performances, including strength, durability, corrosion resistance, crash worthiness, and must be light in weight, in line with a design attractive to users¹⁾. This resulted in hundreds of panels, large and small, constituting the auto body with the specifications of sheet thickness and steel grade strictly established for respective parts. On the other hand, the number of parts should be limited for the improvement of auto body accuracy and productivity.

As Fig. 1¹⁾ shows, Tailored Blanks, hereinafter abbreviated to TBs, refer to the panels before pressing prepared for respective purposes with plural steel sheets by welding. With TB, steel grade can

*¹ Steel Research Laboratories

*² TS Center

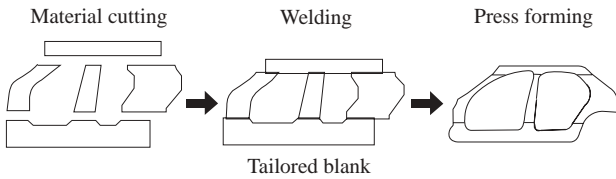


Fig. 1 Example of the application of Tailored Blank (TB) to a side panel outer

be partially changed in a panel with an expectation of reducing the number of parts.

TB was commercialized in around 1985 for a reinforce sun-roof and a cowl inner, with the same steel sheets joined together, for the improvement of material yield, auto body accuracy by reducing the number of panels, and productivity. Later in 1990, a front-side member was manufactured using TB joined steel sheets with different grade. This prompted a new stage of development with a strong consciousness of improving auto body performances including the improvement of crash worthiness by the optimal arrangement of sheet thickness and steel grade.

3. Welding of TBs

3.1 Welding processes of TBs and their characteristics

TBs are produced by laser welding, mash seam welding, and plasma welding. A high frequency induction welding technique is also applied abroad.

As **Fig. 2** shows, the laser welding is the one of fusion welding process by irradiation of laser beam, focused to a diameter of about 0.5 mm, to a steel sheet²⁾. When beam high in energy density is irradiated to a steel sheet, the steel sheet instantly starts melting and evaporating. A keyhole is formed in the molten steel by recoil pressure of evaporation, with its wall heating the steel sheet as a heat source to proceed welding. A typical width of weld bead is short of 1 mm.

In the mash seam welding process, two steel sheets are overlapped with each other to an overlap space of 1.5 to 2 times the average thickness, and applied current and pressure with an electrode wheel to melt the overlapped surfaces. This technique is excellent in productivity, because it enables high speed welding. However, it becomes necessary to control the conditions strictly at applying to coated steel sheets, because an electrode surface is polluted with coated metal. In addition, it is comparatively difficult to weld high

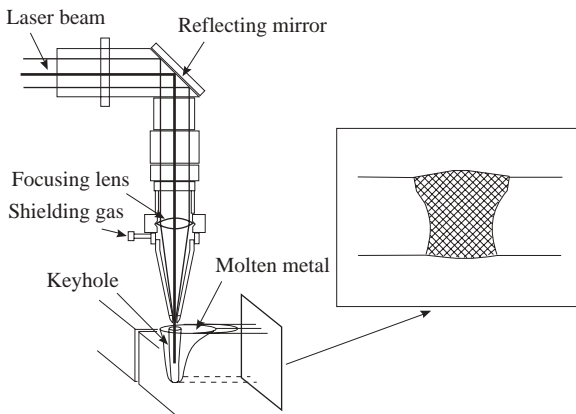


Fig. 2 Laser welding process

strength steel sheets. It is comparatively excellent in formability because of its weld being less hard than a laser weld. On the other hand, the weld becomes slightly thick and its appearance is not good. A typical weld is about 5 mm wide.

Plasma welding of TBs is heat transfer type, in which welding is carried out by blowing a high-temperature plasma jet to the butt joint. Since a tungsten electrode is not exposed, the frequency of exchanging electrodes is less than in TIG welding, making this technique suitable for automation. A typical weld bead is as wide as 3 to 4 mm and is wider than in laser welding. Thus, the TBs welded by plasma may be inferior in formability depending on the forming conditions. On the other hand, it is characterized by the overwhelmingly low cost of its equipment.

3.2 Laser welding of TBs

3.2.1 Characteristics of laser weld

Since the weld bead is a little less than 1 mm narrow, the weld is excellent in appearance with a very limited range of material deterioration due to heat affection at welding. A molten pool is rapidly solidified and cooled due to the conduction of heat to base metal with a cooling time of about 0.3 s from 800 to 500°C, a cooling rate of about 1000°C/s. Therefore, the weld metal is strongly hardened with its structure nearly converted to martensite. Then the hardness of the weld metal mainly depends on the content of carbon in steel and it can be accurately estimated from the chemical compositions of a base material^{3,4)}.

3.2.2 Points to notice in laser welding and under-fill

The small gap between butted sheets and slight miss tracking of the weld line make welding impossible because of the scarcity of molten pool. **Fig. 3** shows a weldable range when mild steel sheets, 0.7 and 1.4 mm thick, with a machined edge, were welded in terms of the relationship between a laser beam position to weld line and a welding speed²⁾. The wider the gap, the smaller is a weldable range. Furthermore, even when it is possible to weld, the gap results in under-fill, because a weld bead becomes thinner than the sheets due to the short supply of molten metal. **Fig. 4** shows the decreasing of formability of due to the decreasing of bead thickness in mild steel in terms of the forming height in the Erichsen test²⁾. The thickness of a weld bead should be over 70% of that of a base material to prevent

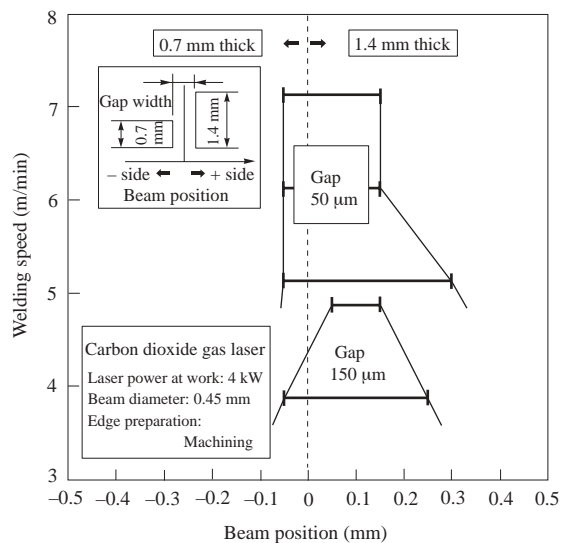


Fig. 3 Gap width and weldable range

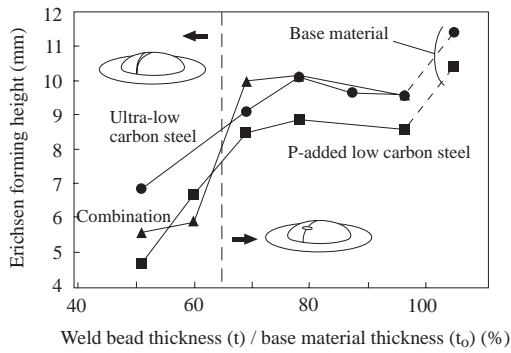


Fig. 4 Influence of under-fill on formability

formability from decreasing. However, when a weld bead is required to be as strong as a base material in fatigue strength, it is necessary to control its thinning to a minimum because of the stress concentrated on a concaved weld bead.

3.2.3 Imperfections of welds

Beside the under-fill as above-described, porosity may decrease the formability. When a carbon dioxide gas laser is used as a beam source, a laser-induced plasma is formed because of its long wavelength. When nitrogen molecules in the air are dissociated into atoms in this plasma, nitrogen easily dissolve into molten metal. When this phenomenon takes place on the under surface of the sheet usually unshielded, a large quantity of nitrogen dissolves into molten pool to form nitrogen bubbles due to an abrupt decrease in solubility at solidification. Those bubbles remain as pores when they fail to surface from the molten pool before the completion of solidification. Fig. 5 shows an increase in the number of pores due to this phenomenon when the laser beam is high in power density⁵⁾.

3.2.4 Influences of the kinds of lasers

At present the application of YAG laser to the manufacture of TBs has started. The wavelength of this laser is 1.06 μm, 1/10 of that of carbon dioxide gas laser. Incidentally, the absorbability of the light in this wavelength zone at the metal surface depends on the wavelength. Generally, the shorter the wavelength, the more easily absorbed is the light⁶⁾. A comparison of the efficiency to melt (molten

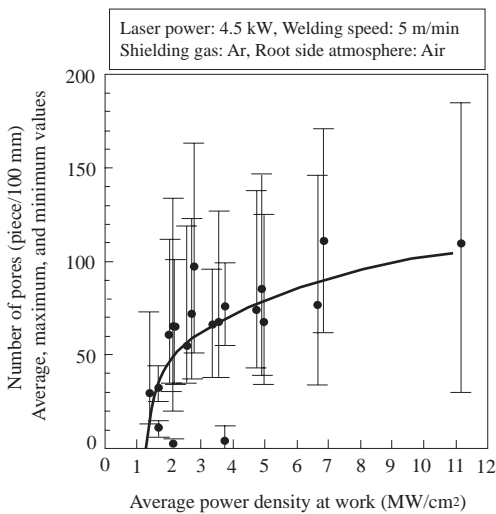


Fig. 5 Power density for welding and number of pores

volume per unit power) between these two lasers reveals that YAG laser is over two times higher. As a result, it is possible to weld with YAG laser at a higher speed⁷⁾.

4. Formability of TB

4.1 Classification according to the fracture pattern

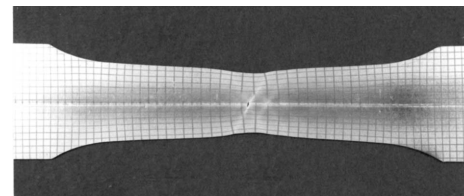
On the assumption that TB is welded in good condition, its forming defects, particularly its fracture can be classified into 1) fracture at the weld seam and 2) fracture at the lower strength material of TB in a combination with different strength materials.

4.1.1 Fracture at the weld seam

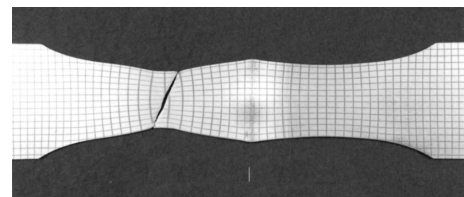
In the tensile test with tension applied parallel to the weld seam, fracturing is caused by necking at the weld seam as Photo 1 (a) shows. This is because a less ductile weld seam first reaches its ductility limit although uniform strain is given to the test piece in perpendicular direction at a tensile test⁸⁾. Since this fracture pattern is determined by strain, it is called the fracture pattern of “strain rule”, in other word “breakage determined by strain”⁹⁾. The deterioration in ductility of laser-welded TB, same in material and thickness, remains to the extent of 4 to 6% of that of the base material. This is considered that the peripheral base material of the weld seam alleviates the strain concentration at the weld seam although the deterioration in ductility of the weld seam is great. It is to be noted that the influence of the welding methods on the deterioration in ductility of the weld seam is less in the order of laser, mash seam and plasma welding.

4.1.2 Fracture of a base material on the lower strength side in TB with different kinds of materials combined

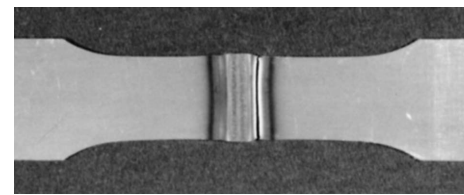
Photo 1 (b) shows examples when the tensile test was carried out in the direction perpendicular to the weld seam. In this case, uniform



(a) When tension was applied parallel to the weld bead (SPCE, laser welding)



(b) When tension was applied perpendicular to the weld bead (SPCE, laser welding)



(c) When HAZ fracture took place (High strength material, plasma welding)

Photo 1 Various forms of fracture in uni-axial tensile tests

tension is applied parallel to the test piece. While in the central weld seam, strain is held down low with an increase in strength, deformation of a test piece is concentrated on the lower strength side (or on the thinner side) of the base material and the maximum strain at the lower strength material reaches the fracture limit⁸⁾. Since this fracture pattern is determined by stress, it is called the fracture form of “stress rule” in other word “breakage determined by stress”⁹⁾. When total elongation (gauge length 50 mm) of several kinds of TB which are produced by welding a 0.8-mm-thick 440-MPa material with various kinds of steel sheets at the center of the test piece compared each other, the test piece welded with the same 440-MPa steel sheet was most ductile. This means that a decrease in ductility from that of the base material becomes higher in proportion to an increase in strength ratio of the materials joined together. This point is detailed in clause 4.2.1.

A unique example of stress-rule fracture is found in the fracture of a heat-affected zone (HAZ). In part of the high strength steel sheets, a zone near the weld bead is softened due to the welding heat during TB manufacturing process resulting in a decrease in strength. When the degree of softening is great, fracture may occur at HAZ. Photo 1 (c) shows an example of the test piece fractured at HAZ.

4.2 Forming defects peculiar to TB material in actual forming

In the actual forming of TB unexpected forming defects peculiar to the composite material sometimes occur. However, this phenomenon can be grasped from the findings of the simple tensile test.

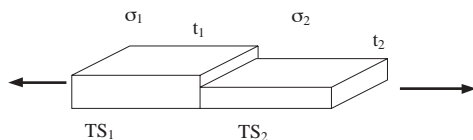
4.2.1 Phenomena of the fracture on the lower strength material in TB composed of different strength materials or the fracture on the thinner material in TB composed of different thickness materials.

In recent years there are many cases in the manufacture of TB, in which materials respectively different in strength and thickness are combined, resulting in the fracture of the base material on the side of the material low in the product of TS (tensile strength) and sheet thickness, that is, TS × sheet thickness, abbreviated hereinafter merely to “strength” as described in clause 4.1.2. Fig. 6 is based on the assumption of TB with a combination of different strength or thickness¹⁰⁾. Then, the tensile strength of high strength material, sheet thickness, stress at a certain point, and hardening parameter n are respectively given as TS₁, t₁, σ₁, and n₁ with those of low strength material, as TS₂, t₂, σ₂, and n₂. In this case, maximum plastic strain ε_{1max} of the high strength material when the low strength material was fractured can be given in formula (2) from TS₁ and TS₂ by using formula (1).

$$\sigma_1 = K_1 \epsilon_1^{n_1}, \sigma_2 = K_2 \epsilon_2^{n_2}, \sigma_1 t_1 = \sigma_2 t_2 \tag{1}$$

$$\epsilon_{1max} = n_1 \sqrt[n_1]{\frac{t_2}{t_1} \cdot \frac{TS_2}{TS_1} \cdot \frac{\exp(n_2)}{\exp(n_1)}} \tag{2}$$

Fig. 7 compares the findings calculated by the above formulae with those of the actual tensile test. Both of the findings agree well.



TS₁, t₁, σ₁, n₁ : Tensile strength of high strength (or thicker) side, sheet thickness, stress at a certain point, n value
 TS₂, t₂, σ₂, n₂ : Tensile strength of low strength (or thinner) side, sheet thickness, stress, n value

Fig. 6 Forming stress balance of TB different in material or thickness

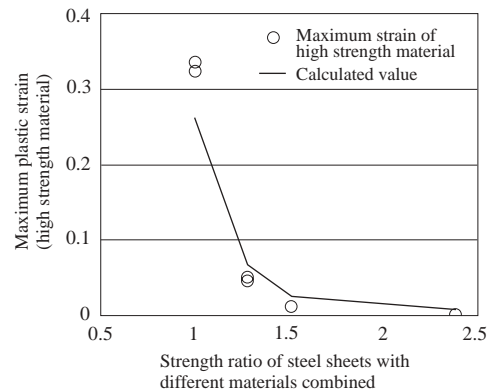


Fig. 7 Maximum elongation strain of high strength material when low strength material was fractured in uni-axial tensile tests

Particularly the strain of elongation of the high strength material is 0.07 with a strength ratio of about 1.25, decreasing to 0.025 with a strength ratio of 1.5. This means that the high strength material is deformed only slightly even with a remarkably high strength ratio of 1.5 and that deformation takes place mostly on the side of the low strength material thus leading to fracture.

4.2.2 Slip of weld seam line¹¹⁾

As described in the previous clause, a variation in the amount of deformation according to the difference in strength of the steel sheets combined leads to an uneven material flow. This results in a phenomenon in which the weld seam slips from the direction of the material flow. Once this phenomenon occurs with TB in which steel sheets different in thickness are combined, it becomes difficult to take into consideration of this slip in the die design. In this case, it is necessary to estimate beforehand the amount of a slip of the weld bead as a result of forming simulation by FEM, and take it into consideration.

4.2.3 Fracture in deep drawing¹¹⁾

In TB with different kinds of materials combined, the formability of each steel sheet is greatly influenced by the ratios of their respective areas. Photo 2 shows how drawing samples of rectangular shell, formed of SPCE and 590-MPa materials in respectively different proportions, were fractured. Let’s consider how the fractured forms differ from each other. First, in the state in which a high strength material is fully caught in the punch bottom so that the high strength material can bear the resistance of flange deformation (Photo 2(c)), the formability of TB depends on that of the high strength material. This induces us to think that formability is enhanced when a high strength material easily formable is used.

Next, when the high strength material is not fully caught in the punch bottom (Photo 2(b)), the low strength material should be powerful enough to draw the high strength one into the die. When the ratio of strength between the two is great, fracturing occurs on the low strength material side at the punch bottom (Stress-rule fractured form). As measures to counter the fracture in such deep drawing, the following should be considered:

- 1) The ratio of a high strength steel sheet to be caught in the punch bottom should be increased by moving the bead position.
- 2) A strength ratio should be lessened so that a stress-rule fractured form can be prevented.
- 3) As a forming method, hydraulic counter punch forming should be selected.

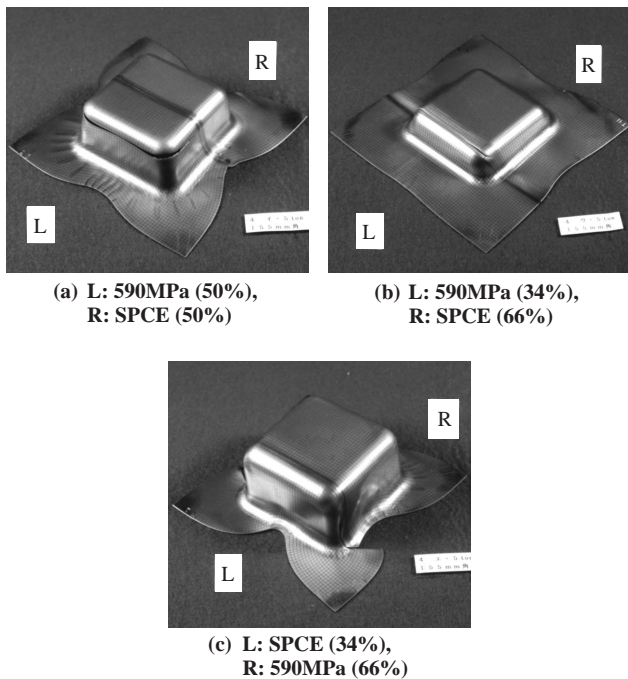


Photo 2 Various forms of fracture when the combination of steel materials was varied in proportion

4.2.4 Fracture in stretch flange forming¹¹⁾

It is difficult to classify into two kinds, that is, the stress rule (low strength material fracture) and the strain rule (weld bead fracture) in the hole expanding test, because the material to be used is restrained by the tool. What is more, formability is influenced by the ratio of combination of materials in the original hole. This means that the evaluation by “the ratio of hole extension” is not effective. Accordingly, as in the study of the findings of the uni-axial tensile test in clause 4.2.1, the influence of a combination of materials in hole extending was evaluated in terms of maximum plastic strain.

Fig. 8 shows the findings of the test put in order by the ratios of strength of the materials combined, together with those of trial calculation of the maximum plastic strain, ϵ_{1max} , by formula (2). The

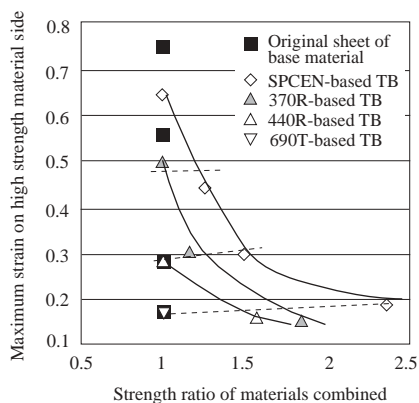


Fig. 8 Comparison between maximum strain of high strength material and that of original sheet in TB with various kinds of steel combined

dotted lines in the Figure are auxiliary ones connecting the maximum strains of the higher strength materials when combining different strength of materials in the original sheet and TB. The Figure clearly shows that the maximum strains of the higher strength materials in various combinations are almost equal to the fracture limit strains of respective original high strength sheets. Again, after the strain of the high strength material has reached a maximum, deformation is concentrated on the low strength material to lead to fracture. It therefore becomes necessary to enhance the fracture limit strain on the higher strength material side so that the stretch flange property can be improved.

4.2.5 Fracture due to stress concentration at the starting and end parts of welding

In TB by laser or plasma welding, shrinkage may occur at the starting or end part of welding due to melting, and this shrinkage often leads to stress concentration during forming resulting in fractures. The starting or end part is therefore slightly trimmed sometimes. In mash seam welding, welding conditions become unstable when the electrode ring moves on to or slips off the starting or end part resulting in fractures due to insufficient welding at the starting or end part.

5. Conclusion

The forecast of consumption of steel sheets for TBs in Europe is quoted in the literature 1). This forecast is for year 2000 with consumption rising at an annual rate of about 20% after 2000. Even at this point, the consumption of TBs is not hitting the peak not only in Europe but also all over the world. Incidentally, in the projects of ULSAB and ULSAB-AVC in pursuit of a possibility of utilizing steel material and its utilization technology for lessening the weight of steel auto bodies, a proposal was made of the application of TB parts at a weight ratio of 45% to the auto bodies¹²⁾. The ratio of using TB parts has not reached this level at this point of time, leaving much room for the improvement of the performance of auto bodies by the application of TBs in the future as well.

In this paper are discussed laser welding for the TBs manufacturing and the utilization of TBs for auto bodies. It is highly desirable that this paper, though not entirely satisfactory, will contribute not only to the development of TB as production technology, but also to the development of steel auto bodies.

References

- 1) Natsumi, F.: Press Technology. 34(8), 18(1996)
- 2) Miyazaki, Y. et al.: Press Technology. 34(8), 30(1996)
- 3) Miyazaki, Y. et al.: Journal of Japan Laser Processing Society. 2(1), 85(1995)
- 4) Yurioka, N.: Journal of the Japan Welding Society. 61(4), 288(1992)
- 5) Miyazaki, Y. et al.: Quarterly Journal of the Japan Welding Society. 19(2), 242(2001)
- 6) Uji: Basics for Welding and Jointing Processes. Sanpo Publications, Inc., 1996
- 7) Miyazaki, Y. et al.: Proceedings of the 50th Laser Materials Processing Conference. 2000, Japan Laser Processing Society, p.59
- 8) Usuda, M. et al.: Press Technology. 34(8), 26(1996)
- 9) Hiwatashi, S. et al.: Proceedings of the 46th Japanese Joint Conference for the Technology of Plasticity. 1995, p.167
- 10) Ikemoto, K. et al.: Journal of the Japan Society for Technology of Plasticity. 32-370(11), 1383(1991)
- 11) Hashimoto, K. et al.: The 202nd Symposium on Technology of Plasticity. 2001, p.27
- 12) Kuriyama, S. et al.: Journal of the Japan Welding Society. 71(8), 6(2002)