AN EXPERIMENTAL STUDY ON WARM DEEP-DRAWING PROCESS OF LAMINATED SHEETS UNDER VARIOUS HEAT TREATMENTS

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ABSTRACT: The objective of present paper is to investigate the warm deep-drawing process of laminated sheets consists of aluminum alloy series 1050, 5052 and stainless steel 304(SUS) experimentally. The effects of temperature within the blank on formability and punch force are investigated. To study the laminate sheet behavior; three blank temperatures namely, 25˚C, 100˚C and 160˚C are examined. In addition, the effect of grain size on punch force and material behavior for aluminum alloys 5052 and 1050 are studied. The aluminum sheets are annealed at 350˚C 400˚C and 450˚C. The grain size effect, which strongly affects some properties such as formability parameters, stress, elongation and friction coefficient, is investigated. To measure the grain size the microstructure of Al 5052 and Al 1050 sheets is revealed by Polarized Light Microscope (PLM). In addition, to clarify the relative influences of grain size on the formability of Al 5052, some tensile tests on annealed specimen at 350˚C, and 450˚C are performed. It is found that the effect of grain size and sheet temperature on punch force may be dissimilar for different blank-holder forces.

KEYWORDS: Warm deep-drawing, laminated sheet, blank-holder force, grain size, punch force

1 INTRODUCTION

Nowadays, laminated sheets are used in various industrial fields such as aerospace, automobile, chemical and electrical industries. Laminated sheets have the benefits of high strength, low density, damping covering structures and corrosion resistibility, simultaneously in the single compound. A laminated sheet consists of two or more metals with different material combinations and different thicknesses. In general, laminated sheets can be made by several processes, such as explosive bonding, adhesive bonding or cold hot roll bonding [1, 2].

One of the most applicable sheet forming processes used to form laminated sheets, is warm deep-drawing process which is one of the unconventional deep-drawing processes. In comparison to the conventional deep-drawing, this process can cause better metal flow and achieves optimal parameters for a quality product such as formability, punch force, fracture and limit drawing ratio (LDR) [3].

The laminated sheets formed by warm deep-drawing process, can be used in manufacturing of parts with different inner and outer conditions for instance, corrosion, wear resistance, and thermal and electrical conductivities [1].

Annealing and grain size are main factors in deep-drawing in order to improve the quality of product such as, formability, wrinkle pattern, punch force, limit drawing ratio and forming limit diagram (FLD). The grain size is strongly reliant on annealing treatment and re-crystallization and the effect of cold rolling is omitted by it and therefore, properties of metal are changed.

Aluminum sheets are used in wide range of industrial for advantages like, high strength-to-weight ratio and their great corrosion resistance [4]. Warm deep-drawing process of aluminum was investigated in order to evaluate formability by Palumbo and Tricarico [4]. Boogaard and Hue ´tink conducted a survey of formability of aluminum under various temperatures [5]. Draw ability of

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stainless steel 304 is studied in warm deep-drawing [3, 6, 7]. Due to advantages of laminated sheets, researchers pay more attention on forming and producing industrial parts from these sheets [1, 8-10]. Effect of grain size on hot deformation behavior of aluminum was investigated by Rezaei Ashtiani et al. [11]. In the present study, laminated sheets are formed by warm deep-drawing process, which still have not been studied too much, and the effects of grain size and blank temperature on the punch force are investigated.

2 FORMING

2.1 WARM DEEP-DRAWING EQUIPMENT

The scheme of the experimental equipment used for warm deep-drawing is illustrated in Fig. 1. The test equipment specially designed so that warm deep-drawing operations can be performed at various temperatures. To increase the temperature two annular electrical heaters with 1400 W power are utilized. The annular electrical heaters are set on outer circumference of drawing die and blank-holder. A thermocouple TTL type is placed in die and to control the temperature a digital thermostat with the precision of 1°C is used. The required time to reach the temperature to 160°C is about 20 min. The test rig consists of a draw die flange with circular shape, a blank-holder, 8 springs which provide blank-holder force (BHF), punch and heat equipments, Fig. 2. Moreover, some features of test rig are shown in Table 1.

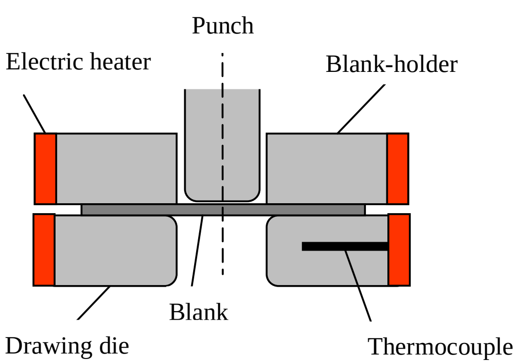


Fig. 1 Schematic representation of the equipment for the deep-drawing test

Deep-drawing of laminated sheet is carried out using a 60 ton hydraulic press. To measure the force of forming process, a pressure sensor is installed on the hydraulic press which transforms the pressure to electric current. In addition, to measure the of punch displacement a linear magnetic displacement sensor with the accuracy of micron is used. All information come to a data acquisition card and the Matlab software is used to analyze the obtained data.

Fig. 2 Experimental test equipment

Table 1 Dimensions of various parts of the deep-drawing die set

Dimension	Value (mm)
Punch diameter	65.5
Die inner diameter	70
Die outer diameter	153.5
Punch and die profile radius	5
Blank-holder inner diameter	67
Blank-holder outer diameter	164
Clearance	2.25

2.2 MATERIALS AND SPECIMEN PREPARATION

The materials of layers in this study are stainless steel 304 (SUS), aluminum alloy grades 1050 and 5052 which their mechanical properties are given in Table 2. Based on punch force, die diameter and drawing depth, the optimal diameter of the sheet is selected as 13.2 mm and thickness for aluminum alloys 5052 and 1050 and stainless steel 304 are 1, 0.8 and 0.4 mm, respectively. In this study, two grades of aluminum alloys 1050 and 5052 are combined with stainless steel 304 in order to make two different types of laminated sheets. Loctite 5368 adhesive is applied to join the two sheets together. The advantages of Loctite adhesive, which met the condition needed in warm deep-drawing, are high flexibility, medium to high initial strength and high heat resistant up to 300°C. The formed specimen is illustrated in Fig. 3.

3 ANNEALING

The grain size (GS) is a main factor in forming process that should be taken into account. Influences of grain size on parameters such as flow stress, machining, friction coefficient and electrical properties are remarkable. Furthermore, annealing causes to remove any effect of strain hardening and

Fig. 3 *Sample of laminated sheet after forming*

Table 2 *Chemical composition (wt. %) of aluminum alloys and stainless steel*

Element	Al 1050	Al 5052	St 304
Si	0.12	0.25	0.44
Fe	0.28	0.40	70.55
Cu	0.02	0.10	0.14
Mn	0.02	0.10	1.38
Mg	0.02	2.82	-
Zn	0.011	0.10	-
Ti	-	0.15	-
Cr	-	0.10	19.97
AL	99.49	95.98	-
V	-	-	0.12
Ni	-	-	7.00

improve material properties for forming. For these reasons, samples are annealed at 350°C, 400°C and 450°C for 1 h. Then cooling process is done within the furnace for 24 h. To measure the grain size, samples are etched by (50 ml paution's reagent, 25 ml HNO_3, 40 ml of solution of 3gr chromic acid per 10 ml of H_2O) etchant. The best resolution of individual grains and microstructure of Al 5052 and Al 1050 are revealed by Polarized Light Microscope (PLM), see Figs. 4 and 5. The PLM microstructure results showed that the crystallization has taken place for all samples. The grain sizes are measured based on the ASTM-E122-12 standard for various annealing temperatures and they are presented in Table 3. Furthermore, to determine the friction coefficient under various annealing temperatures, the Coulomb friction test is performed, Fig. 6.

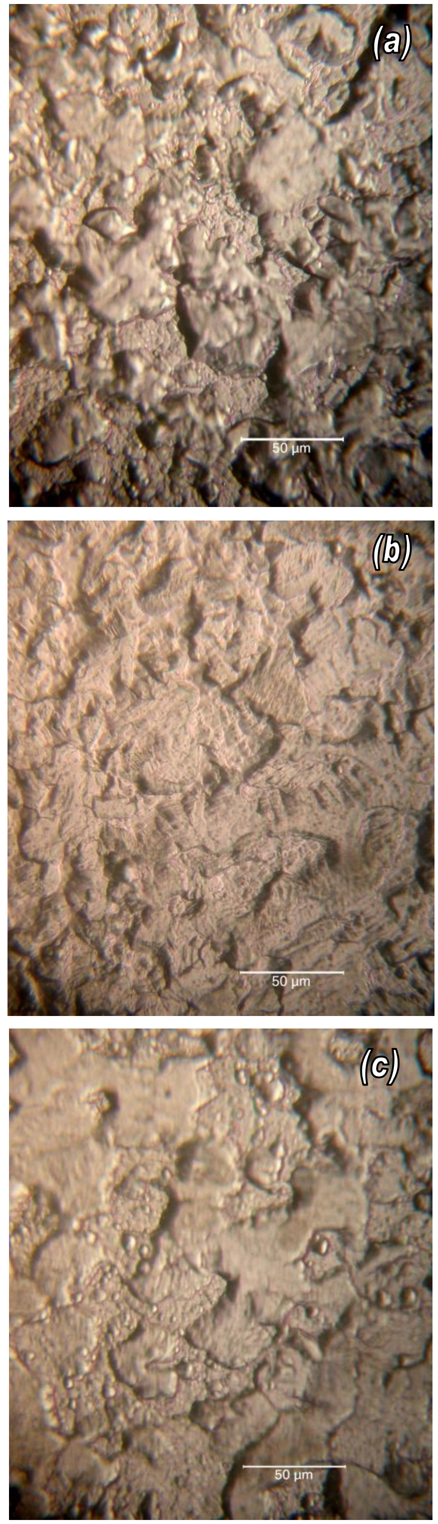


Fig. 4 *PLM microstructure of Al 5052 specimen with three annealing temperatures of (a) 350°C, (b) 400°C and (c) 450°C*

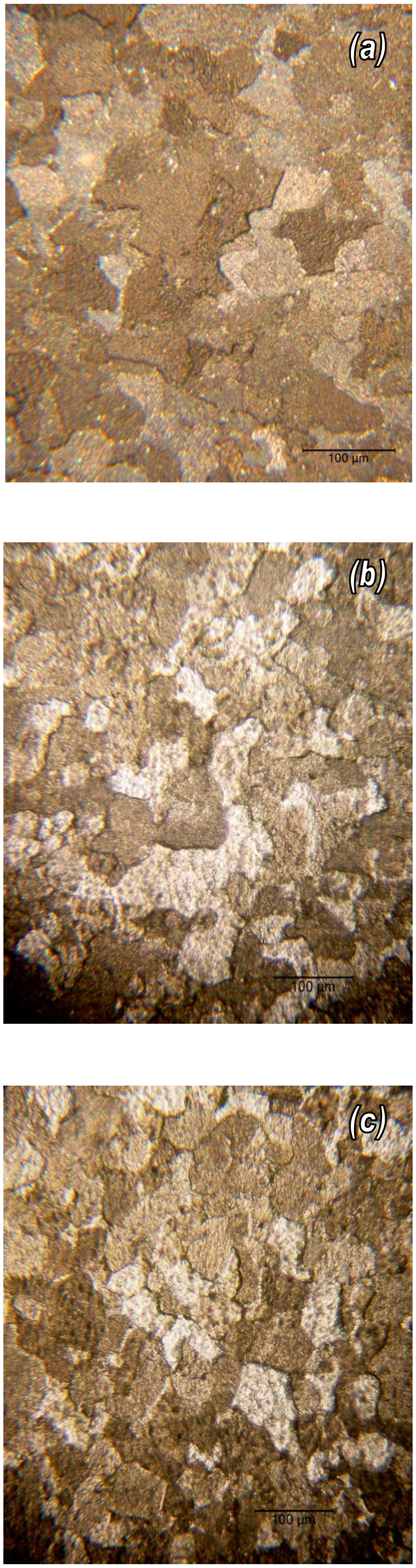


Fig. 5 *PLM microstructure of Al 1050 specimen with three annealing temperatures of (a) 350° C, (b) 400° C and (c) 450° C*

Table 3 *Grain size for aluminum alloys*

Annealing Temperature	GS for Al 5052 (μm)	GS for Al 1050 (μm)
350° C	10	37
400° C	12	40
450° C	14	44

Fig. 6 *Friction test apparatus*

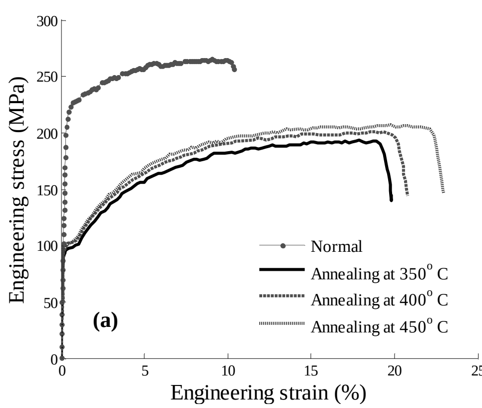
4 TENSILE TEST AND FLOW STRESS

To determine the engineering stress-strain behavior of aluminum alloys tensile test is performed on a Zwick-Z250 uni-axial tensile test machine at room temperature. Tensile specimens of aluminum alloys 5052 and 1050 are prepared to have the dimension with gauge length of 50.0 mm, width of 12.5 mm according to ASTM-0557M-02 standard and are cut in the directions of 0° which conforms directly to the rolling direction. The tensile specimens are annealed at the temperature conditions of 350° C, 400° C, and 450° C for 1 h, after that they are cooled within the furnace in 24 h to investigate the effect of grain size on the flow stress. The testing speed has significant effect on engineering stress-strain behavior. Rezaei Ashtiani et al. surveyed the effect of different speed on behavior of metals [11]. According to the punch speed the tensile tests are carried out with testing speed of 0.002 $(1/S)$. The engineering stress-strain curves for Al 1050 and Al 5052 are illustrated in Fig. 7.

5 RESULTS AND DISCUTION

Aluminum sheets used in this study are produced by rolling technology. This process affects mechanical properties of sheets such as strain hardening exponent, texture, grain size and grain orientation. Furthermore, sometimes during rolling process, depending on thickness reduction, grain boundaries are destroyed. Thus, revealing the microstructure and grains and also measuring grain size is not easy. Re-crystallization of aluminum alloys 5052 and 1050 occurred in the 345° C [12]. Effects of annealing on microstructure and grain size are illustrated in Figs. 4 and 5. Regarding to the PLM microstructure for Al 5052 and Al 1050, re-crystallization occurs in all the samples. As it is seen from stress-strain curves, elongation and ultimate stress increase with increasing the annealing temperature, Table 4. The effects of some variables such as temperatures of blank, annealing temperatures and blank-holder force on the load-displacement displacement curve are presented and discussed here. The process conditions are as blank diameter of 13.2 mm, dry condition and stacking sequence in which aluminum sheets is set as upper layer and in contact with punch and stainless steel sheets as under layer and in contact with drawing die for all specimen. First, the effect of blank temperatures on load – displacement for the specimens consisted of Al 1050 and stainless steel 304 (SUS) are studied. In order to study more comprehensibly, the experiments carried out on three types of specimen that are annealed at different temperatures. The obtained load-displacement diagrams are shown in Fig. 8. During these experiments the blank-holder force is taken as 15 kN.

As it is observed, one may see an unusual behavior here and load for forming laminated sheets increase when the blank temperature increases. To explain this performance, two key factors with interaction effect have to be considered. The first one is the formability and plastic deformation of materials that rise with increasing the temperature and therefore decrease the required forming load [12], and the second one is the friction. In fact, metal behavior in softening and adhesion is changed with raising the temperature and therefore friction coefficient increases and as a result, the forming load increases. The important issue here is how the effect of these parameters may be dominant. The results show that the blank-holder force can play a crucial role here. Choosing lower BHF (near 15 kN) makes the friction effect dominant. On the contrary, using higher BHF (near 19 kN) causes the effect of formability to be prominent. In other word, when drawing process is performed with BHF of 15 kN, the effect of friction affect more than that of the formability and plastic deformation.



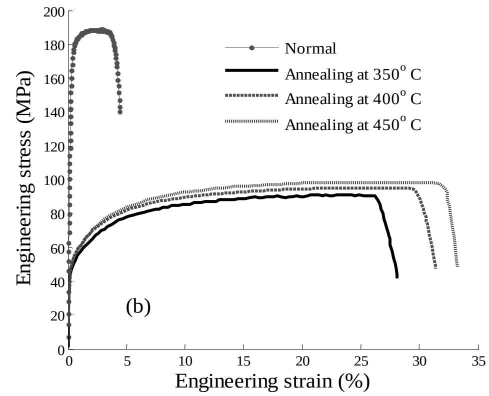


Fig. 7 *Engineering stress-strain behavior for annealing at various temperatures for (a) Al 5052 (b) Al 1050*

Table 4 *Mechanical properties*

(a) Al 5052

Type	S_{uts} (MPa)	Elongation (%)
Normal	266.5	10.37
Annealing at 350° C	193.9	19.8
Annealing at 400° C	200.8	20.7
Annealing at 450° C	206.8	23

(b) Al 1050

Type	S_{uts} (MPa)	Elongation (%)
Normal	189.2	4.5
Annealing at 350° C	91.2	28.1
Annealing at 400° C	95.1	31.2
Annealing at 450° C	98.5	33.3

One can go through this mechanism in more detail. When lower BHF is used, the samples slid across the blank-holder more easily and drawing and elongation in samples are reduced. Measuring diameter of specimen before and after the test showed that the specimen slid about 27 mm on blank-holder and drawing die for all blank temperatures. In addition, by comparison the length of specimen before and after the test, elongation and plastic deformation is about 8 mm.

To demonstrate this incident, the experiments are performed with BHF of 19.3 kN on Al 1050/SUS that annealed in 400° C, Fig. 9. The results show that when the BHF raise, the effect of formability and plastic deformation dominate and different trends are observed. Hence, the specimen tested in 25° C needs more maximum load. The elongation and sliding length for these samples are about 20 and 10 mm, respectively, for all blank temperatures. In comparison with the specimen that tested with BHF of 15 kN, elongation increases 12 mm and sliding decreases 17 mm which shows the effect of formability and plastic deformation overcome the effect of friction.

In continuing, the experiments are performed on specimen made of Al 5052/SUS and BHF of 18.2 kN, Fig. 10. It is observed that with increasing the temperature, the formability increases too and specimens can be formed by lower loads. Finally, the effect of annealing temperatures on load-displacement is investigated for Al 1050/SUS with BHF of 15 kN. The experiments are carried out for three various temperatures including 25° C, 100℃ and 160° C, Fig. 11.

Higher annealing temperatures lead to laminated sheet to be formed by larger load. Like as pervious study, in this situation also BHF is the dominant factor. Considering the stress-strain curves in Fig. 7, it is observed that with increasing the temperature of annealing, ultimate stress increases, therefore, higher forces is needed to form the sheet. Moreover, some experiments are performed to find out the effect of annealing on friction coefficient. The results show that the grain size growth leads to increase of friction coefficient, Table 5.

Similar to previous discussion about BHF and effects of plastic deformation and friction, the trend of curves is reasonable. The experiment is re-carried out for BHF of 19.3 kN. As expected, the order of curves is inverted. The results showed that when the BHF increases, the specimen that annealed at 350° C need higher force for forming, Fig. 12.

6 CONCLOUSIONS

In this research, laminated sheet were formed by warm deep-drawing process with the aim of investigating the effect of annealing and blank temperatures on laminated sheet behavior during deep-drawing process. Considering the facts observed, it can be concluded that (i) raising annealing temperature causes increasing the elongation, ultimate stress, friction coefficient and grain size and (ii) formability and friction coefficient increase by heating the specimen. The crucial factor to analyze the load magnitude in various annealing and blank temperatures was the BHF. With decreasing the BHF, effect of friction became more significant. So that, with increasing temperatures of annealing and blank, the required load to form laminated sheet became higher.

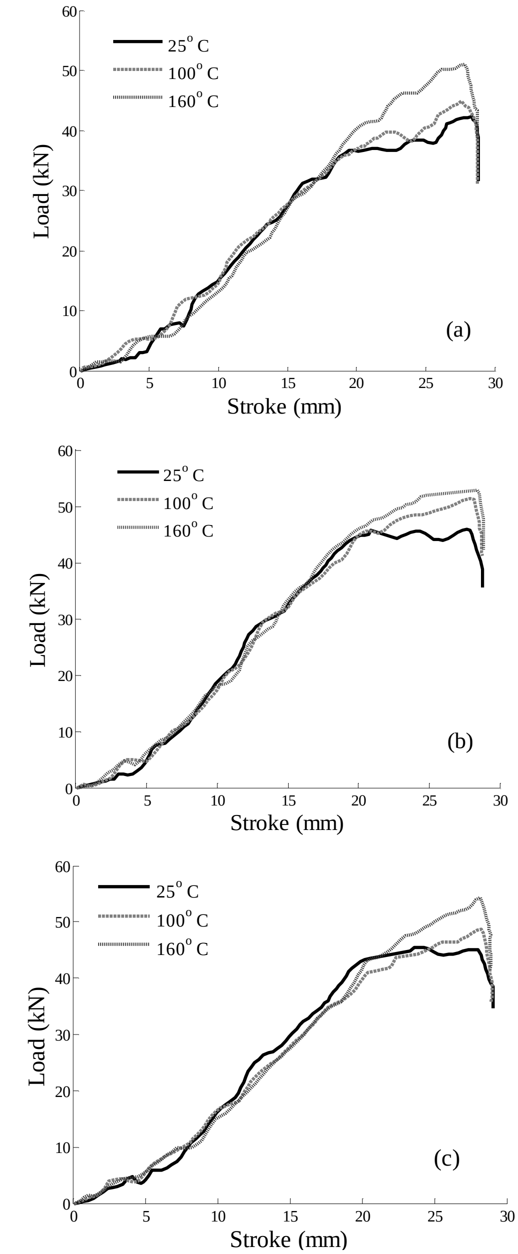


***Fig. 8** Effect of blank temperature on load-displacement for specimen Al 1050/SUS that annealed at (a) 350° C, (b) 400° C, (c) 450° C*

On the other hand, raising the BHF causes the plastic deformation has the dominant effect, which leads to the warm deep-drawing process to be performed with less required load in higher temperatures.

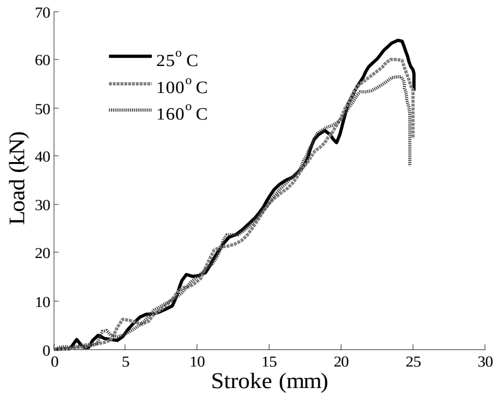


Fig. 9 *Effect of blank temperature on load-displacement for specimen Al 1050/SUS that annealed at 400°C with BHF of 19.3 kN*

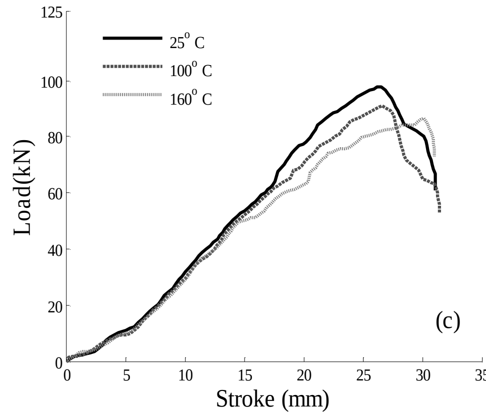
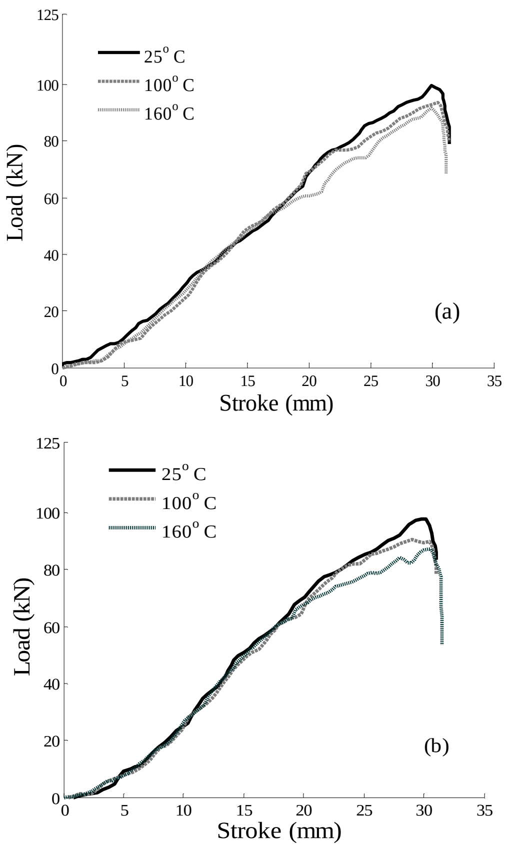
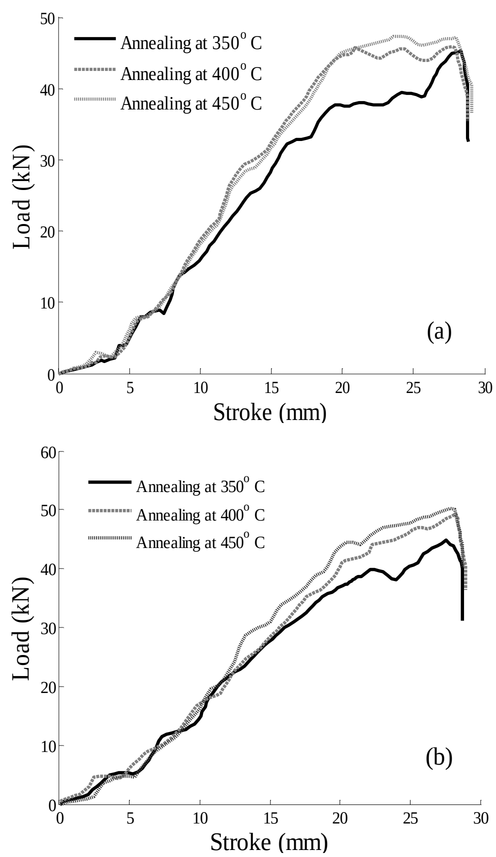


Fig. 10 *Effect of blank temperature on load-displacement for specimen Al5052/SUS that annealed at (a) 350°C, (b) 400°C, (c) 450°C*





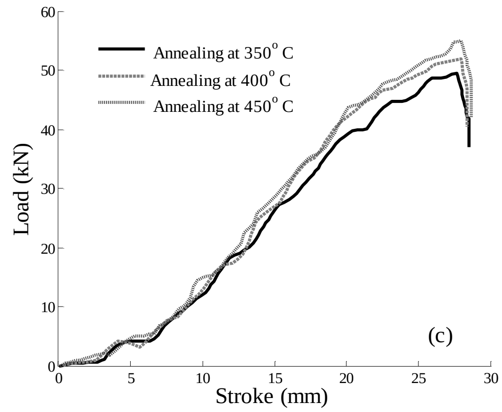


Fig. 11 *Effect of annealing temperature on load-displacement for specimen Al1050/SUS for (a) 25° C, (b) 100° C, (c) 160° C*

Table 5 *Effect of annealing temperature on friction coefficient*

Friction coefficient	350° C	400° C	450° C
Al 1050	0.30	0.37	0.41
Al 5052	0.28	0.34	0.37

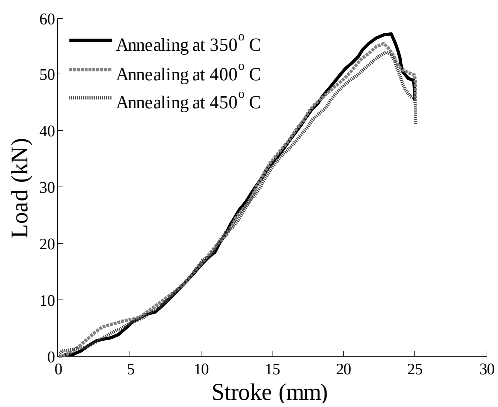


Fig. 12 *Effect of annealing temperature on load-displacement for specimen Al 1050/SUS for 100° C with BHF of 19.3 kN*

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