HIGH TEMPERATURE ERICHSEN TESTS OF ALUMINUM ALLOY SHEETS

Makoto SUGAMATA, Junichi KANEKO and Masahiro NUMA

Department of Mechanical Engineering,
College of Industrial Technology, Nihon University
1-2-1 Izumi-cho, Narashino, Chiba 275-8575, Japan

ABSTRACT Erichsen tests for aluminum alloy sheets were carried out by using self-constructed apparatus in which a blank sheet, die and punch were heated uniformly at temperatures between 293 and 573K. Erichsen value was obtained by measuring punch displacement at an abrupt drop of the punch load. Fully annealed aluminum alloy sheets (1100, 3004, 5052) were used as test materials. Tensile tests were also carried out at temperatures between 293 and 573K. Erichsen values of tested sheets increased with rising test temperature. Increases of Erichsen value was less pronounced for 1100 sheets than 3004 and 5052 sheets. A linear correlation was observed between Erichsen value and total elongation of tested aluminum alloy sheets.

Keyword : *formability, aluminum sheet, Erichsen test, high temperature, mechanical property*

1. INTRODUCTION

In case of using aluminum alloy sheets for the car body parts, their insufficient formability is pointed out as a disadvantage in conventional press forming process in comparison with steel sheets. Improved formability of aluminum alloy sheets at elevated temperatures has been reported[1]. Local heating of the sheets during deep drawing process has been known to increase the forming limit[2]. However, it was reported that the deep drawability of aluminum alloy sheets heated at exactly uniform temperature does not change with rising testing temperatures[3]. As for the further studies of metal sheet forming process at high temperatures, formability of the sheets have to be evaluated at elevated temperatures by various formability test method.

In this study, with an aim of evaluating high temperature stretchability of aluminum alloy sheets, Erichsen tests were carried out by using self-constructed apparatus in which a blank sheet, die and punch were heated uniformly at temperatures between 293 and 573K. Tensile tests of the aluminum alloy sheets were also carried out to establish the relationship between Erichsen value and tensile properties at each testing temperatures. Aluminum sheets tested in this work are 1100, 3004 and 5052 in O temper.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The Erichsen test method standardized by Japanese Industrial Standard (JIS) is classified into following two types according to the method for prevention of drawing-in of flanges during stretch forming of blank sheet. In the A method, a circular blank is inserted with a narrow clearance between upper and lower dies. Friction force which is produced by thickening of flanges due to compressive strain in the circumferential direction prevents drawing-in of flanges. In the B method, the drawing-in of flanges is completely prevented by clamping a blank with applied holding pressure. Because of mechanical simplicity, the A method was adapted to our Erichsen test apparatus at high temperatures used in this study.

A drawing of the experimental tools for the Erichsen test is shown in Fig. 1. Dimension of the tools were determined according to JIS. An upper die was fixed to a lower die by means of T shaped guide rail. Die clearance was set to be 0.85 mm by which additional clearance of 0.05 was allowed when a blank of 0.8 mm in thickness was inserted. A circular blank of 90 mm in diameter was inserted into the die clearance.

Fig. 2 shows schematic diagram of the apparatus for the Erichsen test. The dies and spherical head punch were heated to uniform temperature in an electric resistance furnace. The dies were set on the rod connected to a hydraulic cylinder and the punch was fixed to the upper shaft. The blank was deformed by moving dies upward under constant speed of 0.1 mm s^{-1}. Breakage of the blanks were detected by measuring punch load by a load cell. At the moment breakage occurred, oil pump was turned off. Erichsen values were obtained from the punch displacement which was measured by an inductance transducer.

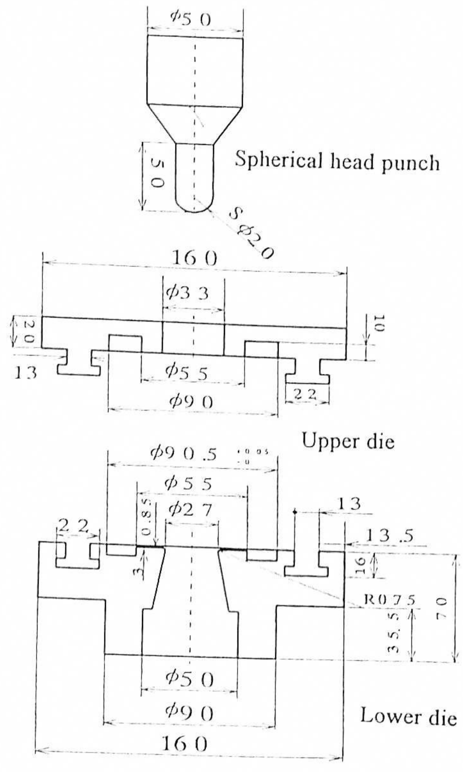

Fig.1 Tools used for Erichsen test.

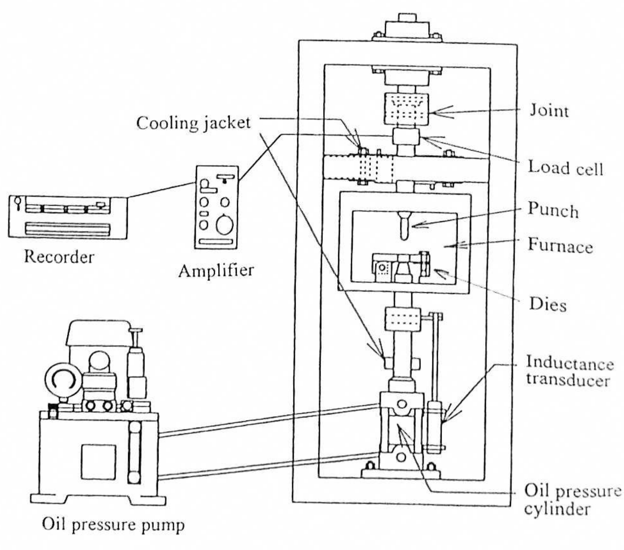

Fig. 2 Schematic diagram of apparatus for high temperature Erichsen test.

Three kinds of fully annealed aluminum alloy sheets of 0.8 mm in thickness were used as test materials; 1100-O, 3004-O and 5052-O of which average grain size is 25, 29 and 45 μ m, respectively. Erichsen tests were carried out at room temperature, 373K, 473K and 573 K. Graphite-grease lubricant was applied at all testing temperatures. Erichsen values were obtained by averaging the values of three tests for each testing temperature.

Tensile tests pieces of 8 mm width over the 50 mm gage length were prepared from the sheets at angles 0°, 45° and 90° between the tensile and rolling direction. Tensile tests were done at an initial strain rate of 1.6×10^{-3} s^{-1} at the same temperatures to Erichsen tests. Tensile strength, total elongation, strain hardening exponent and Lankford value were obtained by the average of triplicate tests. The Lankford value was measured at about 20% elongation in case that uniform elongation was higher than 20%. If not, the Lankford value was determined at near the maximum uniform elongation. The strain hardening exponent was obtained by natural logarithms of plastic strain at the maximum tensile load.

3. RESULT AND DISCUSSION

Fig. 3 shows temperature dependence of Erichsen value of aluminum alloy sheets. Erichsen value of 1100 aluminum sheet at room temperature is nearly equal to the value of 11.0 mm in the handbook[4]. Thus, it was confirmed that proper Erichsen values can be obtained by this self-constructed apparatus. Erichsen values of all the tested sheets at 473 and 573 K are higher than those at room temperature. However, small decreases of Erichsen values were observed at 373 K. Among the tested sheets, 1100 shows the highest Erichsen value at room temperature and smaller increase with rising testing

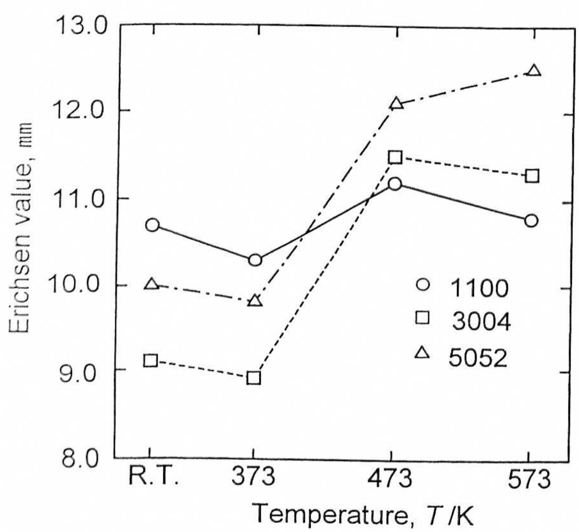

Fig. 3 Erichsen values of aluminum alloy sheets at various temperatures.

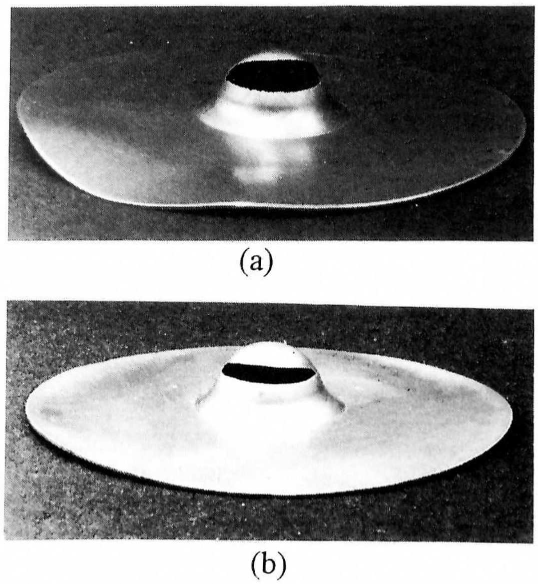

Fig. 4 Appearance of Erichsen tested specimen of 5052 (a) R.T., (b) 573 K

increase up to at 573 K, whereas slight decreases were observed at 573 K in the other sheets. Erichsen value of 3004 sheet is lowest at room temperature comparing with other sheets. However, the value of 3004 sheet increases above the value of 1100 sheet at higher temperatures.

Appearance of Erichsen tested specimens for 5052 sheet is shown in Fig. 4. Changes of blank diameter of all specimens after Erichsen tests were less than 0.2 mm. Thus, the drawing-in of flanges was well prevented and pure stretch forming was almost realized during Erichsen tests. Breakage tended to occur at the point apart from the center of a blank due to restriction of deformation under higher friction at the blank center. Slight movement of dies after turning off oil pump opened up a crack further. However, Erichsen values were not overestimated because they were obtained by measuring punch displacement at an abrupt drop of the punch load. Warping of flanges is observed more clearly in the specimen tested at room temperature (Fig. 3(a)) than at 573 K (Fig. 3(b)).

Fig. 5 shows breakage load of the Erichsen tests at various temperatures. The breakage load decreases with increasing temperatures in all the sheets. The breakage load of 5052 aluminum alloy sheets is higher than the other sheets at all testing temperatures. Tensile strength of the sheets at room temperature was 99.5 MPa for 1100 sheets, 160 MPa for 3004 sheets and 201 MPa for 5052 sheets. The decrease of breakage load at elevated temperatures implies decreased force in forming process.

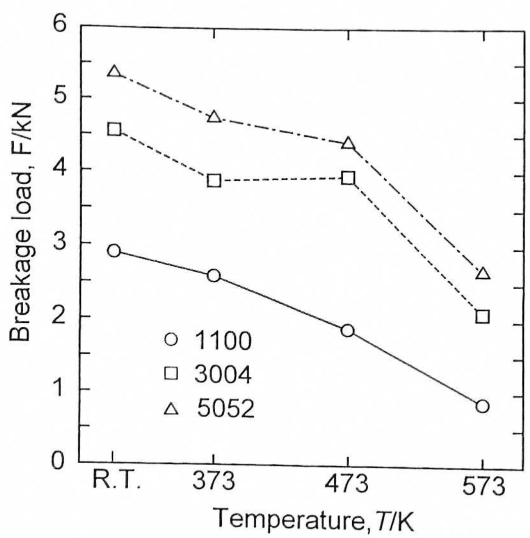

Fig. 5 Breakage load of Erichsen test of aluminum alloy sheets at various temperatures.

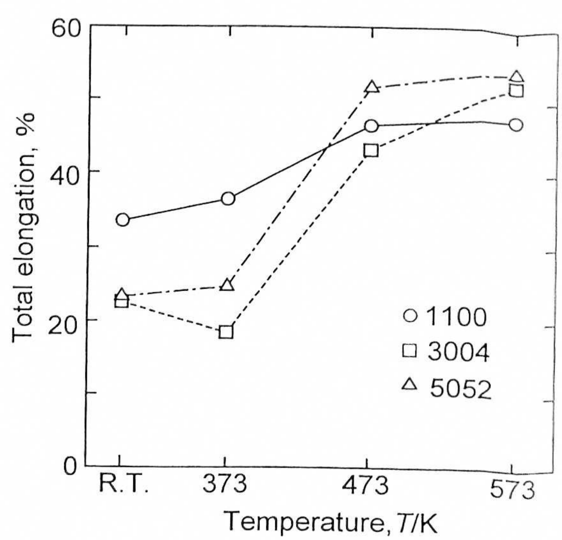

Fig. 6 Total elongation of aluminum alloy sheets at various temperatures.

Fig. 6 shows total elongation of aluminum alloy sheets at various temperatures. Total elongation of all the tested sheets increase with rising testing temperatures. 1100 sheet shows the highest total elongation at room temperature. However, increasing rate of total elongation of 1100 sheets is lower than that of 3004 and 5052 sheets. Total elongation of 5052 sheets are higher than other sheets at 473 and 573 K.

Fig. 7 shows Lankford value of aluminum sheets at various testing temperatures. Lankford values of all tested sheets are ranged between 0.75 and 0.89 at room temperature, and slightly decrease with rising temperature. Strain hardening exponent is shown in Fig. 8 against testing temperatures for aluminum alloy sheets. Strain hardening exponent tends to drop at elevated temperature in all tested sheets.

Erichsen values are plotted against total elongation at various test temperatures for all the tested sheets in Fig. 9. Symbols and figures in the symbols indicate kind of sheet and testing temperatures, respectively. A linear correlation is observed between Erichsen value and total elongation of tested aluminum alloy sheets. Meanwhile, it was difficult to find a certain correlation between Erichsen value and other obtained tensile properties.

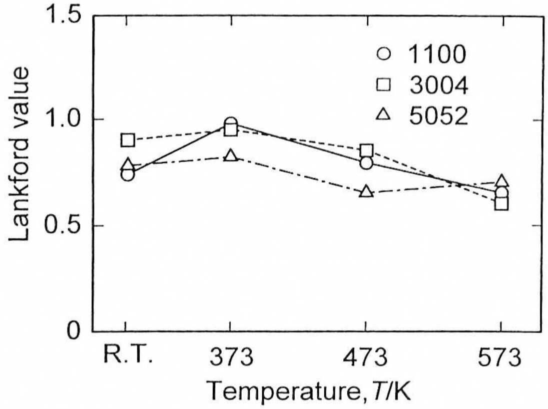

Fig. 7 Lankford value of aluminum alloy sheets at various temperatures.

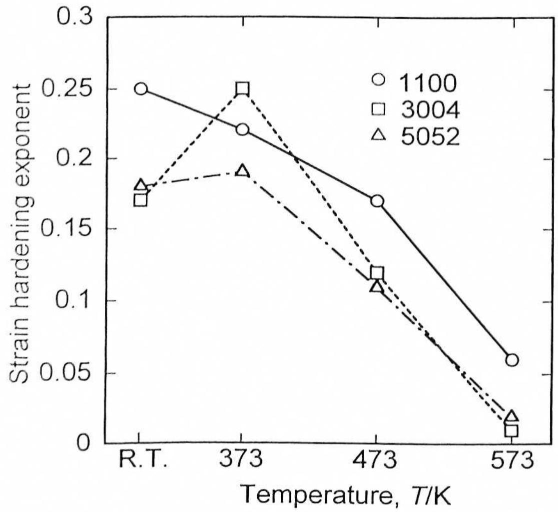

Fig. 8 Strain hardening exponent of aluminum alloy sheets at various temperatures.

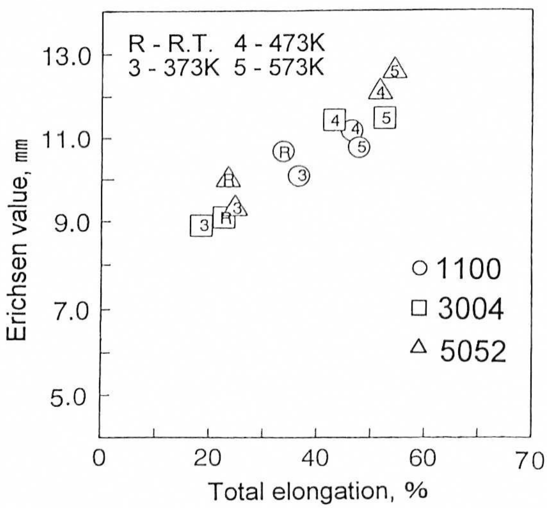

Fig. 9 Relation between Erichsen value and total elongation at various temperatures.

4. CONCLUSIONS

1) Stretchability of aluminum alloy sheet at various temperature were evaluated by Erichsen test by using self-constructed apparatus which was confirmed to show proper Erichsen value.

2) Erichsen value of 1100-O, 3004-O and 5052-O sheets increased with rising test temperatures. The increasing rate of 1100-O sheet were lower than those of the other aluminum alloy sheet. It

was concluded that stretchability of aluminum alloy sheets was improved in warm press forming.

3) A linear correlation was observed between Erichsen value and total elongation of tested aluminum alloy sheets from room temperature to 573K. However, strain hardening exponent was not correlated to the Erichsen value.

ACKNOWLEDGMENTS

The authors wish to thank Messrs. K. Terashima, and H. Watarai for their experimental assistance. This work was supported in part by the Amada Foundation for Metal Work Technology of Japan.

REFERENCES

[1] Y. Abe and M. Yoshida : J. Jpn. Inst. Light Metals, 44(1994), 240.

[2] Y. Tozawa : J. Jpn. Soc. Tech. Plasticity, 1(1960), 23.

[3] M. Sugamata, J. Kaneko, H. Usagawa and M. Suzuki : Proc. 2nd Int. Conf. Technology of Plasticity, ed. K. Lange, Springer-Verlag, (1987), 1275.

[4] Aluminum Handbook (fifth edition), ed. Japan Light Metal Association, (1994), 99.