
Adaptation of a servo-hydraulic load frame to carry out the Olsen ball punch deformation test at elevated temperatures on magnesium sheet

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Abstract

Formability assessment of magnesium sheet should replicate the elevated temperature forming conditions the sheet is likely to experience. Typically AZ31 is hot formed at temperatures below 160°C. This article looks at the application of the Olsen/Erichsen ball punch deformation test, which simulates biaxial and shell wall stretching, at hot forming temperatures. The equipment required to bring about the elevated temperature and controlled deformation was incorporated into a standard uni-axial load frame. This not only reduces cost, but also removes some of the ambiguity associated with the test technique.

Formability testing

A material's formability can be defined by "the ease with which a sheet metal can be shaped through plastic deformation" (ref 1). Formability is a characteristic measured by a range of mechanical tests and parameters. Several examples are listed below:

- The tensile test can provide modulus, yield strength, ultimate tensile strength, uniform and total elongation, work hardening exponent (n) and plastic strain ratio (r).
- The hardness test is a measure of a material's resistance to plastic deformation, and there is some relationship to formability but in general it is an indication of strength.
- The hydraulic bulge test simulates biaxial stretching. Stress and strain can be determined from this test, depending on the level of instrumentation.
- The Erichsen/Olsen test combines biaxial stretching over a spherical indenter and stretching in the shell wall.
- The Swift cup test uses a flat bottomed punch and circular blanks of different diameters to draw cups. The limiting draw ratio is the largest blank diameter that can be drawn satisfactorily to the diameter of the punch.

This paper discusses the application of the Olsen ball punch test conditions to a servo-hydraulic load frame. It must be noted that the only difference between the Olsen and Erichsen methods is the spherical indenter diameter; Erichsen uses Ø20mm, whereas Olsen uses Ø22.22mm. The tooling considerations described in this paper conform to ASTM E643, (ref 2). However, the design intent was to include elevated temperature testing as this is a basic requirement for characterising the formability of magnesium sheet.



The test requires a sheet clamped between two circular dies with sufficient clamping force to avoid any “draw-in” from the deformation force. The sheet is then biaxially deformed by a spherical indenter until fracture. The fracture/failure point is when a crack is visible to the operator, or when a drop in load is detected. The height of deformation at this point is the Olsen number. This test offers a unique capability in that it simulates biaxial stretching as found in a pressing operation, and it also provides material properties such as deformation/spherical indenter force and bulge height. Conventionally the test is carried out with the spherical indenter being driven from below. The operator watches the deformation and stops the test when a crack becomes visible, normally at the dome peak. However, this does introduce a level of operator variability from both the reaction time for stopping the machine, and also from the interpretation of “when is a crack a crack”. It is possible to remove this subjectivity by the inclusion of a load cell and data acquisition to measure indenter force and travel.

The Equipment

The use of an existing servo-hydraulic load frame, as described in this paper, offers numerous benefits not only from the cost savings on capital equipment but also from hydraulic power pack maintenance, floor space and calibration/maintenance costs. The test can also be incorporated into a screw driven machine.

The majority of uni-axial mechanical test load frames consist of a two column frame with a fixed or adjustable headstock, a single hydraulic actuator or a moving crosshead driven by two rotating lead screws. This basic layout is ideal to incorporate the Olsen test as long as the sheet clamping force can be provided independently of indenter force. The Instron™ 8501 servo-hydraulic machine in the Mechanical Testing Department at Brunel University, UK, was the machine used to mount the Olsen tooling, as described in this paper. This machine has the actuator mounted in the moveable cross head with the load cell secured to the bottom platen. To accommodate this configuration, the Olsen test has been inverted with the sheet deformation taking place into the fixed tooling main body, out of sight of the operator. The main tool body is mounted on the load cell with the spherical indenter spigot attached directly to the actuator, as shown in figures 1 and 2.

The sheet clamping force, which is defined within ASTM E643 as 9800N (total), is applied to the top die using 6 springs with a compressive strength of 176.7N/mm. These are housed inside steel sleeves that have been precision ground to a specific length to limit the compressive travel ($(9800/176.7)/6=9.2\text{mm}$) of each spring. A bolt running axially through the middle of the spring and the two dies into the main tool body was used to compress the spring, transferring the force onto the top die. Heating was provided by 6 x 100watt cartridge heaters mounted radially in each die half (figure 2). This provided a reasonable heating rate of the sheet, which took approximately 8 minutes to reach a test temperature of 150°C.

Testing and results

Once the tooling had reached the required temperature, all six bolts, springs and collars were removed (using heat proof gloves), and a 90mm square sample was placed centrally between the dies. Then the bolts, springs and collars were re-fitted and evenly compressed to the length of the sleeve. The temperature of the central un-heated/test region of the sheet was monitored with a contact probe until the test temperature was reached. Graphite grease was applied to the spherical indenter



before it was driven into the sheet at 10 mm/minute. Force displacement data was collected at 20 points/second. For room temperature tests this procedure was replicated but with petroleum jelly as a lubricant.

Figure 3 shows the load displacement data for twin roll cast AZ31 magnesium sheet which was hot rolled at 400°C to final gauge, and was then given a final anneal prior to testing. The advantage of using a load displacement trace is that the absolute dome height is determined from the drop in load, thus removing the element of operator subjectivity.

Typically at room temperature the dome heights were 2mm, which was similar to the Erichsen number. Comparative testing on an Erichsen 129 machine at room temperature gave 2.15. At 150°C the dome heights were 4 - 4.3mm. An attempt to replicate the elevated temperature testing with a standard Erichsen machine was not successful. The sheet was heated to 10°C above the test temperature in a separate oven and then transferred as rapidly as possible to the Erichsen machine. This produced results that were no better than the room temperature tests, presumably as a result of heat extraction from intimate contact with the cold tooling.

Figure 4 is a side elevation of two tests carried out with the Olsen tooling. The test on the right shows the 2mm room temperature dome height, while the test on the left is the 4mm dome height obtained at the elevated temperature.

Summary

Olsen tooling fitted to a tensile test frame provides an excellent and reliable method for heating and testing magnesium sheet. Comparison with room temperature data has been very good, and the advantages of heated tooling and a thermally stable sheet can clearly be shown by the doubling in dome height, which could not be reproduced with cold tooling, heated sheet and a standard Erichsen machine. This simple set of tests demonstrates the advantages of warm forming and, more importantly, an accurate means of property measurement.

It should be noted that extended use of the tooling or use at higher temperatures would require permanent cooling to avoid thermal drift in the load cell, as well as the use of coarse threads to reduce the time required to compress the clamping springs.

Figures

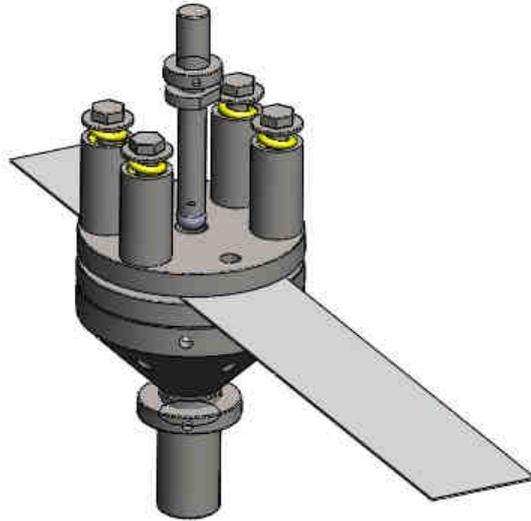


Figure 1 Solidworks™ Model (no heating)



Figure 2 Heated tooling in load frame

load displacement curves for twin rolled cast Az31.
Hot rolled at 400C to 1.6mm + final anneal before testing.

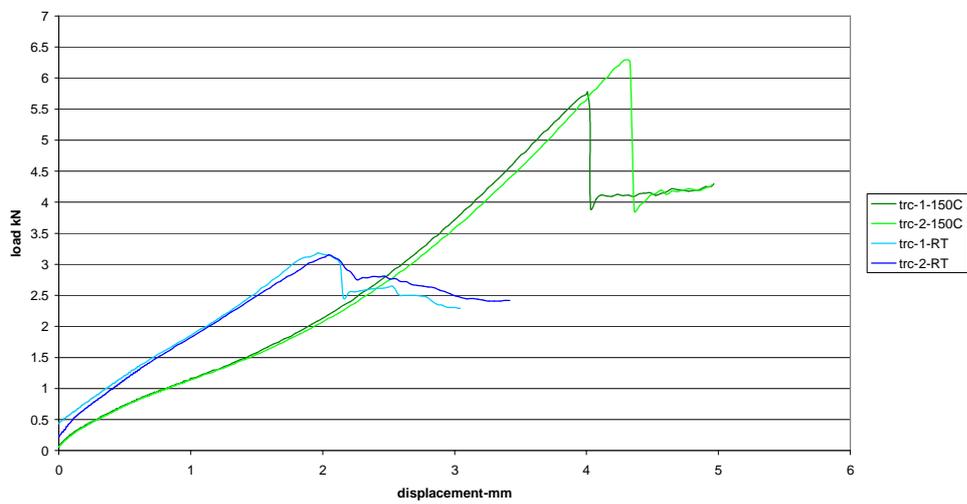


Figure 3 Olsen load displacement data

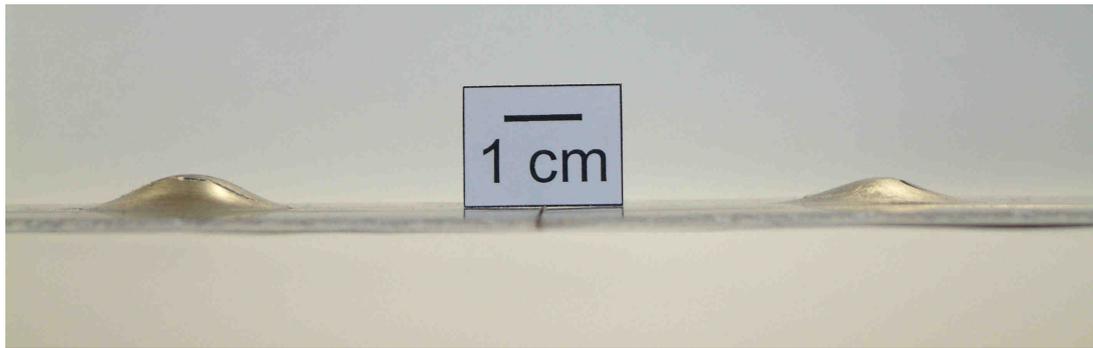


Figure 4 Comparison of Olsen dome heights.

References

- 1 ASM Handbook 14B Metalworking: "Sheet Forming"
- 2 ASTM 643-09 "Standard Test Method for Ball Punch Deformation of Metallic Sheet Material"

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