Drawbeads in Sheet Metal Forming

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Drawbeads are used to control the flow of sheet metal into the die cavity during stretch-draw forming of large panels. They prevent wrinkling in formed panels, reduce the blankholder force, and minimize the blank size needed to make a part. Drawbead restraining forces (pulling forces) and failure locations in the formed sheets are usually evaluated by using drawbead simulation tooling. In this article, a drawbead simulation apparatus is used to assess the influence of variation in material, bead penetration, and friction conditions on the drawbead restraining force. Results from the test can be used as input for sheet metal forming simulation programs.

Keywords
computer simulation, drawbeads, forming

1. Introduction

The stamping of large sheet metal panels is generally a two-step process. In the first step, the binder clamps the sheet metal to hold it in place, and in the second step, the punch contacts the sheet and forms the part. The binder surface may be flat, or it may contain drawbeads. A flat binder surface provides little braking action (restraining force) as the sheet metal flows into the die cavity. Friction in a flat binder may not provide enough restraining force to control metal flow and prevent wrinkling in the formed panels. The presence of drawbeads in the binder area increases the braking action substantially and provides extra restraining force because the sheet metal would have to bend around the bead as it is being pulled through the binder. The pulling force (drawbead restraining force) is the force required to pull the sheet metal through the drawbeads. The magnitude of this force and, consequently, the amount of draw-in allowed is determined mainly by the geometry of the drawbead and the clamping force in the binder area. The clamping force is the force needed to maintain a certain depth of the bead. It is important to note that too much metal flow into the die cavity may produce wrinkling, whereas too little metal flow may cause splitting in the formed panel.

Drawbead restraining force is caused, to a large extent, by deformation resulting from bending and unbending of the sheet metal in the drawbead area and, to a lesser extent, by the frictional forces resulting from the sliding contact between the binder and the sheet metal. The bending force was found to be inversely proportional with the radius of curvature, whereas the friction force was found to be directly proportional with the coefficient of friction (μ) and the binder hold-down force (BH). The bending force was also found to be larger than the friction force by a factor of about 3:1 for good lubrication condition and about 1:1 for poor lubrication.[1]

Drawbead action occurs in two stages. In the first stage, the binder closes, and a protrusion on one binder face pushes the sheet metal into a matching groove on the other binder face to form a bead. The depth of movement of the protrusion into the sheet surface determines the amount of bead penetration. In the second stage, the sheet metal is pulled through the bead and into the die cavity. The restraining force of a drawbead increases with increase in penetration because the metal would be subjected to more bending. The amount of bead penetration is controlled by the magnitude of the normal force (hold-down pressure).

During prototype development and tryout of sheet metal panels, drawbeads are physically adjusted or altered to obtain the proper restraining force. Adjustments are usually done by an elaborate method of welding and hand grinding until the proper amount of metal flow in the die cavity is achieved. In some situations, a single drawbead with more restraining force may replace multiple drawbeads, and this may result in reducing the blank size needed for the finished product.

2. Computer Simulation of Panels

Computer modeling and simulation is now replacing prototyping to help die designers, during tool development, to explore alternative die designs and to evaluate tradeoffs on the computer. Using this methodology, proposed product designs can be tested without the need for expensive tooling and time-consuming tryouts. A successful computer simulation, however, depends greatly on the relevance of the simulation model and the accuracy of the input parameters. Such parameters usually are derived from experience or from experimental evaluation.

An important input for sheet metal forming simulation programs is the drawbead restraining force. This input is essential to determine the proper amount of metal flow needed for successful stamping. Because the magnitude of the drawbead restraining force, for a specific bead geometry, is determined largely by the amount of bead penetration, a relationship between the two parameters must be established for various materials.

The importance of drawbeads in sheet metal forming simulation has been demonstrated by two numerical simulation examples for autobody panels.[2] In the first example, the introduction of a full set of drawbeads in the binder area produced the proper amount of stretching in the plane of the sheet and resulted in the elimination of the loose metal problem. In

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Table 1 Mechanical properties of test materials

Material	Thickness, mm	Yield stress, MPa	Tensile stress, MPa	*K*, MPa	Elongation, %	*n*	*R*	μ
Cold rolled steel (CRS)	0.79	186	309	549	45	0.23	2.01	0.134
Hot dip galvanized steel (HD)	0.76	174	285	481	39	0.20	1.42	0.101
Electrogalvanized steel (EG)	0.81	206	320	536	44	0.20	1.94	0.230
HSLA steel	0.86	447	528	847	25	0.17	1.03	0.155
2036-T4 aluminum	1.02	203	339	645	22	0.23	0.76	0.170

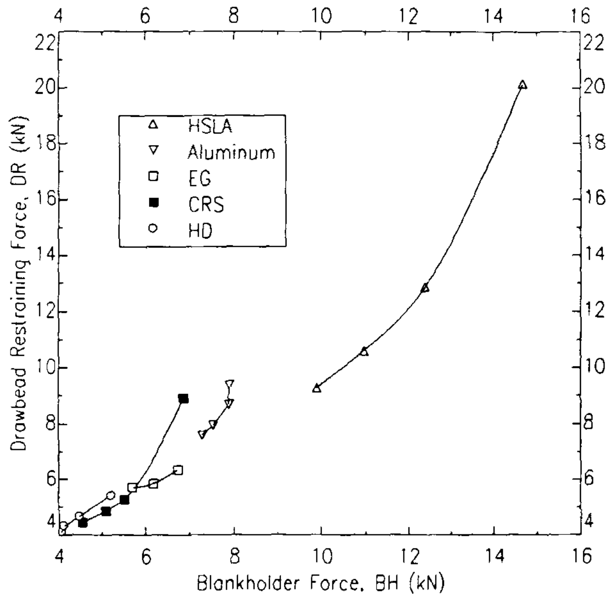

Fig. 1 Effect of blank holder force on drawbead restraining force.

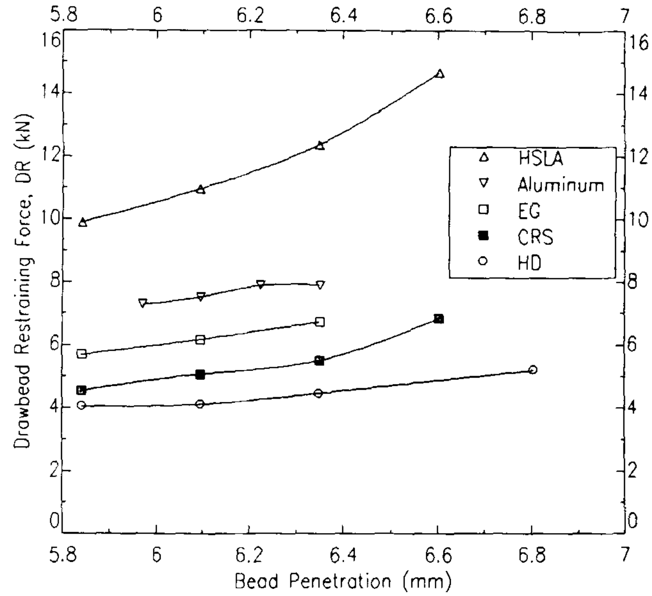

Fig. 2 Relationship between drawbead restraining force and bead penetration.

the second example, sheet metal wrinkling was eliminated by simply increasing the drawbead restraining force to reduce the amount of metal flow into the die cavity.

3. Experimental

A standard drawbead simulation apparatus, similar to the one described in Ref 1, was used to measure the drawbead restraining force (DR) and the binder hold-down force (BH) for a single round bead with a male radius of 6.5 mm and a female radius of 7.21 mm. A limited number of tests were also conducted on a double bead set with bead dimensions identical to those of the single round bead. Centers of the double beads were 25 mm apart. Only one punch-to-die clearance of 0.9 mm was used, because other experimental work showed that clearance changes have a relatively small effect on the drawbead restraining force (DR).[3] Such a clearance is also typical of values used in production dies. Clearances are generally determined by adding 0.05 mm to the sheet thickness to avoid pinching the sheet metal at maximum penetration. The materials tested are listed in Table 1 with their typical mechanical properties. *K* is the strength coefficient, *n* is the strain hardening exponent, *R* is the plastic anisotropy parameter, and μ is the friction coefficient.

Test samples were in the form of sheet strips 368 mm long and 50.8 mm wide. Mill oil was used as a lubricant. Samples were pulled through the drawbead fixture at the typical rate of 85 mm/s. At predefined drawbead penetration, the load versus stroke for both drawing and clamping loads was recorded. Bead penetrations of 5.84, 6.10, 6.35, 6.60, and 6.73 mm, to cover a wide range of bead heights, were used. The deepest penetration provided the maximum drawing and clamping forces for a specific drawbead shape. Drawbead penetration beyond the maxima shown for various materials caused complete locking of the sheet metal. This resulted in fracture of the test samples. Maximum bead penetration is not a practical bead depth for stretch-draw forming of panels because it restricts the flow of metal into the die cavity. For most applications, shallower depths are normally used.

4. Results

Tests were carried out to establish a correlation between bead penetration and drawbead restraining force for a number of materials. Results of the tests are shown in Fig. 1 to 5. Figure 1 shows the relationship between blankholder force and drawbead restraining force for the five test materials. The pulling force increases with an increase in the clamping force. The

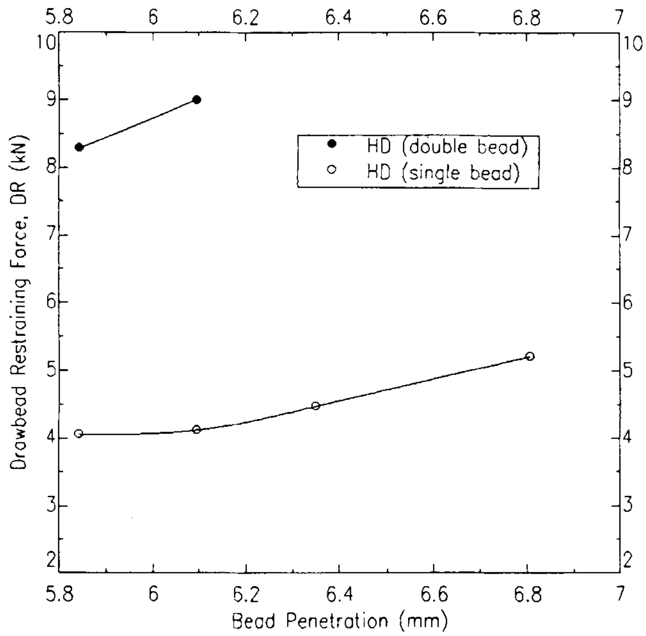

Fig. 3 Effect of single and double beads on the DR forces.

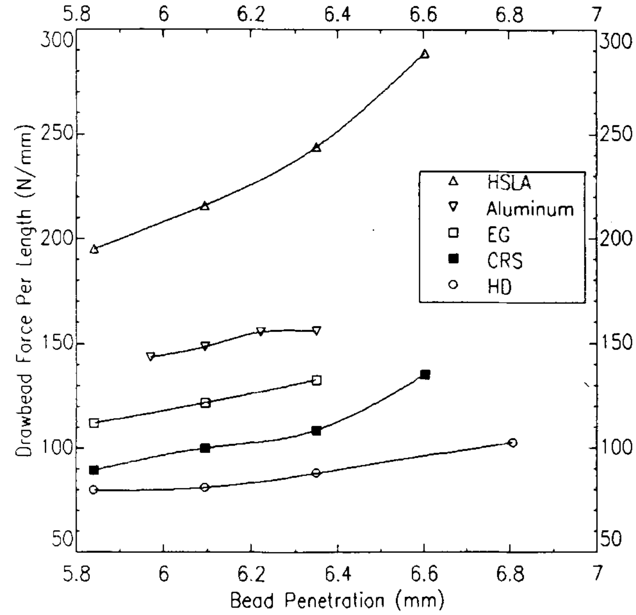

Fig. 5 Relationship between bead penetration and drawbead restraining force per unit width of test sample.

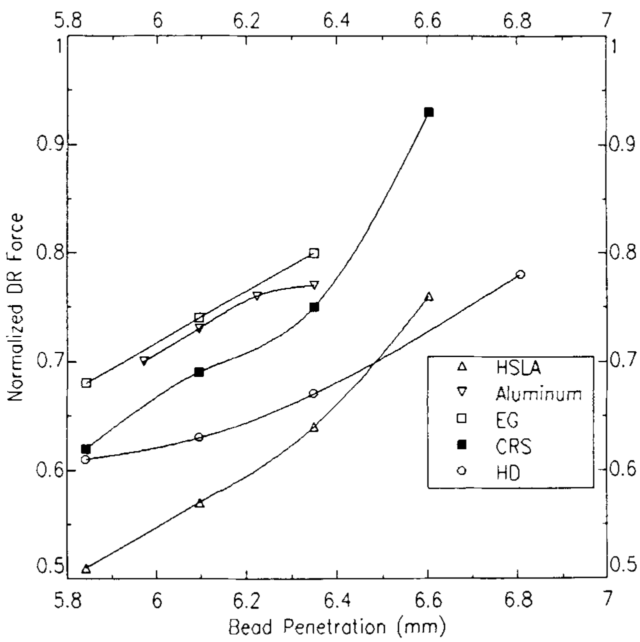

Fig. 4 Relationship between normalized drawbead restraining force and bead penetration.

magnitude of the drawbead force is the sum of two components. The first component results from material deformation, which for a constant bead geometry is proportional to the yield strength of the material. The second component is determined by the friction condition, which depends on the coefficient of friction of the material and the magnitude of the hold-down pressure.

Figure 2 shows the drawbead restraining force (DR) as a function of the bead penetration for five materials. The drawbead restraining force increases with an increase in bead penetration. This result is in agreement with those reported in the literature.[3] Explanation of this behavior is based on the fact that increasing bead penetration decreases the effective bead radius and hence increases the bending deformation along the drawbead. Also, friction increases because increasing bending deformation increases the contact force normal to the binder surface. Both effects contribute to increasing the drawbead restraining force.

Figure 3 shows the relationship between the DR force as a function of bead penetration for a single and a double bead set. Results for the HD material show that, by adding another bead to the binder, the DR force is more than doubled. Drawbead penetration, for the double bead set, beyond 6.1 mm caused complete locking of the sheet material and resulted in necking and then fracture of the test sample outside of the bead area. In this case, the drawbead acted as a grip, and the sample behaved like a tensile specimen.

Figure 4 shows the relationship between the normalized drawbead restraining force and bead penetration for the five materials. The normalized data are obtained by converting the drawbead force in (kN) to drawbead stress in (MPa). The drawbead stress is then divided by the yield stress of the material to obtain the normalized drawbead restraining force. Normalization is important because it allows drawbead forces measured for samples with different thicknesses to be compared. Figure 3 shows that the normalized drawbead force increases with increasing bead penetration. It is important to note that, if the normalized force reaches a value of 1.0, the material starts to yield before it can be pulled through the bead. Drawbead forces should not be high enough to cause excessive deformation and necking in the material outside of the bead area.

5. Application of Drawbead Forces to Simulation Programs

Drawbead restraining forces, shown in Fig. 2, are measured for 50.8 mm wide samples. This does not correlate with the length of the binder area in actual panel forming. Because computer simulation programs are based on thin-shell theory, drawbead restraining forces are implemented in those programs as a force per unit length rather than a force per unit area. Input of this type enables the simulation to apply drawbead forces along the entire periphery of the sheet metal panel. Figure 5 shows the relationship between bead penetration and drawbead force per unit width of test sample. A unit width of the test sample is the same as a unit length along the perimeter of the binder area in a sheet metal panel.

6. Discussion

In sheet metal forming simulation, the appropriate DR force needed to successfully form a specific panel is determined by varying the DR force input until a panel with the appropriate stress and strain distribution is obtained. Once a proper value is determined, the die designer must relate this value to a specific drawbead configuration. That is, the designer must known which bead shape and penetration would produce the proper drawbead restraining force. Without a correlation between drawbead forces and drawbead configuration, it would be extremely difficult for the die designer to specify the proper binder design for a specific stamping.

Computer simulation of large panels showed that a typical value of the DR force of about 150 N/mm would be required to successfully form a CRS sheet metal into an auto panel. According to Fig. 5, this value corresponds to a single round bead penetration of about 6.7 mm. This information provides engineers with guidelines for correct binder design and successful stamping of large panels.

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