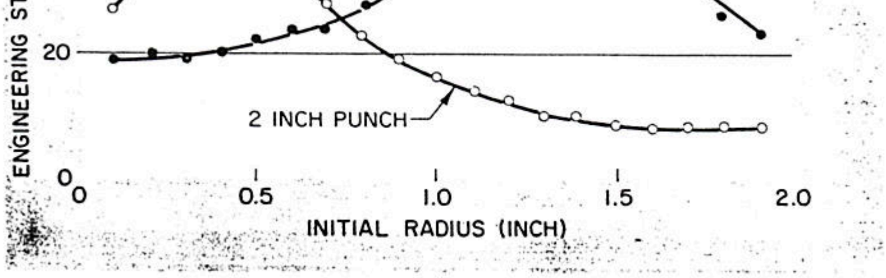
Part 5—Die Design and Lubrication

Understanding Sheet Metal Formability

When a stamping cannot be successfully formed, the fault may lie in the material, die design or lubrication. Here's how these variables influence formability.



1. DISTRIBUTION OF PRINCIPAL STRAIN at maximum (failure) depth in Teflon-lubricated steel disks securely clamped and stretched over hemispherical punches 2 inches and 4 inches in diameter. Failure locations are indicated by the arrows. All measurements are plotted as radial distances from the center of the undeformed specimen. The smaller punch localizes the peak strain, resulting in failure at a depth of 1.42 inches. The larger punch forms the material to a depth of 2.10 inches before failure. This illustrates how the formability of a sheet metal stamping is affected by punch geometry.

Successful forming of a stamping depends on three variables—the forming characteristics of the material, punch and die geometry, and lubrication. If the formability is below a certain level, the stamping breaks or tears during forming.

The three variables are interrelated. When a material has good forming characteristics, poor die design or poor lubrication may not cause trouble. When a material has poor forming characteristics, good die design and good lubrication may overcome forming difficulties.

Slight die modifications—reducing the size of draw beads, increasing the length of die radii, changing the size and shape of the blank, inserting lances and the like—can improve the formability of a stamping to a much greater extent than a change in material. This is also true of changes in lubrication.

Because of the multitude of materials, stamping designs and press conditions, there are no universally valid

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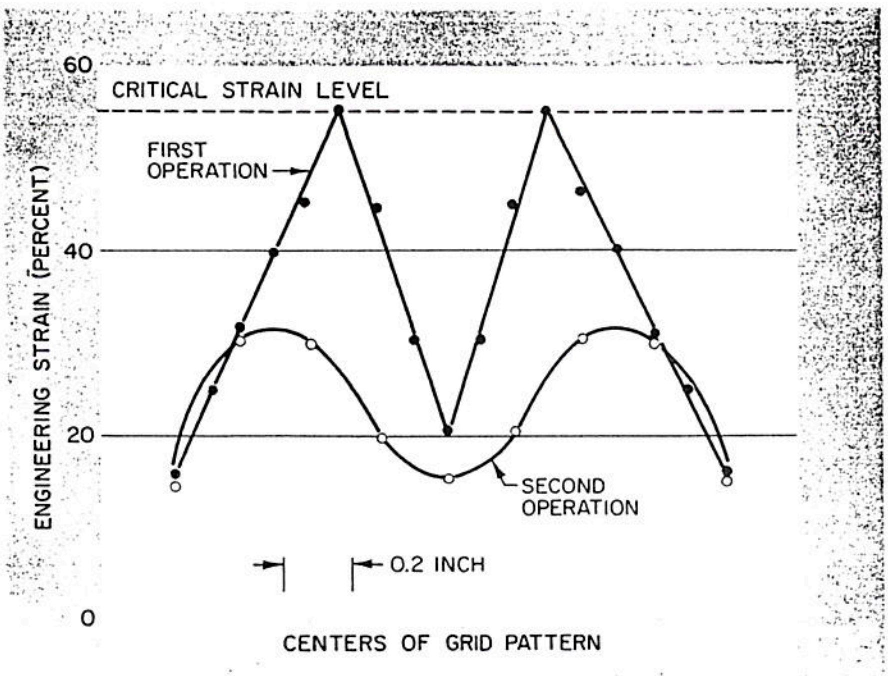
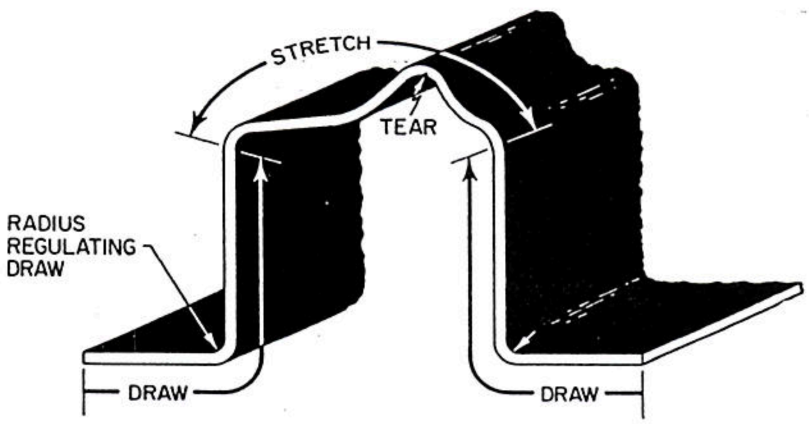


2. *CAUSE OF FAILURE of an automotive brake backing plate was discovered when the distribution of principal strain across a formed dome was analyzed. The strains were measured from an electro-chemically marked grid of 0.2 inch diameter circles. All measurements are plotted at the center position of the undeformed circles. The analysis showed that the cause of breakage at the seventh operation was the high peak strain in the first operation.*



3. *STRETCHING AND DRAWING are both required to form this complex stamping. Minor modifications in die geometry can change the balance between stretching and drawing, with consequent improvement in the formability of the stamping. In this case, enlarging the radius between the flange and wall of the stamping allowed more metal to be drawn into the draw cavity so that less stretching was required. Torn stampings were not a problem.*

rules for improving the formability of stampings through changes in die design or lubrication. An analysis of certain critical stampings, however, has resulted in the development of some guidelines for the modification of die design or lubrication to improve the formability of these stampings. These guidelines are applicable to similar stampings formed under similar conditions but cannot be expected to improve formability in all cases.

One of these guidelines is to create a strain distribution that is as nearly uniform as possible when stretching material over a rigid punch. As discussed in Part 4 of this article, a uniform strain distribution will result in a lower peak strain and therefore less breakage.

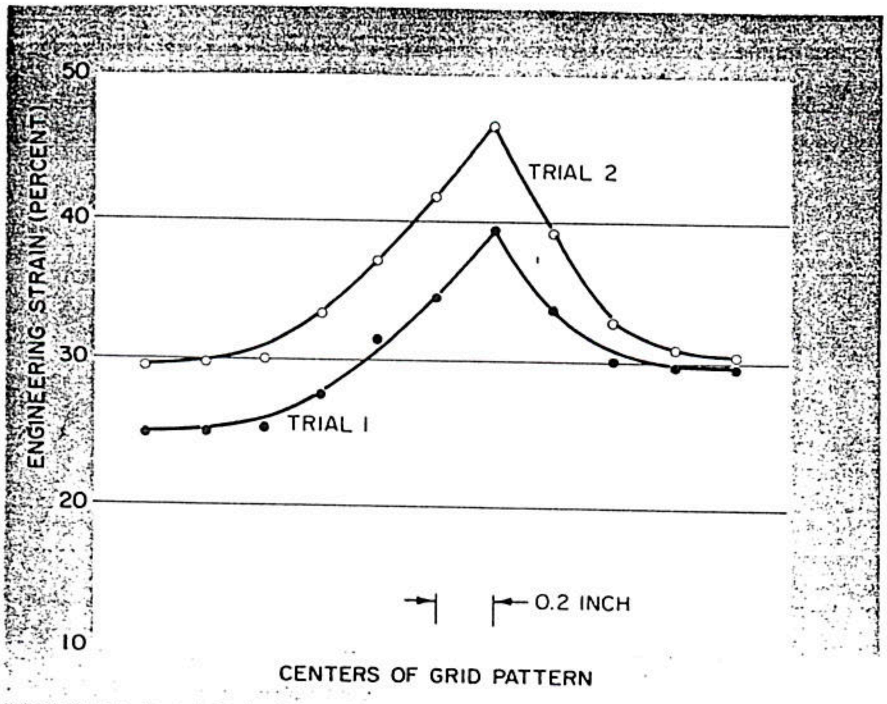
Experiments show that the strain gradient (or nonuniformity of the strain distribution) is strongly dependent on the radius over which the sheet is stretched. The smaller the radius, the more localized the peak strain.

This is evident from *Figure* 1, which shows the results of a laboratory test. In the test, hemispherical punches—one 2 inches in diameter and one 4 inches in diameter—were pushed into a sheet of steel clamped to a die with a 4 inch opening. Peak strains at failure were identical for the two punches but the smaller punch localized the strain more highly, creating a more sharply defined strain peak.

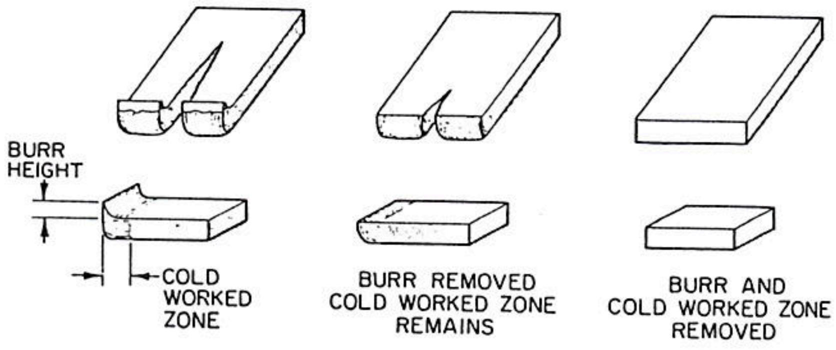
The change from a 2 inch punch to a 4 inch punch is usually impractical for production dies. This change resulted in a 50 percent increase in depth of the stamping before failure. In practice, little additional depth is required and it can be obtained with very small changes in punch radii.

One production problem, for example, involved a mismatch between the contour of the punch and the binder line. The peak strain—located in the area of greatest mismatch—was high enough to cause breakage. Removing 1/64 inch from the punch at the peak strain location lowered the peak strain sufficiently to eliminate breakage. The circular grid system described in Part 2 of this article, which appeared in the March issue, indicated the location of the peak strain and provided a quantitative means of assessing the modification.

Formability of another stamping—a bumper wing—was dramatically improved by a small change in punch radius. The amount of material removed from the punch at the critical strain location was so small that no change in profile could be seen. This slight modification caused the location of the peak strain to shift from the top of the stamping to the front, rotated its



4. *INCREASED PAD PRESSURE caused strain to increase during forming of an automotive panel. During Trial 1, satisfactory stampings were produced. During Trial 2, strain level was higher and all of the stampings broke.*



5. *SHEARING LEAVES BURR and cold worked area having reduced ductility on edge of blank. When the sheared edge is pulled in tension during forming, it may crack. Complete removal of the burr and cold worked area is one solution to this problem. Cracking and part failure are eliminated.*

principal direction 90 degrees and decreased its magnitude from 60 percent to 20 percent.

Similar results are observed in bending. Increasing the bend radius/thickness ratio creates a more uniform strain distribution and a lower peak strain.

In multistage forming operations, it may be difficult to determine which dies should be modified to minimize breakage. Recently, breakage of stampings occurred in the seventh operation in a multiple-die sequence. Examination of the strain distribution showed that the critical strain level was reached in the second operation, *Figure* 2. The initial condition that led to the critical strain level was the nonuniform strain distribution created in the first operation, however.

Once a nonuniform strain distribution is generated, subsequent straining usually increases the amount of nonuniformity. When the first set of dies was modified to smooth out the nonuniformity, the peak strain in the second operation was radically lowered and breakage of stampings in the seventh operation was ended.

This leads to a second guideline or generalization on die modification. In multistage operations, modification of dies in an early operation is usually easier and more beneficial than in subsequent operations. A multiplying factor is present. Small changes in an early distribution result in large changes in the final strain distribution. In early operations, more metal is available from the flange or other locations for relocation into the critical area. And when restrike operations are available for final control of the geometry of the stamping, there is more latitude for modifying the design of dies used for early operations.

The control exerted by the peripheral or flange areas of a blank can radically change the strain requirements over the head of the punch. A typical complex stamping, *Figure* 3, requires a combination of stretching and drawing. The surface area of the completed stamping is fixed. Part of this surface area is supplied by material within the die opening. Any additional surface area required for the surface is generated by pulling metal from the flange or by stretching metal already within the die cavity.

The balance between stretching and drawing can be easily changed. Any additional restraint on metal flowing in from the flange requires additional straining over the head of the punch and vice versa. Blank size, blank geometry, draw beads, wall-flange radii, pad pressure, lubrication and other factors contribute to this restraint.

If the metal in the binder or flange areas is restrained too much, the stretching limit is reached at the head of the punch. Too little restraint can be just as bad. The edge of the blank may be pulled too far into the die, leaving insufficient metal within the trim line. Buckles may form, too, causing the stampings to be rejected for appearance reasons or, in extreme cases, causing the stamping to lock in the die or over a radius. This restricts further drawing and leads to failure.

When two mirror-image stampings are being formed, breakage often occurs in only one "hand." In such cases, the punches and die cavities are carefully compared to see if there are any variations between hands. The peripheral area of the die requires the same careful inspection.

In one case, bumper wings consistently broke even though blanks were switched from the right-hand die to the left-hand die. Analysis of circular grid patterns on the stampings showed that the distribution of strains along a certain axis was different for left-hand and right-hand stampings. When the peripheral dimensions of good and broken stampings were compared, it was found that the material in broken stampings was not pulled as far into the die as the material in good stampings. This caused increased straining of the material over the punch. Point-to-point comparisons between hands showed that there was a smaller die radius on the die that produced the defective stampings, *Figure* 3. This caused high peak strain and failure.

Pad or blankholder pressure strongly influences the relative amounts of stretching and drawing. This was apparent when two trials of an experimental steel were conducted. In the first trail, the steel was successfully formed. In the second trial, one week later, all stampings broke.

Since the material was stabilized, no change in its properties had occurred. Strain distribution patterns, *Figure* 4, showed that the strain over the entire punch area was greater in the second trial than in the first.

Further investigation showed that buckles or wrinkles had developed in the production steel during the interval between the two trials. In order to eliminate these buckles, the press operator had increased the pad pressure. This resulted in an overall increase in strain in all stampings that caused breakage in the trial steel.

Problems other than breakage can also be traced to a strain distribution characterized by a highly localized peak strain. High strain areas in some metals tend to coarsen or granulate the surface of the sheet. If the surface of the stamping is exposed in the end product, this condition is objectionable, and the surface will look even worse if it is plated.

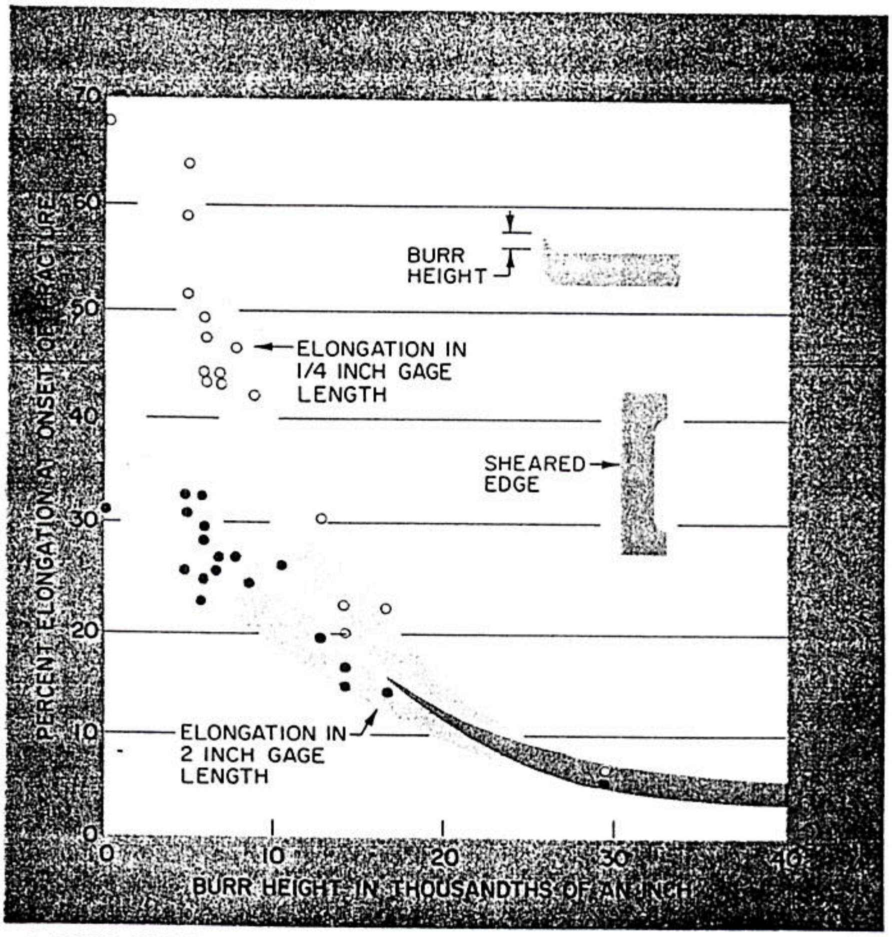
Granulation of the surface of a very sharp radius was a problem encountered in the forming of an automobile bumper. The bumper was formed with a punch that had an almost zero radius. Analysis of circular grid patterns showed that the peak strain at the radius was very high. In some areas there was a localized band of shear strain or thinning—often called a neck in the forming industry. This indicated the onset of breakage. When a large punch radius was used, strain was distributed better. The peak strain was lowered and granulation was eliminated.

High peak surface strains can also cause large amounts of thickness strain (thinning). When a stamping is used as a structural element, or for carrying loads, or where it must withstand high pressure, a minimum final thickness is usually specified. Smoothing out the strain distribution reduces the thickness strain, thereby reducing the initial thickness of steel required to attain the minimum specified thickness after forming.

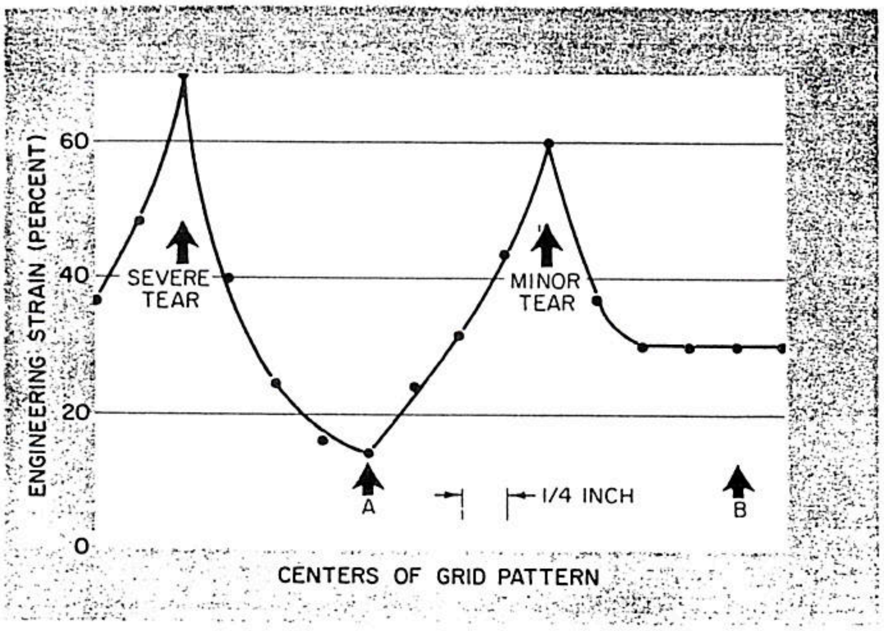
Many breakage problems are created by tension along a blanked or sheared edge. Some of these problems are the result of dull shearing knives or incorrect clearances. A heavily worked lip or burr, which has reduced ductility, is formed. When the heavily worked zone is subjected to high strain, a crack can develop, as shown in *Figure* 5. If the crack occurs in an area that is not subsequently trimmed off, the part must be scrapped or repaired, usually by welding.

Removing the lip or burr will reduce the length of the crack but may not eliminate it. Even though the area where the greatest amount of cold working has taken place—the lip—has been removed, severe deformation from shearing may extend well into the base metal and reduce the ductility of that area as well. To eliminate tearing of the blank during forming, the burr and cold worked area must be completely removed or prevented from developing.

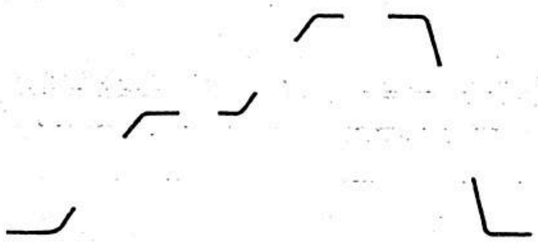
The reduction in ductility caused by a poor blanking operation is shown in *Figure* 6. In this test, long strips from one lift of steel were sheared on machines with incorrectly set blades. Burrs of various heights were generated. Specimens were prepared by milling a reduced section into the edge opposite the sheared edge. These specimens were then pulled in tension until edge cracking—the start of failure—was evident on the sheared edge. Elongations in 1/4 inch gage length



6. POOR BLANKING OPERATION leaves burr and cold worked zone. These curves show the empirical relationship between percent elongation at fracture and burr height. Values were obtained at the onset of fracture in special specimens having one sheared edge. They were pulled in tension during tests.



7. STRAIN DISTRIBUTION along the edge of an automotive outer frame member. Two tears were associated with the peak strains. Notches were filed in the edge of the blank at Points A and B to smooth out strain distribution.



8. ALTERNATE DESIGN can improve the formability of a stamping without interfering with its function. For functional reasons, this stamping must have seven flat areas, indicated by heavy lines. When these segments are connected by large radii (dashed lines) forming in production presents fewer problems.

were measured since it reflected the conditions in an edge-elongated stamping more than a 2 inch gage length.

A very slight burr reduces the permissible percent elongation severely.

When forming an outer frame member, the blanked edge tore in two places. Severe edge elongations were noted in several locations. A bad burr, combined with these elongations, caused tearing. The strain distribution is seen in *Figure* 7.

Three experimental techniques were used to produce acceptable stampings. In the first, the burr and the cold worked base metal were removed by filing. Results similar to those shown in *Figure* 5 were obtained. A second technique—edge annealing of the blanks—restored the ductility of the base metal to a level approaching that of the unblanked material. In a third technique, scallops or notches were filed into the metal at Points A and B in *Figure* 7. The result was a general smoothing out of the strain distribution and a reduction of the peak strain. Such notching devices could be inserted into blanking dies. Another remedy would be to keep the blanking or trimming dies sharp and adjusted to provide a correctly sheared edge.

Part designers often have great latitude in specifying final shapes of stampings, especially when styling considerations are not dominant. The part shown in *Figure* 8 is an example. This part is required, for structural reasons, to conform with flat areas at the seven locations indicated by the heavy lines. These may be weld points, attachment surfaces or clearance locations.

Between these required segments, the configuration is at the discretion of the designer. The generous radii indicated by the dashed lines would contribute to the successful forming of the stamping. The length of line—and therefore average stretch—is less for the large radii. Moreover, movement of metal from one area to the next is facilitated.

Unfortunately, straight-line segments with sharp radii are more appealing to many part designers and are often the chosen design.

The example shows how diemaking and die tryout problems can be reduced by giving thought to formability when parts are being designed.

The influence of lubrication on formability of a stamping is difficult to predict. It must be evaluated on a trial-and-error basis. Tool and die men sometimes reduce the level of lubrication by putting a sheet of newsprint between the blank and the punch. To increase friction (reduce lubrication) in a small area, a piece of emery paper may be fastened to the punch with an adhesive. The effects of these changes can be quantitatively evaluated with the aid of a circular grid pattern.

There are a few broad guidelines for predicting the influence of lubrication on formability. Good lubrication aids in stretching material over a large-radius punch, *Figure* 9. Without lubrication, the straining of material near the pole of the punch is retarded. This means that increased straining is required in areas away from the pole. As a result, strain distribution is more nonuniform and depth at failure is reduced. Good lubrication—using a Teflon lubricant in the case illustrated—allows material near the pole of the punch to participate in the straining, thereby adding to the total depth of the stamping at breakage.

A punch with a small-radius point, *Figure* 10, presents a different type of problem that requires a different solution. The small radius localizes strain. The problem is to prevent strain from becoming critical in the pointed area. Any reduction in the peak strain will permit adjoining material to undergo additional straining. The problem was solved, in one instance, by roughening the punch for a bumper every 4 hours for an entire model year. The added friction made the strain more uniform and minimized breakage.

Large changes in peak strain from changing from one lubricant to another were reported by G. M. Goodwin of Chrysler Corporation in his recent SAE paper. As shown in *Figure* 11, strain measurements made on the leading edges of production automotive hood panels produced from rimmed steel showed a reduction in peak strain from 50 percent to 20 percent when one lubricant was substituted for another. Both lubricants were considered good. As a result of the lubrication change, an expensive change from rimmed steel to aluminum-killed steel (another method of reducing peak strain) was avoided.

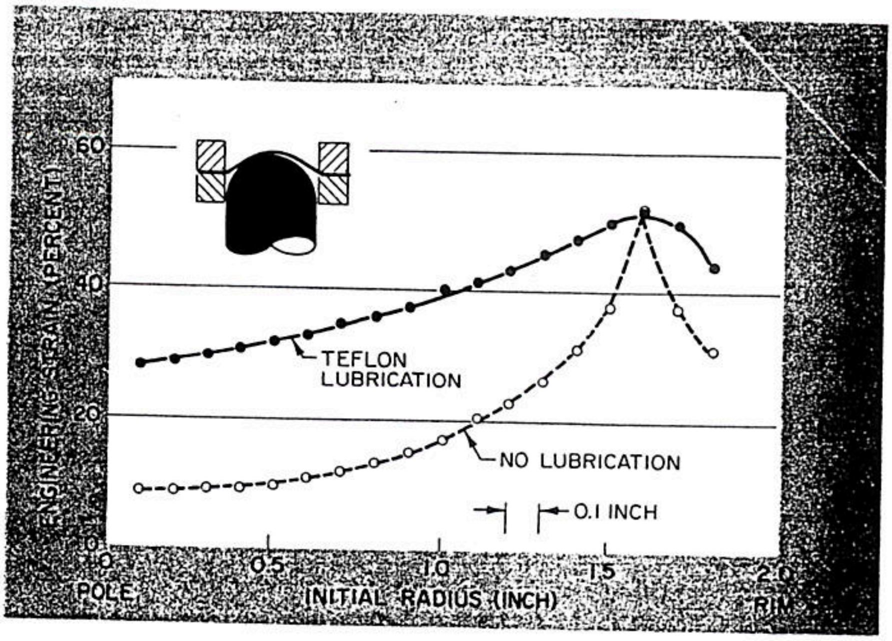
The surface roughness of the material being formed influences formability in a manner similar to lubrication. Smooth surfaces act as if they were lubricated. There is a limit to the effectiveness of smoothing the surface, however. If it is too smooth, it will not retain sufficient lubricant to cover newly generated surface areas. Seizure of the tool material and the work material may result.

The effect of lubrication depends on forming speed, interface pressure, material properties, die design and many other factors. Punch lubrication is undesirable in deep drawing, for example, but the punch must be lubricated for stretch forming. Bench type evaluations of lubricants are only marginally useful. An excellent lubricant for one stamping may turn out to be a poor lubricant for another stamping of different design.

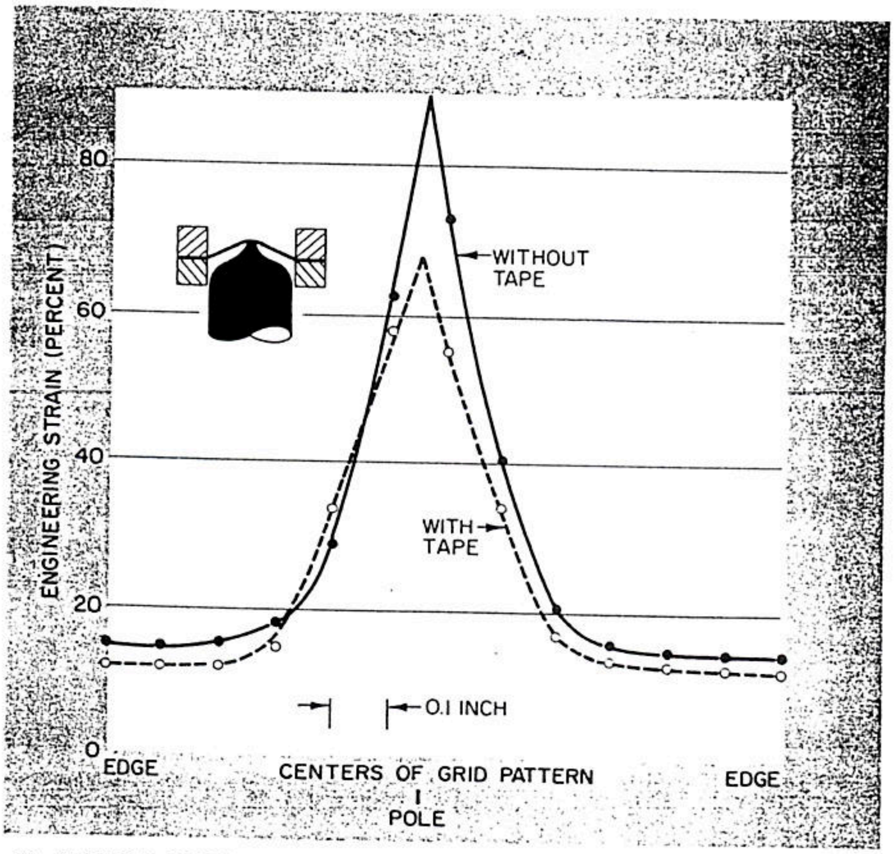
In applying the techniques just described, a circular grid system was used on production blanks. The advantage of this type of test procedure is that all variables—material properties, die design and lubrication, and press parameters—are combined in one production trial.

The circular grid system enables causes of breakage to be discovered quickly, and provides a basis for determining the effects of changing materials, die design, lubrication and other parameters during die tryout and production.

In the automotive and appliance industries, die designers draw on past experience, plus general guidelines, in an attempt to design dies that will form stampings without breakage. When stampings are produced by the



9. GOOD LUBRICATION aids in stretching material over a large-radius punch. Here securely clamped brass disks are stretched over a 4-inch-diameter hemispherical punch, with and without Teflon lubricant. Without lubrication, failure occurred at a depth of 1.40 inches. With lubrication, failure occurred at a depth of 1.85 inches. All measurements are plotted from blank center.

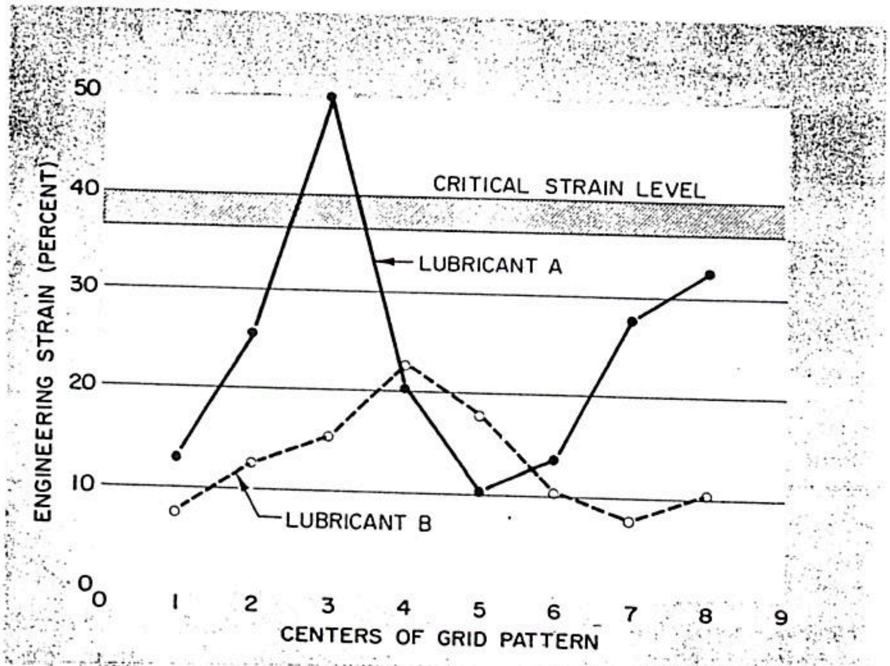


10. SMALL RADIUS LOCALIZES STRAIN. Here the peak strain was reduced by putting emery tape on the punch at the high strain region to restrict metal flow. The strain distributions were determined from an EC marked grid.

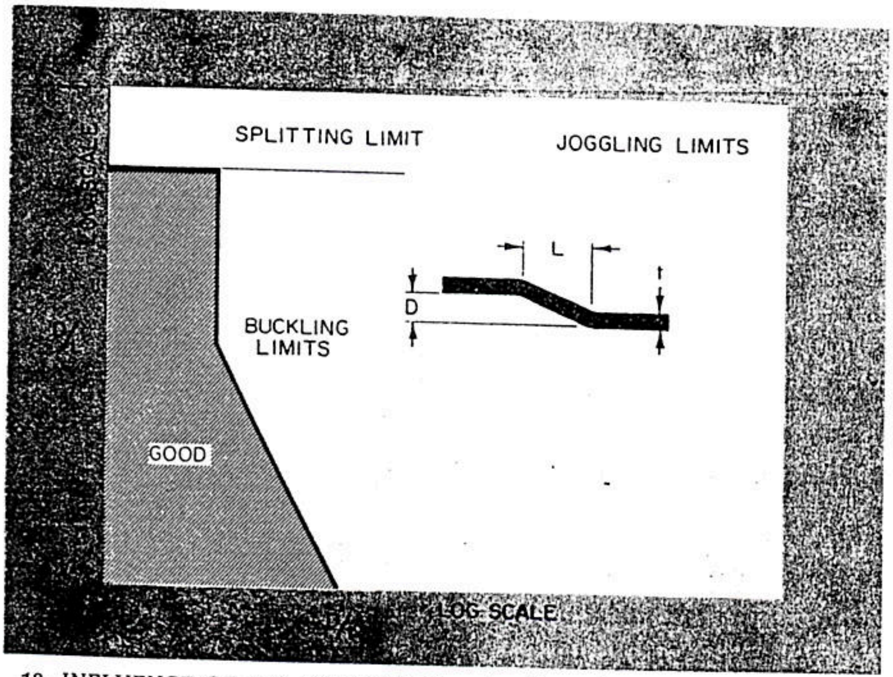
millions—hoods, fenders, quarter panels and other automotive sheet metal components—die tryout and die modification to obtain optimum formability are justified.

In the aerospace industry, production runs are short, materials are sometimes expensive and inherently difficult to form, and there is somewhat greater emphasis on designing parts—and dies—on the basis of known formability parameters.

William W. Wood and his associates at Vought Aeronautics Division of Ling-Temco-Vought Corporation have catalogued a series of design factors for use in designing parts to be formed from certain materials. This group conducted a large number of tests to develop empirical data on the interaction of die design parameters and material properties.



11. TWO DIFFERENT LUBRICANTS were used in forming of an automotive hood panel. Strains were determined from an electrochemically marked grid of 0.2-inch-diameter circles. The critical strain level was predicted from an empirical curve. Although both lubricants were considered "good" the peak strains were different. (From SAE Paper 680093, by Goodwin of Chrysler.)



12. INFLUENCE OF DIE VARIABLES on joggling. The scale of each axis is fixed for a given material on the basis of elongation in an 0.02 inch gage length. Empirical tests were used to develop the forming limits shown. (From Air Force Publication ASD TR 61-191, I and II, by W. W. Wood, et al.)

Types of forming included in the study were deep drawing, spinning, linear and plane stretch forming, stretch and shrink forming of flanges with rubber pads, dimpling, brake bending, drop hammer forming, joggling, Androforming, and tube and dome bulge forming. In the tests, emphasis was placed on structural limits of deformation, such as buckling. Some of the most-used aerospace alloys—magnesium, aluminum, titanium, stainless steel, tool steel, nickel-base and cobalt-base superalloys, and the refractory metals—were covered.

In the resulting design data, elongation over various gage lengths is the property correlated with formability. An example of the design data for one type of forming—joggling—is shown in *Figure* 12. The upper limit is splitting, caused by too much elongation of the angled region. The other limit is buckling. Numerical values along each axis are different for each material, based on a 0.02 inch gage length. Such diagrams were obtained by introducing the measured elongation for a sample of a material—say Inconel X—into empirically developed formulas.

Vought Aeronautics engineers also investigated forming temperatures and speeds—two other variables that affect formability.

All variables, other than the ones indicated in the formulas and the diagram, are chosen in the standard ranges that optimize the forming operation. If, for example, a 1/2 inch jog radius is standard in the aerospace industry, then the data are valid only for this radius.

The Vought Aeronautics system provides good preliminary data for the designer but it does not always eliminate forming difficulties. The circular grid system is more universally applicable and does provide information that can be used to minimize breakage of critical stampings.

This article will conclude with Part 6, to appear in the July issue of *Machinery*. The application of the circular grid system to specific stampings will be covered. ▲▲