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(54) **Method of reducing cycle time for metal forming**

(57) A method for reducing the part-to-part cycle time of quick plastic forming and superplastic forming of a metallic sheet alloy into an automotive sheet metal component by locally modifying a die surface (18) to control friction which militates against undesirable necking and thinning.

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Description

FIELD OF THE INVENTION

[0001] The invention relates to a method of reducing the cycle time for metal forming and more particularly to a method of reducing the part-to-part cycle time of quick plastic forming and superplastic forming of a metallic sheet alloy into an automotive sheet metal component by locally modifying a die surface to control friction.

BACKGROUND OF THE INVENTION

[0002] Typically, an automobile sheet metal component is made by stamping or shaping a low carbon steel or an aluminum alloy sheet stock into a desired shape. Automobile sheet metal components are formed and welded or otherwise joined to form vehicle body or closure panels. It is a goal to make the panels from as few parts as possible in order to minimize manufacturing cost and the overall weight of the vehicle. It is another goal to make the sheet metal components as quickly as possible to minimize manufacturing cost. In order to accomplish these goals, there is an incentive to devise more formable metal alloys and better forming processes so that fewer automobile body panels having a more complex shape can be made and joined to form either the vehicle body or closure panels rather than welding or bolting together a myriad of smaller, simpler pieces.

[0003] Lubrication is a critical aspect of the forming process. Typically, a lubricant with a low coefficient of friction is selected to enhance material flow in a die. By minimizing friction, sticking between a blank and the die is likewise minimized, and part removal without distortion is facilitated.

[0004] Superplasticity is the capability of a material to develop unusually high tensile elongation with a reduced tendency toward local necking during deformation at elevated temperatures. Necking is a defect that results from excessive local thinning during forming and can ultimately lead to failure during or after forming. Alloys which exhibit superplasticity are capable of being subjected to superplastic forming, wherein portions of a preform are expanded by the application of fluid pressure against the surface of a forming member. The forming member is usually in the form of a die which produces structures of predetermined shapes. The expansion of the preform occurs through an increase in the surface area of the preform produced by an elongation in the length and a reduction in thickness of individual material elements.

[0005] The above process is typically called superplastic forming or SPF. Recent advances have resulted in a mixed-mode deformation process termed quick plastic forming or QPF.

[0006] In superplastic forming and quick plastic forming operations, the preform is clamped firmly at its periphery, thus ideally allowing for material to be stretched

from the area inside of the clamped periphery only. Thinning of a preform as a result of stretching is highly uniform except in areas coming in contact with the forming surface. A unique area that comes in early contact with the forming surface is the forming member cavity entrance radius area, i.e., the intermediate region between the peripheral portion of the preform and the part expanding into the cavity. As the preform drapes over the radius area there is a tendency to increase the local rate of material elongation at sharp features which, in turn, may produce localized thinning or necking in this area. The necking can ultimately lead to splits or tears during subsequent forming. If the forming cycle is too aggressive at a given temperature, the blank will neck and/or split just below the entry radius. Necking makes it difficult to obtain uniform thickness profiles in the structure and can lead to failure during forming. To reduce necking, and obtain uniform thickness profiles, a release coating which is capable of producing a high coefficient of friction has been used. The use of the release coatings in specific areas results in an increase in the frictional force and a lower net force causing material expansion, and, in turn, reduced necking at the radius area. The alternative to preventing necking is to form components at very slow cycle times, which is prohibitive for high volume production.

[0007] While conventional thinking in metal forming has been that increasing the amount of lubricant enhances forming, it has been shown that in specific cases, using lubricants having different coefficients of friction actually improves formability. Varying lubricant types across a blank may be plausible for low volume applications. However, such a method is difficult to use in high volume automobile production. In addition, forming lubricants are costly and can lead to surface blemishes on automobile outer body components.

[0008] It would be desirable to produce an automobile sheet metal component using a superplastic for quick plastic forming process where forming time, necking, excessive thinning, and splitting are minimized by locally modifying a die surface to control friction.

SUMMARY OF THE INVENTION

[0009] Consistent and consonant with the present invention, a method of producing an automobile sheet metal component where forming time, necking, thinning, and splitting are minimized by locally modifying a die surface to control friction has surprisingly been discovered.

[0010] The method of producing an automobile sheet metal component comprises the steps of:

- providing a metal blank;
- providing a metal forming die having a die surface to effect forming of the metal blank thereon, the die surface having at least one coefficient of friction; and

forming the metal structure by applying pressure to the metal blank with the metal forming die;
forming the metal structure at an elevated temperature using one of a superplastic forming and a quick plastic forming process;

wherein at least a portion of the die surface is modified to change the at least one coefficient of friction thereon to minimize a cycle time for the forming and militate against at least one of necking, localized thinning, and splitting of the metal blank during the forming.

DESCRIPTION OF THE DRAWINGS

[0011] The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

[0012] Fig. 1 is a top view of a panel formed by a die in accordance with the method of the present invention;

[0013] Fig. 2 a sectional view of the panel illustrated in Fig. 1 taken along line 2-2;

[0014] Fig. 3 is a table showing pressure-time cycle data for blanks having various friction characteristics obtained during experimentation to arrive at the method of the present invention;

[0015] Fig. 4 is a table showing pressure-time cycle data for die surfaces having various friction characteristics obtained during experimentation to arrive at the method of the present invention;

[0016] Fig. 5 is a graphical representation of the effect of die lubricant on a license plate pocket panel wall thickness distribution;

[0017] Fig. 6 is a graphical representation of the effect of die lubricant on a license plate pocket panel wall thickness distribution shown in Fig. 5, compared with a graphical representation of the effect of die lubricant on a license plate pocket panel wall thickness where a die has a higher coefficient of friction at a die entry radius;

[0018] Fig. 7 is a partial cross-sectional view of the panel of Figs. 1 and 2 showing a die having a surface thereof modified to control the die friction; and

[0019] Fig. 8 is a partial cross-sectional view of the panel of Figs. 1 and 2 showing a die having a metal insert to control the die friction.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0020] Referring now to the drawings, and particularly Fig. 1, there is shown generally at 10 a license plate pocket panel formed by a die in accordance with the method of the present invention. The license plate pocket panel 10 was used in the development of the present invention since there exists therein a very aggressive die entry radius 12. A cross-section of the license plate pocket panel 10 is illustrated in Fig. 2. All testing was performed on a 1.2 mm thick aluminum alloy 5083-H18

such as that produced by Pechiney Rolled Products, Ravenswood, WV. Three lubricants were also used in the testing, a Boron Nitride (BN) lubricant sold under the trademark LUBRICOAT, Milk of Magnesia or $Mg(OH)_2$, and a lubricant sold under the trademark SEALMET. The BN lubricant and the SEALMET lubricant were supplied by ZYP coatings, Oak Ridge, TN. The SEALMET lubricant contained an unspecified mixture of metal oxides. The BN lubricant was provided in two forms: (a) as an aerosol spray which contained 97% hexagonal BN and 3% magnesium silicate with an alcohol/acetone carrier; and (b) as a paint which consisted of a suspension of hexagonal BN (25 wt%) and Al_2O_3 (4 wt%) in a water carrier. The Milk of Magnesia consisted of an aqueous suspension of $Mg(OH)_2$ at a concentration of 80 mg of $Mg(OH)_2$ per ml of water. Forming was conducted on an up-acting, 320 ton hydraulic press designed for superplastic forming.

[0021] Two types of experiments were performed. The first type involved forming lubricated blanks in a bare or uncoated die to show the effect on cycle time by varying lubricity. The blanks were lubricated with one of two lubricants: (1) BN LUBRICOAT lubricant or (2) Milk of Magnesia. The license plate pocket panel 10 was formed with the two different lubricant conditions at incrementally faster cycle times ranging from 6 minutes down to 13 seconds, to determine when necking and splitting occurred. The difference in cycle time was produced by changing the pressurization rate of the forming operation, as well as by increasing the dwelling time at the peak pressure. For the sake of clarity, results are compared using cycle time, but could also be easily compared using pressurization rate. All blanks were formed at a temperature of 450 degrees Celsius with a 5 minute preheat to ensure proper blank temperature. The pressure-time cycles for each trial using the BN LUBRICOAT lubricant or Milk of Magnesia are shown in Fig. 3. After forming, each of the license plate pocket panels 10 was evaluated for necks or splits at or near the die entry radius 12.

[0022] The second type of experiment consisted of forming bare or unlubricated blanks in a selectively lubricated die to show the effects on necking and splitting by varying die surface friction. The friction condition was varied across the die by one of two methods. The first method, called Pattern 1, involved spraying lubricants with extremely different lubricity on the two halves of the die. This was accomplished by masking one half of the die with tape and spraying a thick layer (approx. 0.001") of BN LUBRICOAT lubricant on the die using the BN lubricant spray. The surface was burnished by rubbing with wax paper to create a very slippery surface. The second half of the die was then sprayed with the SEALMET coating without any subsequent polishing or burnishing. This provided a very rough surface with high friction. The second method for varying friction in the die, called Patterns 2, 3, 4, and 5, involved masking off selected regions of the die and then spraying with the

BN lubricant aerosol spray. The die surface was then burnished as described previously. After burnishing, the tape was removed leaving areas of bare tool surrounded by highly lubricious BN lubricant. The license plate pocket panel 10 was formed under similar conditions to the previously described lubricated blank trials to determine the onset of necking and splitting. The pressure-time cycles for each trial are shown in Fig. 4.

Bare Die Trials

[0023] Blanks lubricated with either BN lubricant or Milk of Magnesia were formed in an unlubricated license plate pocket die at successively faster pressurization rates (i. e. faster cycle times) until necking or splitting occurred. The goal of these trials was to establish the effect of lubricity on cycle time. BN lubricant and Milk of Magnesia have been previously shown to exhibit different lubricity during elevated temperature friction testing, with BN lubricant giving a significantly lower coefficient of friction. **[0024]** Referring now to Fig. 3, blanks coated with Milk of Magnesia could be formed using cycles as fast as 13 seconds without evidence of necking or splitting. However, the license plate pocket panels 10 formed using the BN lubricant coated blanks exhibited necking, at cycles of 4 minutes or less, and splitting at cycles of 2 minutes or less. Thus, the "poorer" lubricant, Milk of Magnesia, actually produced a lower cycle time than the "better" lubricant, BN. These results clearly demonstrate that frictional modifications can significantly affect cycle time. It should be noted, however, that the forming of parts with a poor lubricant often leads to sticking during part release, which affects the dimensional accuracy of the part. In addition, a poor lubricant can also cause formability problems in very deep sections, as the material will be unable to flow into the critical feature areas without splitting.

Lubricated Die Trials

[0025] The goal of the second set of experiments was to determine whether locally tailored coefficients of friction on the surface of the die could produce the same cycle time reductions that were observed for blanks lubricated with BN lubricant and Milk of Magnesia. Four different lubricant test patterns were produced. Each test pattern will be described below, followed by the forming results for experiments using the described pattern. The pressure-time cycles and trial results are summarized in Fig. 4.

Pattern 1

[0026] Pattern 1 was made by coating one-half of the die with the lubricious BN lubricant and the other half with the non-lubricious SEALMET lubricant. The purpose for testing this first pattern was to determine whether drastically different friction conditions in only a portion

of the die produced the same effect as when the entire die or blank consisted of the same frictional condition. The license plate pocket panels 10 were formed using different pressurization rates to determine the onset of necking and splitting.

[0027] For cycle times greater than 4 minutes, no significant difference in necking behavior was observed between the two sides of the die. Both halves of the die successfully formed without necking. For cycle times between 2 and 4 minutes, necking at the die entry radius 12 was observed on the side of the license plate pocket panel 10 that was provided with the "good" lubricant (BN). The SEALMET lubricant side of the die showed no evidence of necking. The difference in friction or roughness between the two coatings is demonstrated by examining the differences on the die side of the formed license plate pocket panels 10. The BN lubricant side of the license plate pocket panel 10 was very clean with no evidence of galling or scratching, indicating low friction. The SEALMET lubricant side of the license plate pocket panel 10 showed evidence of galling marks, scratches, and other blemishes indicating significant interaction between the tool and the blank during forming.

[0028] For cycle times at or below 2 minutes, splitting occurred, but only on the side of the license plate pocket panel 10 which was formed in the BN lubricant side of the die. These results indicate that the presence of BN lubricant on half of the tool controlled the ability to form the part. Necking and splitting were observed at similar cycle times to the tests with BN lubricant coated blanks in the bare die trial section above.

[0029] The thickness profile for each "side" of a license plate pocket panel 10 formed in 4 minutes was also measured, as shown in Fig. 5. The side of the license plate pocket panel 10 formed with the SEALMET lubricant coating showed more overall variation in thickness than the side of the license plate pocket panel 10 formed with BN lubricant. The die entry radius 12 regions were thicker on the SEALMET lubricant side of the license plate pocket panel 10, but the bottom corners were thinner. The BN lubricant side showed a more uniform thickness across the entire bottom of the license plate pocket panel 10. The thickness profile indicates that while the SEALMET lubricant side of the license plate pocket panel 10 did not exhibit necking, it exhibits higher strain values at the bottom of the pocket and a less uniform strain distribution than the BN lubricant side of the panel 10. This would become an increased issue of concern if the depth of the license plate pocket panel 10 were increased.

Pattern 2

[0030] Pattern 2 was produce by masking off specific regions of the die to produce unlubricated areas, while the remainder of the die was coated with BN lubricant. The goal of evaluating Pattern 2 was to determine whether locally increasing friction in the vicinity of the

die entry radius 12 could prevent necking and to determine the optimal location for increasing friction. Regions were masked off either slightly above the die entry radius 12 on a plateau 14, on the die entry radius 12, or slightly below the die entry radius 12 on a wall 16, as illustrated in Fig. 1. Some of the die entry radius 12 regions were not masked off for comparison. The trials were performed at a temperature of 510 degrees Celsius to help exaggerate the necking phenomena. The gas pressure time cycles for these trials are summarized in Fig. 4.

[0031] Initial trials were conducted using a seven-minute cycle time with pressurization rates of either 90 psi/min or 30 psi/min. In both trials, the license plate pocket panels 10 split catastrophically in the areas where there was full BN lubricant coverage. A subsequent trial was performed at a slower cycle of 12 minutes with a pressurization rate of 15 psi/min. In that trial, the license plate pocket panel 10 split at the die entry radius 12 along the entire side, except the region where the die entry radius 12 was void of BN lubricant. The split occurred right up to the point where the lubricant was removed from the die, at which point it arrested. The split traveled into the region where the lubricant was removed from the plateau 14. Some slight necking was observed at the die entry radius 12. No necking was observed in the region where the die entry radius 12 was void of lubricant. However, removing the lubricant either above or below the die entry radius 12 did not prevent necking, indicating that the best pattern for minimizing necking is to remove the lubricant from the region right at the die entry radius 12.

Pattern 3

[0032] The results from lubricant Pattern 2 indicated that locally increasing friction at the die entry radius 12 could prevent necking. To evaluate this, a third pattern was studied where the die entry radius 12 on half of the die did not have lubricant while the other half of the die was completely coated with BN lubricant. Blanks were formed using three different ramp rates. 200 psi/min, 100 psi/min, and 25 psi/min at a temperature of 450 degrees Celsius. In all three cases, the license plate pocket panels 10 split during forming on the side of the die where the lubricant was present on the die entry radius 12. No splitting or necking was observed on the side of the die where the lubricant was removed from the die entry radius 12. In fact, the split that initiated on the side of the die where the die entry radius 12 was lubricated did not spread into the region of the die where the die entry radius 12 was bare. The gas pressure time cycles for these trials are summarized in Fig. 4.

Pattern 4

[0033] The success in preventing necking demonstrated by locally removing the lubricant at the die entry

radius 12 led to testing of a fourth pattern to see whether the locally tailored friction could produce an improvement in cycle time. The die entry radius 12 along both sides of the die was masked off to eliminate lubricant. Bare blanks were formed at an aggressive ramp rate of 400 psi/min. During testing for Pattern 4, it was discovered that the region of the unlubricated die entry radius 12 did not extend far enough along the side of the die. The license plate pocket panels 10 split along the edge in the area where the die entry radius 12 was lubricated. None of the other regions showed evidence of necking. While this test was unsuccessful in reducing cycle time, it clearly demonstrated the effect of friction at the die entry radius 12 on necking and splitting. The gas pressure time cycles for these trials are summarized in Fig. 4.

Pattern 5

[0034] Pattern 5 involved removing lubrication from the die entry radius 12 portion of the entire die. Blanks were formed at a temperature of 450 degrees Celsius using pressurization rates from 400 to 2000 psi/min. No splitting or necking at the die entry radius 12 was observed in any of the trials for Pattern 5. The fastest cycle time was 23 seconds.

[0035] The thickness distribution in the license plate pocket panel 10 formed using a cycle of 2.5 minutes with pattern 5 is shown in Fig. 6. The license plate pocket panel 10 formed with the tailored BN lubricant die coating showed a more gradual change in thickness across the bottom of the license plate pocket panel 10 than the license plate pocket panel 10 shown previously with the SEALMET lubricant coating illustrated in Fig. 5. This clearly demonstrates that the use of dies having tailored friction areas can significantly reduce cycle time while also preventing localized splitting and necking. The gas pressure time cycles for these trials are summarized in Fig. 4.

[0036] The testing described above demonstrates that metal forming cycle time can be significantly reduced by locally modifying the friction characteristics of a die, i.e. the coefficient of friction. In addition to cycle time reduction, local control of friction characteristics in metal forming tools has other benefits including: control of as-formed panel thickness distribution; the prevention of localized thinning; part release is facilitated, thereby improving the dimensional accuracy of parts; and improved surface quality of formed parts by minimizing lubricant buildup on die entry radii.

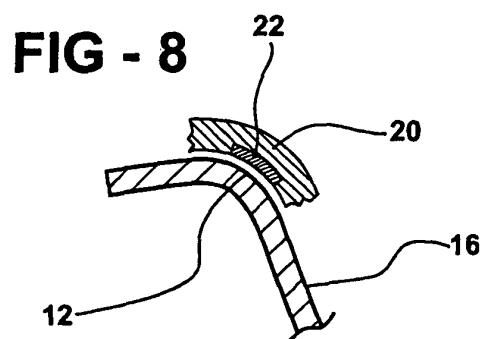
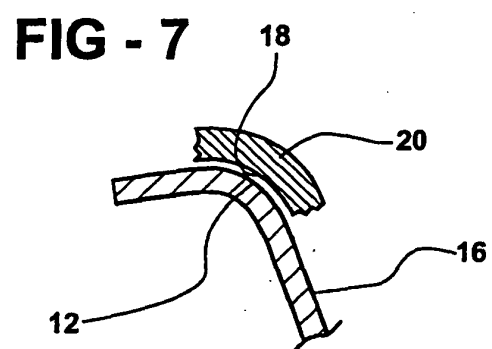
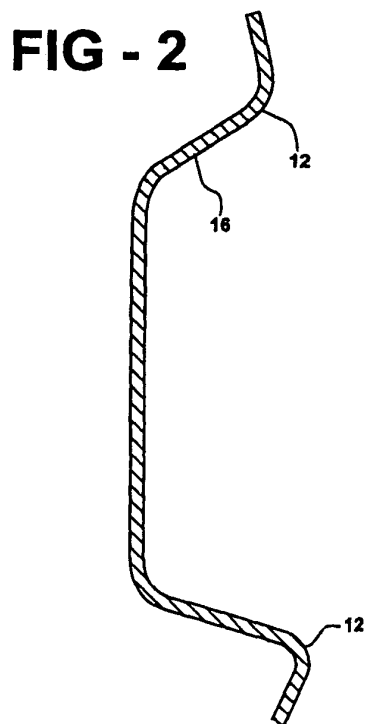
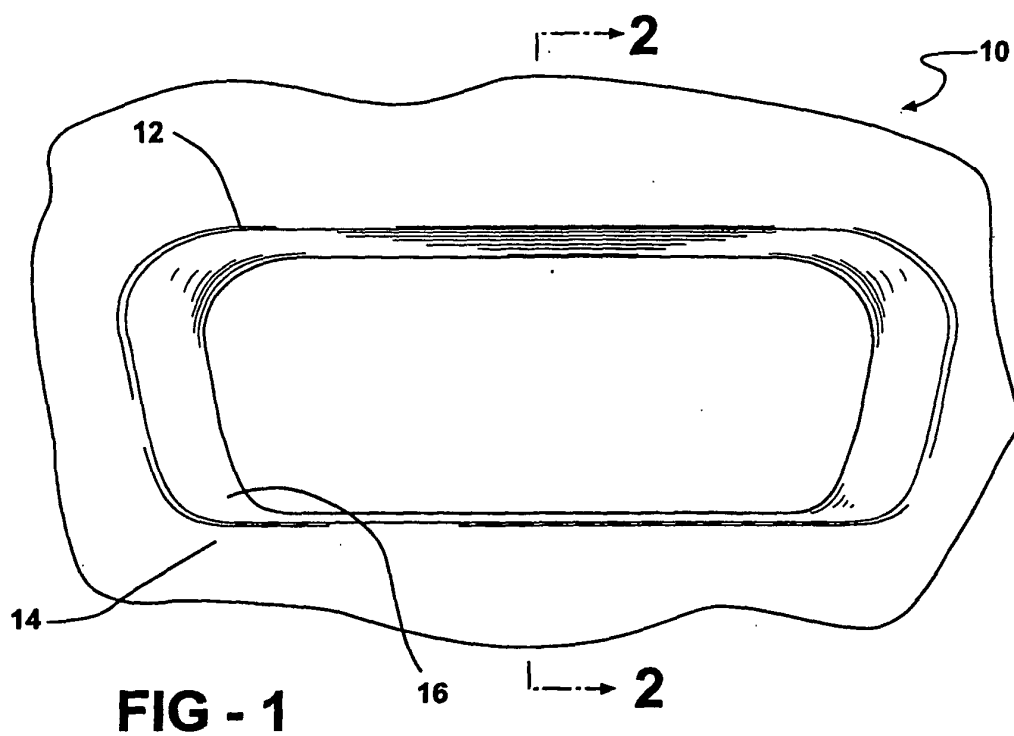
[0037] Tailoring the friction characteristics of a die by surface modification has proven to be a critical enabler for cycle time reduction. While the methods used in the present study were excellent for characterizing the phenomenon, they are not practical for high speed production. The lubricant sprayed on the tooling was almost completely removed after only forming a few of the license plate pocket panels 10 and would require reapp-

plication. It is also difficult and time consuming to apply the spray coating uniformly to create a smooth surface that would be acceptable for an exterior body panel. Thus the method of the present invention for directly modifying the die to control friction solves this problem. Thus, referring to Fig. 7, by directly modifying a surface 18 of a die 20 to control die friction, production can proceed without lengthy interruptions for lubricant application and the like. Methods for modifying the surface 18 of the die 20 may include chemical etching, laser surface dimpling, scribing, sand blasting, laser particle injection, laser ablation, local oxidation, and combinations thereof, for example. Referring to Fig. 8, a dissimilar metal insert 22 can also be used to control friction as desired for the die 20. It is understood that other methods of controlling die friction can be used without departing from the scope and spirit of the invention.

[0038] From the foregoing description, one ordinarily skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications to the invention to adapt it to various usages and conditions.

Claims

1. A method for tailoring friction characteristics of a die to minimize a cycle time for metal forming, the method comprising the steps of:
 - providing a metal forming die having a die surface to effect metal forming of a structure thereon, the die surface having at least one coefficient of friction; and
 - modifying a portion of the die surface to change the at least one coefficient of friction on the portion of the die surface.
2. The method according to claim 1 wherein the die surface is modified by chemical etching.
3. The method according to claim 1 wherein the die surface is modified by laser surface dimpling.
4. The method according to claim 1 wherein the die surface is modified by scribing.
5. The method according to claim 1 wherein the die surface is modified by sand blasting.
6. The method according to claim 1 wherein the die surface is modified by laser particle injection.
7. The method according to claim 1 wherein the die surface is modified by inserting dissimilar metal inserts therein.
8. The method according to claim 1 wherein the die surface is modified by laser ablation.
9. The method according to claim 1 wherein the die surface is modified by local oxidation.
10. The method according to claim 1 wherein the metal provided is at least one of aluminum, magnesium, titanium, and stainless steel.
11. A method of making a structure by metal forming, the method comprising the steps of:
 - providing a metal blank;
 - providing a metal forming die having a die surface to effect forming of the metal blank thereon, the die surface having at least one coefficient of friction; and
 - forming the metal structure by applying pressure to the metal blank with the metal forming die;
 wherein a portion of the die surface is modified to change the at least one coefficient of friction on the portion of the die surface to minimize a cycle time for said forming and mitigate against at least one of necking, localized thinning, and splitting of the metal blank during said forming.
12. The method according to claim 11 wherein the die surface is modified by chemical etching.
13. The method according to claim 11 wherein the die surface is modified by laser surface dimpling.
14. The method according to claim 11 wherein the die surface is modified by scribing.
15. The method according to claim 11 wherein the die surface is modified by sand blasting.
16. The method according to claim 11 wherein the die surface is modified by laser particle injection.
17. The method according to claim 11 wherein the die surface is modified by inserting dissimilar metal inserts therein.
18. The method according to claim 11 wherein the die surface is modified by laser ablation.
19. The method according to claim 11 wherein the die surface is modified by local oxidation.



Lubricant	Ramp Rate (psi/min)	Final Pressure (psi)	Dwell Time (min)	Total Cycle Time (min)	Result
BN	30	90	3.0	6.0	OK
BN	45	90	3.0	5.0	OK
BN	90	90	3.0	4.0	Necking at entry radius
BN	150	90	2.0	2.6	Necking at entry radius
BN	200	200	1.0	2.0	Split at entry radius
BN	1000	200	1.0	1.2	Split at entry radius
BN	2000	200	0.3	0.4	Large tear at radius
Milk of Magnesia	90	90	3.0	4.0	OK
Milk of Magnesia	150	90	2.0	2.6	OK
Milk of Magnesia	150	150	1.0	2.0	OK
Milk of Magnesia	200	200	1.0	2.0	OK
Milk of Magnesia	400	200	1.0	1.5	OK, not fully formed
Milk of Magnesia	1000	200	1.0	1.2	OK, not fully formed
Milk of Magnesia	1000/20	200	-	0.7	OK, not fully formed
Milk of Magnesia	2000/15	200	-	0.4	OK, not fully formed
Milk of Magnesia	2000/40	200	-	0.2	OK, not fully formed

FIG - 3

Lubricant Pattern #	Ramp Rate (psi/min)	Final Pressure (psi)	Dwell Time (min)	Total Cycle Time (min)	Result
1	30	90	3.0	6.0	OK
1	90	90	3.0	4.0	Neck on BN side
1	200	200	1.0	2.0	Split on BN side
2	90	90	6.0	7.0	Split at BN regions
2	30	90	4.0	7.0	Split at BN regions
2	15	90	6.0	12.0	Split at BN regions
2	10	90	14.0	23.0	Neck at BN regions
3	200	200	2.0	3.0	Split on BN half
3	100	200	2.0	4.0	Split on BN half
3	25	200	2.0	10.0	Split on BN half
4	400	200	2.0	2.5	Split in BN region near edge of part
5	400	200	2.0	2.5	OK
5	2000/15	200	0.0	0.4	OK

FIG - 4

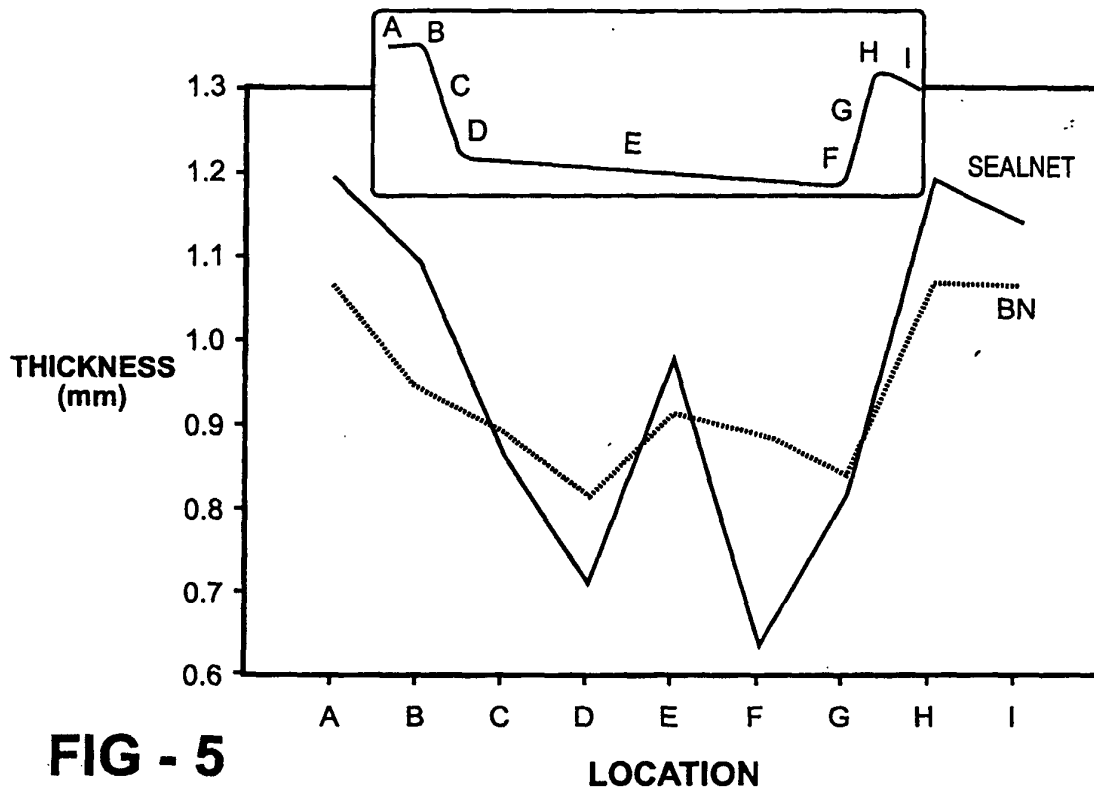


FIG - 5

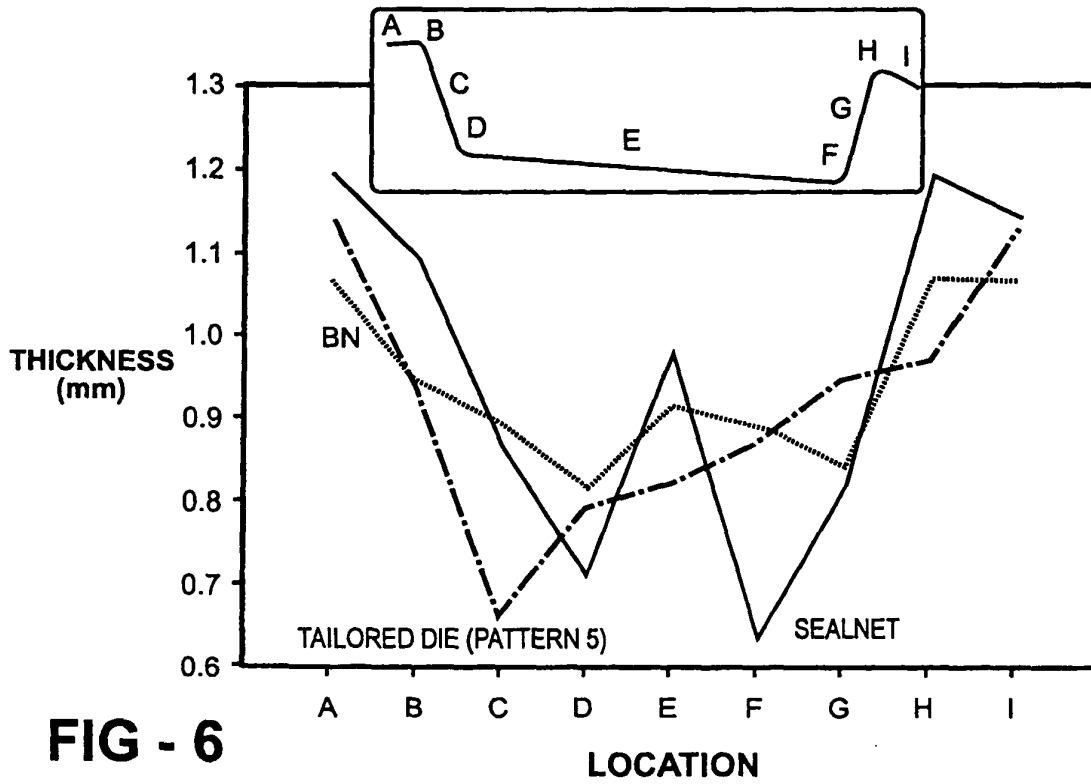


FIG - 6



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EUROPEAN SEARCH REPORT

Application Number
EP 04 00 0131

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The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 4 May 2004	Examiner Vinci, V
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)



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EUROPEAN SEARCH REPORT

Application Number
EP 04 00 0131

DOCUMENTS CONSIDERED TO BE RELEVANT			
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The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 4 May 2004	Examiner Vinci, V
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