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(56) Documents Cited:
DE 102012007213 A1 **DE 102010045025 A1**
US 20130333190 A1 **US 20120090742 A1**

(58) Field of Search:
INT CL **C21D, C22F**
Other: **Online: EPODOC, WPI, TXTE**

(54) Title of the Invention: **A method of forming complex parts from sheet metal alloy**
Abstract Title: **A method of forming a part from precipitation hardenable sheet**

(57) A method of forming a part from precipitation hardenable alloy sheet by solution heat treating the sheet, quenching the heated sheet at a rate sufficient to avoid precipitation to a temperature at which the sheet can be formed into the part and placing the quenched sheet between dies where it is formed. Different areas of the sheet can be quenched to different temperatures, either by applying a solid cooling medium to only a first area of the sheet or by applying a solid cooling medium to a first area at a first pressure and to a second area at a lower pressure or by directing fluid to first and second areas where the fluid is directed to the first area for a longer duration, has a lower temperature and/or has a greater mass flow than fluid directed to the second area. The method can be used to form sheets from 5xxx or 6xxx series aluminium alloys, magnesium alloys and titanium alloys.

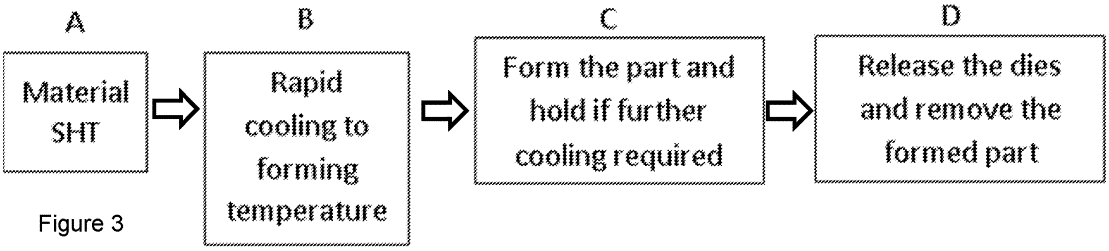

Figure 3

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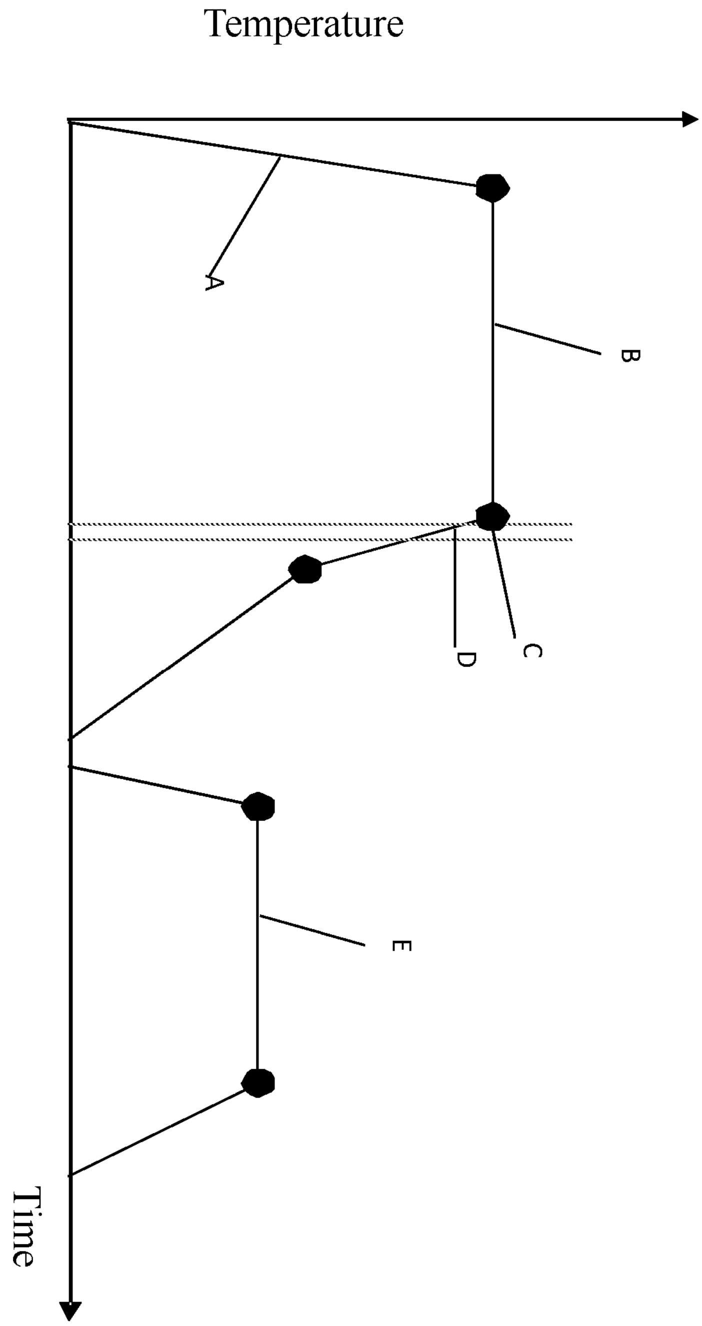

Figure 1

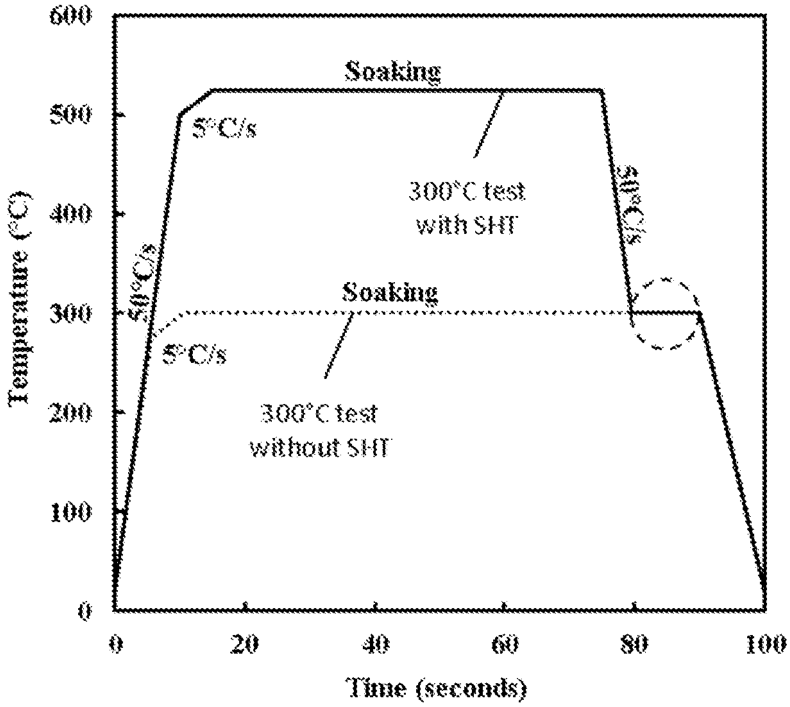

Figure 2(a)

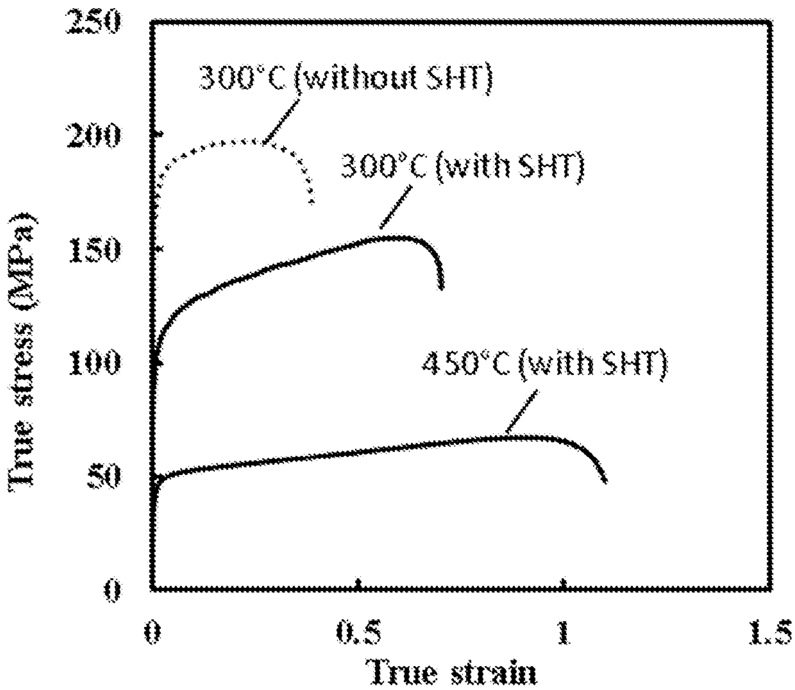

Figure 2(b)

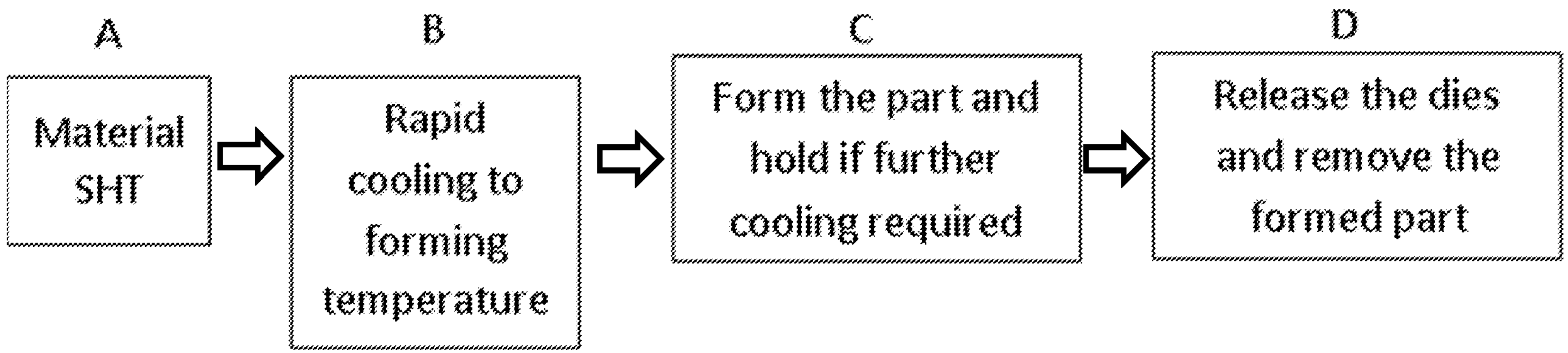
A
Material SHT
B
Rapid cooling to forming temperature
C
Form the part and hold if further cooling required
D
Release the dies and remove the formed part

Figure 3

A METHOD OF FORMING COMPLEX PARTS FROM SHEET METAL ALLOY

FIELD

The present invention relates to the forming of complex parts from sheet metal alloy. In embodiments, it relates to the forming of complex parts from aluminium alloy.

BACKGROUND

It is generally desirable that components used in automotive and aerospace applications be manufactured in as few parts as is compatible with the final use of those components. One method of manufacturing parts which meets this requirement is to form a single sheet of metal into the part using a die set. The complexity of shape of parts which can be formed in this way is, however, limited by the mechanical properties of the sheet metal which is formed in the die set. On the one hand, it may be too brittle; on the other, it may be too ductile. In either case, formability would be limited. The present inventors have discovered that solution heat treating a sheet of metal and then rapidly forming it into a part in a cold die set improves the formability of the metal, allowing more complex-shaped components to be manufactured from a single sheet. Such components therefore no longer need to be formed as a multi-part assembly.

WO 2010/032002 A1 discloses a method of forming aluminium alloy sheet components, using a solution heat treatment, cold die forming and quenching (HFQ) process. The temperature of a sheet of metal alloy as it goes through such a process is shown in Figure 1. Essentially, this existing HFQ process involves the following steps:

(A) preheating a sheet metal workpiece to, or above, the solution heat treatment (SHT) temperature of the metal;

(B) soaking the workpiece at the preheat temperature to enable the material to be fully solution heat treated;

(C) transferring the workpiece to a cold die set and forming quickly at the highest possible temperature and at a high forming speed;

(D) holding the formed part in the cold die set for rapid cooling (cold die quenching) to achieve a super saturated solid solution (SSSS) material microstructure, desirable for post-form strength; and

(E) artificial or natural ageing of the formed part to obtain an improved strength for heat treatable materials.

At stage C, the workpiece is formed at a temperature above the SHT temperature to enable the high ductility of the material to be employed in the forming of the part. At this high temperature, the workpiece is very soft, ductile and easy to deform. While this method therefore has certain advantages over earlier methods, including enabling the forming of parts which are complex in shape (complex parts) with SSSS microstructures desirable for high post-form strength, it also has certain drawbacks. These will now be described.

The workpiece is weak when it is near its SHT temperature. During forming of complex parts, certain areas of the workpiece are constrained by the die, while the others are forced to flow over the die. The flow of material from the areas which are held still in the die to the areas which are being stamped is restricted. This can result in localized thinning and tearing of the workpiece. This is because the forming process benefits less from the effect of strain hardening, which is weaker at higher temperatures particularly in the case of aluminium alloys. Strain hardens the metal so that areas of the workpiece which have been deformed become harder and hence stronger. This increases the ability of these deformed areas to pull other material in the region and draw that material into the die. The drawn in metal is itself strained and thus is hardened. This straining and hardening throughout a sheet inhibits localised thinning and leads to more uniform deformation. The greater the strain hardening is, the greater is the tendency to uniform deformation. With only weak strain-hardening, deformation is localized in areas of high ductility and draw-in is restricted, and so the incidence of localized thinning and failure may therefore increase. This degrades formability. To increase formability and strength in this process, the workpiece is formed in the dies at a very high speed in order to compensate for the weaker strain hardening at high temperatures by maximizing the effect of strain rate hardening.

The requirement for a high temperature to increase ductility and a high forming speed to increase strain hardening and strain rate hardening can lead to the following problems:

(i) A large amount of heat is transferred to the die set from the workpiece. As the forming process requires that the dies remain at a low temperature to achieve the quenching rate required to obtain a SSSS microstructure, they have to be artificially cooled, on the surface or by internal channels (or otherwise). Repeated thermal cycles can lead to quicker degradation and wear of the dies.

(ii) For the mass-production of HFQ formed parts, the requirement that the dies be cooled complicates design, operation and maintenance of the dies, and increases die set cost.

(iii) The holding pressure and time in the die are higher, as the formed part has to be held in between the dies until it is cooled to the desired temperature. This uses more energy than processes with lower forming times and pressures and reduces forming efficiency and thus productivity.

(iv) The high forming speed can cause significant impact loads when the dies are closed during forming. Repeated loading can lead to damage and wear of the dies. It can also necessitate the use of high durability die materials, which increases the die set cost.

(v) Specialized high speed hydraulic presses are required for the process to provide the die closing force. These hydraulic presses are expensive, which limits application of HFQ processes.

It would be desirable to address at least some of these problems with existing HFQ processes.

SUMMARY

According to a first aspect of this invention, there is provided a method of forming a complex part from sheet metal alloy, the method comprising the steps of:

(a) heating the sheet to above the solution heat treatment temperature of the alloy so as to achieve solution heat treatment;

(b) cooling the sheet at at least the critical cooling rate for the alloy; and

(c) placing the sheet between dies to form it into or towards the complex part.

[b]

The method differs from the process described in WO 2010/032002 A1 section in at least that it includes the step (b) of cooling the sheet at at least the critical cooling rate for the alloy, after heating the sheet to above its solution heat treatment (SHT) temperature and before placing the sheet between the dies.

[Rate of Cooling]

The critical cooling rate of step (b) differs according to the alloy. Step (b) may comprise cooling the sheet at at least the rate at which microstructural precipitation in the alloy is avoided. Cooling at or above the critical cooling rate avoids the formation of coarse precipitates at grain boundaries which can reduce the post-form strength. When the sheet metal alloy is an aluminium alloy with a first mass fraction of Mg and Si, step (b) may comprise cooling the sheet at at least 10°C per second. Step (b) may comprise cooling the sheet at at least 20°C per second. When the sheet metal alloy is an aluminium alloy with a high mass fraction of Mg and Si, step (b) may comprise cooling the sheet at at least 50°C per second. When the sheet metal alloy is Aluminium alloy 6082 cooling at at least this rate avoids coarse precipitation in the metal.

[Target Temperature]

The optimum temperature to which the sheet is cooled before step (c) depends on the shape of the part to be formed, the material from which it is formed and the mechanical properties required of the finished part. The sheet may be cooled to the lowest temperature that still allows forming of the part. The sheet may be cooled to the lowest temperature that still allows forming of the part such that it has desirable characteristics. For example, if the sheet is cooled to too low a temperature, springback may occur. The sheet may be cooled to the lowest temperature that allows the part to withstand the maximum strain that it will experience during forming without failure. The sheet may be cooled to between 50°C and 300°C. The sheet may be cooled to between 100°C and 250°C. The sheet may be cooled to between 150°C and 200°C. The sheet may be cooled to between 200°C and 250°C. When the sheet is formed from aluminium alloy AA6082, the sheet may be cooled to between 200°C and 300°C.

[Means of Cooling]

It is envisaged that the cooling of the sheet is by some artificial means, rather than just by ambient, still, air. Step (b) may comprise applying a cooling medium to the sheet. The cooling medium may be a high heat conductivity solid, such as a copper transfer grip or plate. The cooling medium may be a fluid. Step (b) may comprise directing the fluid at the heated sheet. The fluid may be a gas, for example air. The fluid may be a liquid, for example water. The fluid may comprise gas and liquid, for example air and water. The fluid may be directed as a pressurised flow of the fluid. The fluid may be directed as a jet. The fluid may be directed as a mist spray. The fluid may be directed with a duration, temperature and/or mass flow such that the sheet is cooled at at least the critical cooling rate for the alloy. Step (b) may comprise transferring the sheet to a temperature controlled chamber.

[Uniformity or Non-Uniformity of Cooling]

The step (b) of cooling the sheet may comprise cooling the whole sheet to substantially the same temperature. The step (b) of cooling the sheet may comprise selectively cooling at least one area of the sheet to a different temperature than the remainder of the sheet. Step (b) may comprise selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature, to which at least a second area of the sheet is cooled. In other words, the cooling may be non-uniform. In this way, the temperature to which certain areas are cooled may be selected according to the complexity of the die geometry in that area. For example, the first area cooled to the first temperature may be an area of the sheet in which a higher strength is required than in the second area to prevent localised thinning from occurring.

When the cooling is non-uniform and a high heat conductivity solid is applied to the sheet, step (b) may comprise selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature to which at least a second area of the sheet is cooled by applying the high heat conductivity solid with greater pressure to the first area than to the second area. Step (b) may comprise selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature to which at least a second area of the sheet is cooled by applying the high heat conductivity solid to the first area and not to the second area.

When the cooling is non-uniform and a cooling fluid is directed at the heated sheet, the fluid may be directed with a longer duration, lower temperature and/or greater mass flow to the first area of the sheet to cool it to a first temperature which is lower than a second temperature to which at least a second area of the sheet is cooled.

[Effects]

By cooling the sheet at at least the critical cooling rate for the alloy (after heating the sheet to above its SHT temperature and before placing the sheet between the dies) microstructural precipitation in the alloy is avoided, and the sheet is cooler when it is placed in the dies than in a process without the cooling step (b). The sheet can therefore be formed at a lower temperature than in the existing HFQ method described in WO 2010/032002 A1 section. Since the sheet is formed at a lower temperature, its strength will be higher and the strain hardening effect greater, facilitating greater material draw-in. In other words, the strain hardening effect causes the deformation of the sheet to be more uniform, with a deformed area becoming stronger, causing deformation to occur in other areas, which in turn become stronger. This reduces the likelihood of localized thinning, enhancing formability of the sheet. The introduction of the cooling step (b) to the existing HFQ process thus allows the benefits of HFQ forming to be further enhanced while mitigating its drawbacks.

The feature of cooling the sheet at at least the critical cooling rate for the alloy thus increases the strength of the formed part, while maintaining sufficient ductility of the sheet to allow it to be formed.

[a]

[SHT Temperature]

The temperature to which the sheet is heated in step (a) will depend on the alloy and on the application of the finished part. Step (a) may comprise heating the sheet to at least the temperature at which precipitates in the alloy are dissolved. When the sheet metal alloy is Aluminium alloy 6082, step (a) may comprise heating the sheet to between 520°C and 540°C. When the sheet metal alloy is an AA5XXX alloy, step (a) may comprise heating the sheet to between 480°C and 540°C.

[Soaking]

Step (a) may comprise heating the sheet to above its solution heat treatment temperature and maintaining it at this temperature for at least 15 seconds. Step (a) may comprise maintaining the sheet at this temperature for between 15 and 25 seconds. Maintaining the sheet at above its solution heat treatment temperature dissolves alloying elements into the metal matrix.

[Effects]

By solution heat treating the sheet before it is formed, higher ductilities can be attained than in a process without the SHT step.

[c]

In the step (c) of placing the sheet between dies to form it into or towards the complex part, the dies may be cold dies. The dies may be cooled. Thus, the sheet may be further quenched in the dies.

[Effects]

By forming the sheet in cold dies, the problems of warm forming of low cost-effectiveness (due to heating of the sheet and the die set), and of the possibility of microstructure destruction of the workpiece (degrading post-form strength), are avoided.

[Materials]

The sheet may be of an Aluminium alloy. It may be of aluminium alloy 6082. The sheet may be of a Magnesium alloy. It may be of a Titanium alloy. The sheet may be of any alloy which requires solution heat treatment before forming.

[Applications]

The method may be a method of forming parts for automotive applications. The method may be a method of forming parts for aerospace applications. The method may be a method of forming panel parts for aerospace applications. The method may be a method of forming interior structural sheet components, load-bearing parts, or parts adapted to bearing load in static or moving structures.

BRIEF DESCRIPTION OF THE DRAWINGS

Specific embodiments of the invention are described below by way of example only and with reference to the accompanying drawings, in which:

Figure 1 is a graph showing the temperature of a sheet of metal alloy as it goes through an existing HFQ process;

Figure 2(a) shows temperature histories used for uniaxial tensile tests on a sheet of metal alloy at 300°C with and without prior SHT;

Figure 2(b) shows a comparison of the mechanical behaviour of the metal at 300°C with and without prior SHT, to simulate the effect of step (b), in addition to the behaviour of the metal at 450°C with prior SHT, to simulate the conventional HFQ process; and

Figure 3 shows a process diagram for an embodiment of a method of forming a complex part from sheet metal alloy.

SPECIFIC DESCRIPTION OF CERTAIN EXAMPLE EMBODIMENTS

A graph of workpiece temperature against time for the solution heat treatment, cold die forming and quenching (HFQ) method described in WO 2010/032002 A1 is shown in Figure 1. Briefly, this method involves heating a sheet metal workpiece to, or above, its SHT temperature; soaking it at this temperature; transferring it to a cold die set; and rapidly forming it into the part shape. The formed part is then quenched in the dies, and then is artificially or naturally aged. As discussed above, an important consideration in this existing method is that the sheet metal alloy be as close to its SHT temperature as possible when it is formed.

By contrast, the method that will now be described, and which amounts to an embodiment of the present disclosure, includes an additional step of cooling the sheet at at least the critical cooling rate for the alloy, before it is placed in the dies.

With reference now to Figure 3, the method, which is a method of forming a complex part from sheet metal alloy, which in this embodiment is a sheet of AA6082 (the "workpiece"), involves, in overview the following steps: solution heat treating (A) the workpiece; rapidly cooling it (B) to the temperature at which it is to be formed; forming (C) in dies a part from the workpiece, and further quenching it in the dies; and releasing (D) the dies and removing the formed part.

With continued reference to Figure 3, each of these steps is now described in more detail.

Step (A) involves solution heat treatment of the workpiece. The workpiece is heated to above its SHT temperature. In this embodiment, it is heated to 525°C. A furnace is used to heat the workpiece, although in other embodiments other heating stations may conceivably be used. The workpiece is soaked at this temperature to dissolve as much of the alloying elements into the Aluminium matrix as possible. This enables the workpiece to be fully solution heat treated. In this embodiment, the workpiece is soaked for between 15 and 25 seconds. The temperature and time will, however, vary depending on the alloy series.

At step (B), the workpiece is cooled to the temperature at which it is to be formed. In this embodiment, that temperature is 300°C. The mechanical properties of the sheet metal at different temperatures and/or strain rates can be characterized using advanced material testing techniques. Advanced material modelling and finite element (FE) modelling are used to predict the forming limits of the material at specified forming conditions. The most appropriate forming parameters are selected based on the modelling predictions. In some embodiments, FE models of the forming process also help identify the maximum strain levels in a part, and a temperature that enables these strains to be achieved is selected.

In this embodiment, the workpiece is cooled at a cooling station on a production line between the furnace and the dies. At the cooling station, the blank is placed on a surface and cooled by a mist of air and water. Pressurised water is released as a fine spray from an assembly of nozzles. The number of nozzles used is selected according to the rate of cooling required and the size of the component. When cooling of the entirety of a large blank is required at a high rate, then the required number of nozzles is greater than, for example, the number of nozzles required to cool a small blank at a lower rate.

The workpiece is cooled at at least the critical cooling rate for the alloy, that is, at a rate that avoids unwanted formation and growth of precipitates, but maintains high ductility. In this embodiment, a cooling rate of 50°C per second achieves this effect. For other alloys, the critical cooling rate for the alloy will be different.

At step (C), a part is formed from the workpiece in a cold die set. In this embodiment, the part is also held under pressure in the die set to cool it further.

At step (D), the dies are released. Once the part has cooled to a sufficiently low temperature - in this embodiment, it is cooled to about 100°C - it is removed.

The final strength of the component is then enhanced after the forming process by artificial ageing (not shown in Figure 3).

Compared to the existing HFQ process, the advantages of this method may be summarized as follows:

(i) The lower forming temperature results in lower die temperatures and less intensive thermal cycles, increasing die life.

(ii) Less heat is transferred to the dies. In many embodiments, natural convection/conduction is sufficient to cool the workpiece in the dies and the need for die cooling is eliminated. This can simplify die set design and decreases costs. For example, in aerospace applications, parts are typically formed slowly (productivity is low) and so the natural die cooling of the workpiece will be sufficient.

(iii) Holding pressures and times of the formed part in the dies are lower due to the smaller temperature change required, decreasing energy usage and increasing productivity.

(iv) Since the strain hardening effect is greater at lower temperatures, parts can be formed at a lower speed than in the existing HFQ process. Standard mechanical presses can therefore be used for forming.

(v) This lower forming speed can reduce the impact loading on the dies, increasing die life.

(vi) The greater strain hardening effect at lower temperatures can lead to higher drawability of the workpiece in the die and hence improved formability. Combined with the good ductilities achieved after solution heat treating (with true strains to failure (εf) in the range of 30% to 60%; i.e. comparable to that of mild steel), complex-shaped parts may be formed, even at the lower forming temperature.

(vii) In embodiments where the sheet is cooled non-uniformly at step (B), the temperature over different areas of the workpiece can be varied as required to maximize formability and reduce localized thinning.

With reference now to Figures 2(a) and 2(b), a brief discussion will now be made of the effects on the mechanical properties of a workpiece of SHT (step (A)) and of the cooling stage (B).

Uniaxial tensile tests were carried out on Aluminium alloy at 300°C, with and without prior SHT. Figure 2(a) shows the temperature histories used for these tests. The circled region indicates when the specimen was deformed. Figure 2(b) shows the results of the uniaxial tensile tests on the alloy with the test conditions shown in Figure 2(a). It therefore shows a comparison of the mechanical behaviour of the alloy with and without SHT. It also shows the results of tests on the alloy at 450°C with prior SHT (the conventional HFQ process).

The deformation behaviour of the material tested to failure at different temperatures was compared to the deformation of the material when tested after rapid cooling from the SHT temperature to the same temperatures. This would reveal the benefits of prior SHT to the mechanical properties. Tests were conducted at a strain rate of 1/s, with the rolling direction parallel to the loading direction. Also compared are the results for a test conducted at HFQ conditions, assuming that after solution heat treating (at the SHT temperature) and transferring to the cold die set, the workpiece temperature before deformation is 450°C. This would reveal the benefits of introducing the cooling step to the conventional HFQ process.

It can be seen from Figure 2 (b) that the ductility of a workpiece with prior SHT is enhanced compared to when there is no prior SHT. It reaches a sufficient level for the forming of complex features. Deformation at 300°C with prior SHT increased the ductility by approximately 80%. When compared to HFQ conditions, strain hardening was enhanced. By assuming a power law representation of the data, it was found that the strain-hardening exponent (n-value) increased from 0.04 to 0.12. It can also be seen that the flow stress is much higher compared to HFQ conditions. The tensile strength under deformation at 300°C is over two times greater than that achieved at HFQ conditions. It can therefore be seen that the cooling step enhances strain hardening and strength, while sufficient ductility is maintained for the forming of complex-shaped parts, hence improving the sheet metal formability. As can also be seen from the results shown in Figure 2(b), from the comparison of the flow stress curves of 300°C with SHT and 450°C with SHT, the strain hardening effect is more pronounced at 300°C. Therefore, if a part is formed at 300°C, the thickness distribution in the part will be more uniform than for a part formed at 450°C.

With reference once more to Figure 3, in alternative embodiments, the cooling step (B) is carried out differently to the manner described above. In other respects, the process may be the same as the process of the first embodiment. These alternative embodiments will now be described.

In one alternative embodiment, the blank is not placed on a surface at a cooling station, but is cooled by a mist of air and water (as described above) while it is held in grips during transfer from the furnace to the dies. In other embodiments, the workpiece continues to be cooled by a mist of air and water once it has been transferred to the dies. This is achieved by nozzles built into the die set which, as described above, release pressurised water as a fine spray. In still other embodiments, the workpiece is only cooled once it has been transferred to the dies. In embodiments in which the workpiece is cooled once it has been transferred to the dies, the air-water mist can be used to cool and clean the dies.

In other embodiments, the workpiece is cooled by a controlled stream of air from an assembly of air blades. In some embodiments, this is performed at a cooling station between the furnace and the dies, at which the workpiece is laid on a surface and cooled by the stream of air. In others, it is cooled while it is being transferred between the furnace and the dies, while it is held in the grips used to transfer it.

The workpiece is, in yet other embodiments, cooled using conductive plates. As with the embodiments in which the workpiece is cooled using a mist of air and water or by air blades, the workpiece can be cooled using conductive plates either at a cooling station on a production line between the furnace and dies, or during transfer between the furnace and dies. In both embodiments, the workpiece is held between conductive plates and uniform pressure is applied until it is cooled to the desired temperature.

In another alternative embodiment, areas of the sheet where a greater strain hardening effect will be required to form the part are cooled to a lower temperature than the rest of the sheet ("non-uniform cooling"). Which areas are selectively cooled is determined by the geometry of the part to be formed from the sheet. For example, the temperature of an area of the sheet which is to be formed to have small features, which require significant material stretching, will be selected to be slightly lower than the temperature of other areas on the sheet, so that during forming, material draw-in can take place to reduce localized thinning.

In this, “non-uniform cooling”, embodiment, the workpiece is cooled by conductive cooling. The workpiece is held between conductive plates to cool it. Cooling to different temperatures on different areas of the sheet is achieved by increasing the pressure of a conductive plate on the sheet in areas where the sheet is to be cooled to a lower temperature, or by applying the conductive plate only to those areas of the sheet which are to be cooled to a lower temperature. In this embodiment, the workpiece is placed in a cooling station on a production line between the furnace and dies. In other embodiments, it is cooled while it is still held in grips during transfer between the furnace and dies.

In a similar manner to the uniform cooling of the workpiece using a mist of air and water, described above, nozzles releasing pressurised water as a spray are used, in an alternative embodiment, to achieve non-uniform cooling. In this alternative embodiment, streams of air and water mist are directed, using the nozzles, at the areas which are to be cooled to a lower temperature. This cools those areas of the sheet to a lower temperature than areas of the sheet at which the nozzles are not directing air and water mist.

CLAIMS

1. A method of forming a complex part from sheet metal alloy, the method comprising the steps of:

(a) heating the sheet to above the solution heat treatment temperature of the alloy so as to achieve solution heat treatment;

(b) cooling the sheet at at least the critical cooling rate for the alloy; and

(c) placing the sheet between dies to form it into or towards the complex part.

2. The method of claim 1, wherein step (b) comprises cooling the sheet at at least the rate at which microstructural precipitation in the alloy is avoided.

3. The method of claim 1 or claim 2, wherein the sheet is cooled to the lowest temperature that still allows forming of the part.

4. The method of any preceding claim, wherein step (b) comprises applying a cooling medium to the sheet.

5. The method of claim 4, wherein the cooling medium is a high heat conductivity solid.

6. The method of claim 4, wherein the cooling medium is a fluid.

7. The method of any preceding claim, wherein step (b) comprises selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature, to which at least a second area of the sheet is cooled.

8. The method of claim 7 when dependent on claim 5, wherein step (b) comprises selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature to which at least a second area of the sheet is cooled by applying the high heat conductivity solid with greater pressure to the first area than to the second area.

9. The method of claim 7 when dependent on claim 4, or of claim 8, wherein step (b) comprises selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature to which at least a second area of the sheet is cooled by applying the high heat conductivity solid to the first area and not to the second area.

10. The method of claim 7 when dependent on claim 6, wherein step (b) comprises selectively cooling at least a first area of the sheet to a first temperature which is lower than a second temperature to which at least a second area of the sheet is cooled by directing the fluid at the first area of the sheet with a longer duration, lower temperature and/or greater mass flow than at the second area.

11. The method of any preceding claim, wherein step (a) comprises heating the sheet to at least the temperature at which precipitates in the alloy are dissolved.

12. The method of any preceding claim, wherein step (a) comprises heating the sheet to above its solution heat treatment temperature and maintaining it at this temperature for at least 15 seconds.

13. The method of any preceding claim, wherein the dies are cold dies.

14. The method of any preceding claim, wherein the sheet is of an Aluminium alloy.

15. The method of claim 9, wherein the sheet is of an AA5XXX Aluminium alloy, and step (a) comprises heating the sheet to between 480°C and 540°C.

Application No:	GB1404650.2	**Examiner:**	Matthew Lawson
Claims searched:	1-15	**Date of search:**	21 October 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-4,6,11-14	US 2012/0090742 A1 (SMEYERS) -) - paragraphs [0013], [0023], [0025], [0042]-[0043], [0045] & [0063].
X	1-4,6,11-15	DE 102012007213 A1 (DAIMLER) - WPI Abstract Accession No. 12-Q55378, paragraph [0019] and figure 2.
X	1-4,6,11,12,14	DE 102010045025 A1 (DAIMLER) WPI Abstract Accession No.11-E74986, paragraphs [0016]-[0020] and the figure.
X	1-15	US 2013/0333190 A1 (MIZUMURA) - the whole document.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

C21D; C22F

The following online and other databases have been used in the preparation of this search report

Online: EPODOC, WPI, TXTE

International Classification:

Subclass	Subgroup	Valid From
C22F	0001/05	01/01/2006
C22F	0001/00	01/01/2006
C22F	0001/047	01/01/2006
C22F	0001/06	01/01/2006
C22F	0001/18	01/01/2006