The invention relates to a method for forming an Al-alloy sheet component comprising:

(i) heating an Al-alloy sheet blank to its Solution Heat Treatment temperature and maintaining that temperature until Solution Heat Treatment is complete,

(ii) rapidly transferring the sheet blank to a set of cold dies so that heat loss from the sheet blank is minimised,

(iii) immediately closing the cold dies to form the sheet blank into a shaped component, and

(iv) holding the formed component in the closed dies during cooling of the formed component. The claimed method will find application for any alloy with a microstructure and mechanical properties that can be usefully modified by solution treatment and age-hardening. These include magnesium, titanium and nickel alloys.
PROCESS FOR FORMING METAL ALLOY SHEET COMPONENTS

The present invention relates to an improved method of forming a metal alloy sheet component and more particularly an Al-alloy sheet component. The method is particularly suitable for the formation of formed components having a complex shape which cannot be formed easily using known techniques.

Age hardening Al-alloy sheet components are normally cold formed either in the T4 condition (solution heat treated and quenched), followed by artificial ageing for higher strength, or in the T6 condition (solution heat treated, quenched and artificially aged). Either condition introduces a number of intrinsic problems, such as springback and low formability which are difficult to solve. Hot stamping can increase formability and reduce springback, but it destroys the desirable microstructure. Post-forming heat treatment (SHT) is thus required to restore the microstructure, but this results in distortion of the formed components during quenching after SHT. These disadvantages are also encountered in forming engineering components using other materials.

In an effort to overcome these disadvantages, various efforts have been undertaken and special processes have been invented to overcome particular problems in forming particular types of components. These are outlined below:

Method 1: Superplastic forming (SPF) of sheet metal components
This is a slow isothermal gas-blow forming process for the production of complex-shaped sheet metal components and is mainly used in the aerospace
industry. Sheet metals with fine grains and the forming tool are heated together. Post-forming heat-treatment (e.g. SHT + Quenching + Ageing for Heat-treatable Al-alloys) is normally required to obtain appropriate microstructure to ensure high strength. Superplastic behaviour of a material can only be observed for specific materials with fine grain size deforming at specified temperature and strain rates. (Lin, J., and Dunne, F. P. E., 2001, Modelling grain growth evolution and necking in superplastic blow-forming, *Int. J. of Mech. Sciences*, Vol. 43, No. 3, pp595-609.)

**Method 2: Creep Age Forming (CAF) of Al-Alloy panels**

Again, this is a slow process commonly used for forming aircraft wing panel parts with the combination of forming and ageing hardening treatment. The creep forming time is determined according to the requirement of artificial ageing for a material. A small amount of plastic deformation is normally applied to the process and springback is a major problem to overcome. Various techniques, such as those described in US 5,168,169, US 5,341,303 and US 5,729,462, have been proposed for designing CAF tools for springback compensation using computers.

**Method 3: Method of treating metal alloys (FR 1 556 887)** was proposed for, preferably, Al-alloys and its application to extrusion of the alloys in the state of a liquid-solid mixture with a view to manufacture profiles. In this method, the proportion of liquid alloy is maintained below 40% for 5 minutes to 4 hours so that the dendritic phase has at least begun to change into globular form. Quenching is performed on the extrudate at the outlet of the die either with pulsated air or by spraying water, a mixture of air and water or mist. The formed parts are then artificially aged at a specified temperature
for age hardening. This technique is difficult to be applied for sheet metal forming, since (i) the sheet becomes too soft to handle at that temperature (liquid alloy is about 40%), and, (ii) the mentioned quenching method is difficult to be applied for the formed sheet parts.

Thus, a need has arisen for a new process/method for forming high strength and complex-shaped Al-alloy sheet components, so that the disadvantages encountered can be overcome.

According to the present invention, there is provided a method of forming an Al-alloy sheet component comprising:-
(i) heating an Al-alloy sheet blank to its Solution Heat Treatment temperature and maintaining that temperature until Solution Heat Treatment is complete,
(ii) rapidly transferring the sheet blank to a set of cold dies so that heat loss from the sheet blank is minimised,
(iii) immediately closing the cold dies to form the sheet blank into a shaped component, and
(iv) holding the formed component in the closed dies during cooling of the formed component.

The claimed method will find application for any alloy with a microstructure and mechanical properties that can be usefully modified by solution treatment and age-hardening. These include magnesium, titanium and nickel. The invention has been described with reference to aluminium since this is where the most commercially feasible applications are likely to be, but the invention is not exclusively concerned with aluminium.
As used herein, the Solution Heat Treatment (SHT) temperature is the temperature at which SHT is carried out (usually within a few degrees of the alloy liquidus temperature). SHT involves dissolving the alloying elements as much as possible within the aluminium matrix.

Subsequent quenching in steps (ii) to (iv) prevents the formation of precipitates (i.e. the alloying components are maintained in supersaturated solution) and also prevents distortion of the formed component.

A typical temperature for the SHT of step (i) is within the range 450 to 600°C and most preferably within the range 500 to 550°C. A typical time for the SHT is from 20 to 60 minutes, for example 30 minutes.

The transfer of step (ii) should be as rapid as possible and in the order of seconds. Less than 5 seconds and preferably less than 3 seconds is recommended.

The preferred rate of cooling of the formed component in the dies is such that the formed component is cooled to below 200°C in less than 10 seconds. Preferably, the dies are maintained at a temperature of no higher than 150°C. Natural heat loss from the dies may be sufficient to maintain them at a sufficiently low temperature. However, additional air or water cooling may be applied if necessary.
The duration of step (iv) will typically be from 3 to 30 seconds, more typically from 5 to 20 seconds and most typically about 8 to 12, e.g. 10, seconds.

The method may comprise an additional artificial ageing step for heat-treatable Al-alloy components comprising heating the formed component to an artificial ageing temperature and holding at that temperature to allow precipitation hardening to occur. Typical temperatures are in the range of 150 to 250°C. Typical ageing times are in the range of 5 to 40 hours.

Heat treatable Al-alloys suitable for use in the process of the invention include those in the 2XXX, 6XXX and 7XXX series. Specific examples include AA6082 and 6111, commonly used for automotive applications and AA7075, which is used for aircraft wing structures.

Non-heat treatable Al-alloys suitable for use in the process of the invention include those in the 5XXX series such as AA 5754, a solution hardening alloy for which the process can offer benefits in increasing its corrosion resistance.

The invention also resides in a formed part obtained by the process of the invention. Such parts may be automotive parts such as door or body panels.

It should be noted that hot-stamping with cold-die quenching is not new per se. Such a process is known for specialist steel sheets. In the process, the steel sheet is heated sufficiently to transform it to a single austenitic phase to achieve higher ductility. On cold-die quenching the austenite is transformed...
to martensite, so that high strength of the formed component is achieved. This process is developed for special types of steels, which have high martensite transformation temperature with a lower cooling rate requirement and is mainly used in forming safety panel components in the automotive industry. (Aranda, L.G., Ravier, P., Chastel, Y., (2003). The 6th Int. ESAFORM Conference on Metal Forming, Salerno, Italy, 28-30, 199-202).

Embodiments of the invention will be further described by way of example only with reference to the accompany drawings in which:-

Figure 1 is a schematic representation of the temperature profile of a component when carrying out the method in accordance with the present invention,

Figure 2 is a schematic representation of a die arrangement for carrying out the method of the present invention, and

Figure 3 is a plot of temperature against time for a component formed using the die arrangement of Figure 2, when formed over 2, 5 or 10 seconds.

The process is outlined schematically in Figure 1. The blank is first heated to its SHT temperature (A) (e.g. 525°C for AA6082) and the material is then held at this temperature for the required time period (e.g. 30 minutes for AA6082) to allow full SHT (B). The SHTed sheet blank is then immediately transferred to the press and placed on the lower die (C). This transfer should be quick enough to ensure minimal heat loss from the aluminium to the surrounding environment (e.g. less than 5 seconds). Once the blank is in place the top die is lowered so as to form the component (D). Once fully formed the component is held between the upper and lower die until the material is fully cooled, allowing the process of cold die quenching to be
completed. Artificial ageing (E) is then carried out to increase the strength of the finished component (i.e. 9 hours at 190°C for AA 6082). The ageing can be combined with a baking process if the subsequent painting of the formed product is required.

Importantly both top and bottom dies are maintained at a temperature low enough for an efficient quench to be achieved. In the above example, the dies were maintained below 150°C. Due to aluminium alloys having a high heat transfer coefficient and low heat capacity, the heat loss from the aluminium into the cold dies and surrounding environment will be great, providing high quenching rates. This allows the supersaturated solid solution state to be maintained in the quenched state.

The key parameter for success of the forming process is a sufficiently high cooling rate in the cold-die quenching, so that the formation and the growth of precipitates can be controlled. Thus, high strength sheet metal parts can be manufactured after artificial ageing. Cold-die quenching is not traditionally practised on precipitation hardening alloys, since water-quenching is normally required to achieve high cooling rates economically, so that the formation of precipitates can be avoided at grain boundaries at this stage of the heat treatment. Since the alloys in question are capable of precipitation hardening, the quenching with cold-die in fact keeps the maximum amount of elements, which are capable of precipitation when aged, in solid solution in order to improve the properties. The effect of cold die quenching (cooling rate) is directly related to the die temperature in operation, Al-alloy sheet thickness and contact conditions (such as forming pressure, clearance surface finish and lubricant). Mechanical tests were
carried out to investigate if the cooling rate using cold die-quenching is sufficient to achieve the mechanical properties of the heat treated materials.

**Test 1 - Quenching between flat tool-steel dies**

In this investigation, 3 cooling methods have been used and the results are compared. Firstly the samples of AA6082 sheet with thickness of 1.5mm were heated to 525°C and kept for 30 minutes for SHT. Then the samples were either (i) water quenched, (ii) quenched between flat cold-steel dies, and, (iii) quenched with air (natural cooling). The samples were then aged at 190°C for 9 hours. Tensile tests were carried out for all the SHTed samples and the results are given in Table 1. The cold-die quenching without pressure applied resulted in an ultimate tensile stress 95% the value obtained by the ideal water quenching.

**Table 1**: strength measurements for different quenching methods

<table>
<thead>
<tr>
<th>Quench Method</th>
<th>Yield Strength</th>
<th>Ultimate Strength</th>
<th>Ductility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma_y$ (MPa)</td>
<td>$\sigma_u$ (MPa)</td>
<td>$\varepsilon$ (%)</td>
</tr>
<tr>
<td>Water Quenched</td>
<td>230</td>
<td>305</td>
<td>0.17</td>
</tr>
<tr>
<td>Cold Die Quenched</td>
<td>200 87</td>
<td>290 95</td>
<td>0.18 106</td>
</tr>
<tr>
<td>Air Quenched</td>
<td>122 53</td>
<td>210 69</td>
<td>0.22 129</td>
</tr>
</tbody>
</table>

**Test 2 - Forming of channel components**

The tool set-up is schematically represented in Fig. 2 and the forming clearance is 0.5mm. The blank 2 (AA6082 - previously SHTed and at 525°C was laid on the lower die 4 and held between the lower die 4 and the upper die (blank holder) 6. The blank was punched into a channel section by the punch 8 and held in the die set for 10 seconds. In this investigation 3 forming periods (i.e. 2, 5 and 10 seconds) were used for forming the same
Al-alloy sheet material and the temperature variation on the sheet component was measured at 3 locations, indicated in Fig. 3. The initial die temperature was 20°C and no artificial cooling of the die was used. Subsequent to forming, the formed parts were aged at 190°C for 9 hours in a furnace. Tensile test pieces were cut from the 3 locations and the test results are shown in Table 2, with comparison against the ideal water quenched material. From Table 2 it can be seen that the maximum strength of the material could be about 98% of water quenched material, superior strength being obtained at the fastest forming speed.

<table>
<thead>
<tr>
<th>Position</th>
<th>Water Quench (WQ) Max Strength</th>
<th>Slow forming (10 s)</th>
<th>Medium forming (5 s)</th>
<th>Fast forming (2 s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max Strength (MPa) % of WQ</td>
<td>Max Strength (MPa) % of WQ</td>
<td>Max Strength (MPa) % of WQ</td>
<td>Max Strength (MPa) % of WQ</td>
</tr>
<tr>
<td>A</td>
<td>315 Mpa 295.2 93.7</td>
<td>296.7 94.2</td>
<td>302.1 95.9</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>315 Mpa 286.0 90.8</td>
<td>285.7 90.7</td>
<td>297.1 94.3</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>315 MPa 280.7 89.1</td>
<td>299.6 95.1</td>
<td>308.4 97.9</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Results for Test 2.

Figure 3 also shows the temperature profile of the three test pieces during forming, for the location C as indicated in the figure.
Claims

1. A method of forming a metal alloy sheet component comprising:
   (i) heating a metal alloy sheet blank to its Solution Heat Treatment temperature and maintaining that temperature until Solution Heat Treatment is complete,
   (ii) rapidly transferring the sheet blank to a set of cold dies so that heat loss from the sheet blank is minimised,
   (iii) immediately closing the cold dies to form the sheet blank into a shaped component, and
   (iv) holding the formed component in the closed dies during cooling of the formed component,
   wherein said metal alloy is selected from aluminium, magnesium, titanium and nickel.

2. A method as claimed in claim 1, wherein the temperature for the SHT of step (i) is within the range 450 to 600°C.

3. A method as claimed in claim 1, wherein the temperature for the SHT of step (i) is within the range 500 to 550°C.

4. A method as claimed in any one of claims 1 to 3, wherein the SHT temperature of step (i) is maintained for 20 to 60 minutes.

5. A method as claimed in any preceding claim, wherein the transfer of step (ii) takes less than 5 seconds.
6. A method as claimed in any preceding claim, wherein during step (iv) the formed component is cooled to below 200°C in less than 10 seconds.

7. A method as claimed in any preceding claim, wherein the dies are maintained at a temperature of no higher than 150°C.

8. A method as claimed in any preceding claim, wherein the duration of step (iv) is from 3 to 30 seconds.

9. A method as claimed in any preceding claim carried out on heat-treatable metal alloys, comprising an additional artificial ageing step of heating the formed component to an artificial ageing temperature and holding at that temperature to allow precipitation hardening to occur.

10. A method as claimed in claim 9, wherein the heat treatable metal is an Al-alloy in the 2XXX, 6XXX and 7XXX series.

11. A method as claimed in any one of claims 1 to 8, carried out on a non-heat treatable Al-alloy in the 5XXX series.

12. A formed part obtained by the process of any one of claims 1 to 11.

13. A formed part as claimed in claim 12 which is an automotive part.