Thermal Effect On Material In Incremental Sheet Metal

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Abstract:

It is quite familiar in the field of metal forming processes that the properties of a metal while forming may change with an increase in temperature. Studies on thermal effect have not been done before in the case of incremental sheet forming (ISF). For that the paper aimed to investigate the effect of temperature which may result different material properties. In the present paper, the thermal effect is investigated

numerically using Ls-dyna and experimentally using thermograph camera. Both numerical and experimental results are in close agreement. It is found that the maximum temperature reached experimentally 62 °C whereas it only reached numerically 68 °C which means the properties does not change. Therefore, it is considered as low temperature compared to conventional forming processes like deep drawing. Thus, temperature doesn't play roll in effecting on material properties in incremental forming process.

Introduction:

Nowadays, many industries use forming processes like deep drawing and stamping in order to manufacture sheet metal components with high productivity. These processes need large initial investments and long die-preparation times, with specific dies for each part, particularly when the parts have complex shapes or are only needed in small series, as is the case with unique aeronautic and automotive parts. Therefore, there is a need for a flexible technology that is also viable for small and medium-sized enterprises. Incremental sheet forming (ISF) is a new process for manufacturing sheet metal parts which is well suited for small batch production or prototyping (1, 2). ISF, also known as Die-less NC Forming, was introduced in Japan by Matsubara (3) as a method for prototyping and manufacturing sheet metal products in small series. A heating apparatus was developed in order to enhance formability at elevated temperature (4).

However, incremental forming process for the sheet has not been done under temperature influence. Metal-forming processes use a remarkable property of metals which is their ability to flow plastically in the solid state without concurrent damage of their properties. Furthermore, by simply moving the metal to the desired shape, there is little or no waste. In industrial metal forming manufacture there are three basic temperature ranges that the metal is worked at, cold working, warm working, and hot working. These methods or working processes are used to mechanically shape metals into other product forms.

Classification of Temperature-Working Operations:

The properties of the metal are affected by temperature when the work temperature is raised as shown in Figure 1. At higher temperature, ductility increases and both yield strength K and strain hardening n decrease while losing on surface finish and dimension accuracy. The metal will respond in a different way to the same manufacturing operation if it is performed under different temperatures. Hot working is defined as deformation under conditions of temperature (0.6-0.8Tm, Tm is the melting point of the metal) and strain rate such that re-crystallisation process take place simultaneously with the deformation, for example rolling, forging, extrusion. On the other hand, cold working is the deformation carried out under conditions (<0.3Tm) where re-crystallisation does not occur and recovery processes are not effective for instance wire/tube drawing, swaging and coining. In this case, the incremental forming is considered as cold working process.

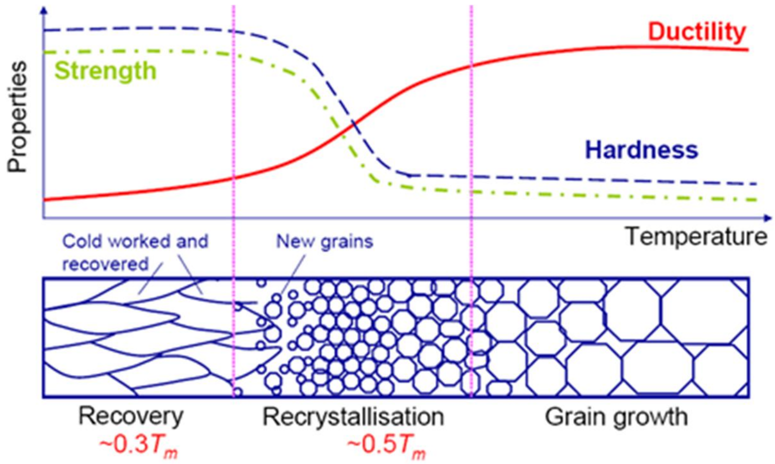

Figure 1: Effect of temperature on metal forming processes

The major cold-working operations, Table 1, can be classified fundamentally under the headings of drawing, bending, shearing, and squeezing, as follows:

Table 1: Classification of cold working operation

Drawing	Bending	Shearing	Squeezing
Incremental forming	Angle	Slitting	Rolling
Stretch forming	Roll forming	Trimming	Swaging
Shell drawing	Flanging	Cut-off	Cold forging
Spinning	Straightening	Dinking	Coining

Working principles of ISF:

The working principle of ISF is illustrated in Figure 2. The setup typically consists of a head forming tool, a fixture, a blank holder, and a blank. The blank is firmly clamped to the fixture. The movement of the forming tool can be programmed in three axes of translation and for spindle rotation. The form-giving tool representing the required shape remains stationary throughout the process. Using a suitable tool path strategy, the forming tool moves around the form-giving tool, from top to bottom. The forming tool is in contact with the blank and pushes the blank down level by level in the predefined vertical steps, and incrementally deforming the blank until the desired shape has been formed. Thus, a CNC controlled movement of a universally usable forming tool produces the desired shape.

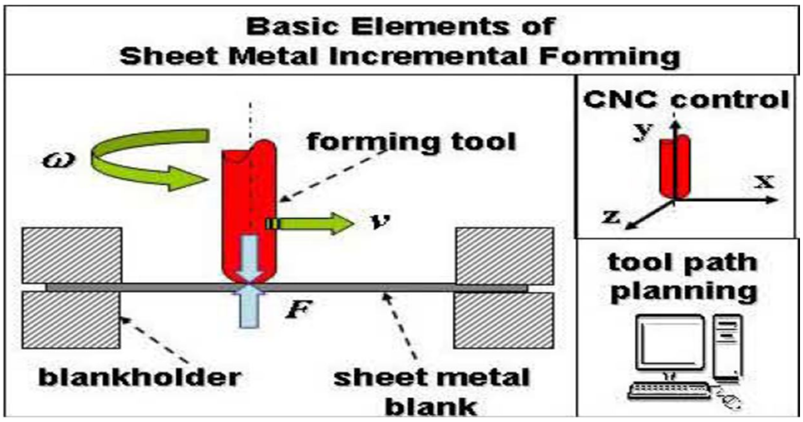

Figure 2 the working principle of ISF

Experimental setup:

The experiment is conducted on a CNC milling machine. A clamping device was used to fix the sheet on the table of the machine. Since a milling machine with a vertical spindle was used, a setup had been designed for this machine. An exploded assembly view and a cross section view of the setup are presented in Figure 3.

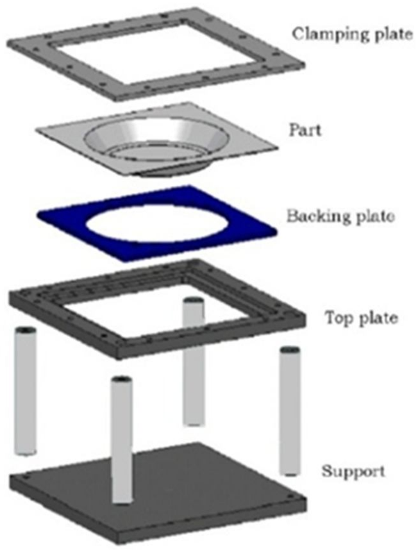

Figure 3: Exploded assembly view

The sheet was 2 mm thick and the feed rate was 1000 mm/min. The forming tool has a diameter of 15 mm with hemi-spherical head which has a spindle speed of 500 rpm. In most metal forming processes, friction is undesirable so metalworking lubricants are applied to sheet interface in all forming passes to reduce harmful effects of friction. Therefore, grease was used for lubrication while forming, and the part is cleaned between each forming pass to remove loose wear particles and apply new grease. Tool paths of each forming pass were generated using CATIA software. The shape of the formed part is a cylindrical cup. The dimensions of the cylindrical cup are h = 60 mm and r = 60 mm. Six forming stages were used to form a final cup.

The thermographic camera THERMOPRO TP8 is used to record the temperature while forming the part in every pass as shown in Figure 4. It gives crisp thermal and visual imaging. It catches the initial temperature at 30 °C. With a 384 x 288 pixel IR camera and a colour 1280 x 1024 visible camera incorporated in the same unit, operators can simply locate the scene to be inspected, snap the shutter and then have both high resolution thermal and visual images taken and saved together in a single file with one name.

Figure 4: Thermal imaging by thermo-graphic camera

The integrated laser locator helps operators accurately associate a hot spot shown in thermal images with the real physical target. Documenting infrared inspections gets much faster and more certain. Offering an unmatched high thermal sensitivity of 0.06°C and high temperature measurement accuracy of ±1°C or ±1%, the camera enables operators to pinpoint the smallest temperature difference quickly and clearly.

Numerical and experimental results:

The cup was successfully formed with six stages numerically and experimentally. The numerical simulation shows the scale of the temperature and the meshed part with the forming tool and backing plate (Figure 5).

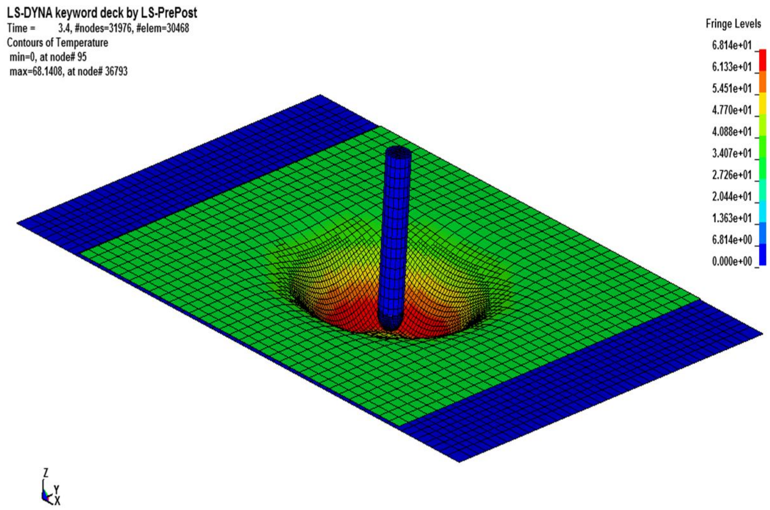

Figure 5: Numerical results for temperature in ISF

The real time measurement of the part temperature recorded from the thermographic camera shows that the maximum temperature appears in the contact area between the tool and the formed sheet as shown in Figure 6.

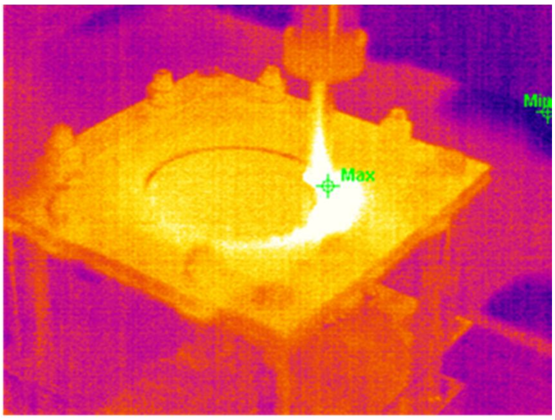

Figure 6: Thermal imaging by thermo-graphic camera

The temperature curve shows six waves that represent the six forming stages as shown in Figure 7. In the first forming pass the temperature increased slightly by increasing forming depth until it reached its peak at the end of the forming pass by 51.3 °C

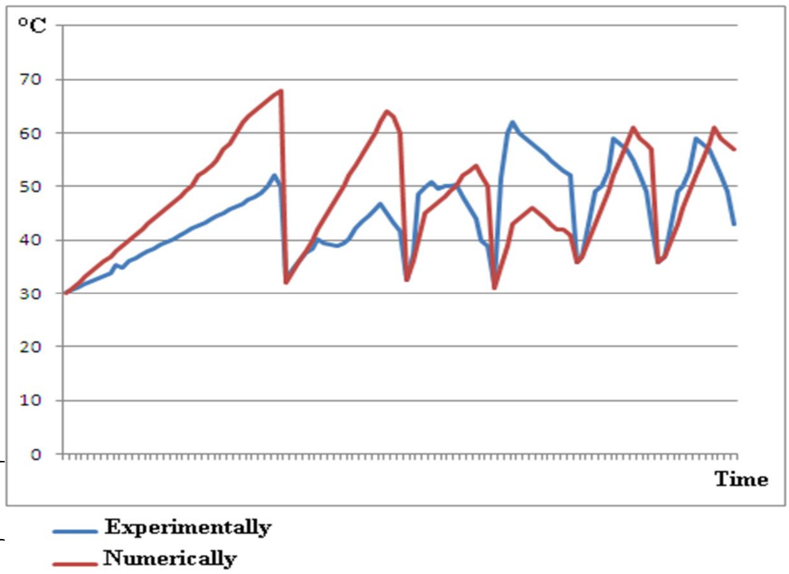

Figure 7: Experimental and numerical results of temperature curve in ISF

The numerical results show a little higher temperature at 68 °C in the first forming pass which represents the highest temperature among the forming passes. Because of the forcible tool on the base material to deform it from scratch to the conical shape, the value of friction appears in the full contact area between the tool and the sheet, making the temperature quite high. On the other hand, the experimental results show higher temperature in the forth forming pass at 62 °C due to a large contact area between the tool and the sheet where the sheet is deformed down vertically (Figure 8). Such low temperature does not play role in affecting material properties in incremental forming process.

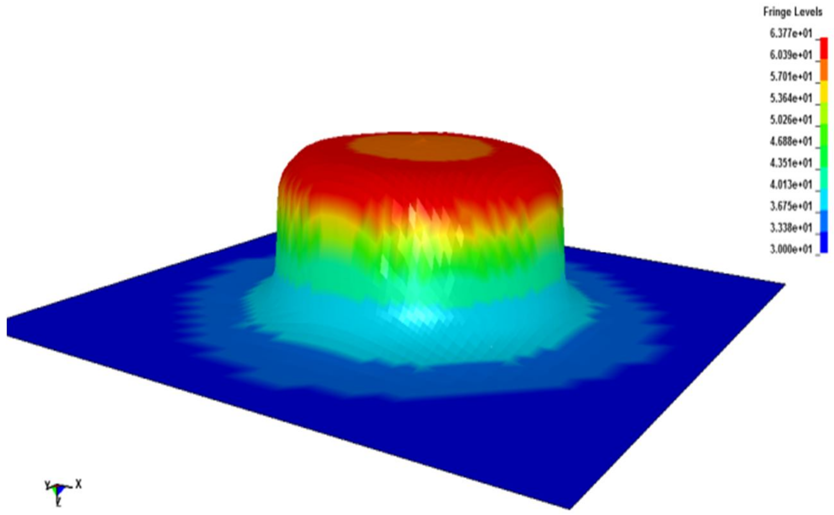

Figure .خطأ! لا يوجد نص من النمط المعين في المستند8: Temperature measurement at the corner

Temperature effect on different materials:

Two materials have been used to compare the results of each metal (same parameters applied force, feed rate, step size, tool size, multi passes). AA-1100 aluminium alloy showed high formability and good dimensional accuracy close to the CAD model. Mild steel showed high strength in forming the sheet because of the high carbon content. However less cracks appeared than in the aluminium sheet. Moreover, the temperature of the mild steel sheet was higher while in the forming process compared to the aluminium sheet. This is simply because of the high carbon content that makes the sheet harder and subsequently increased the temperature.

Conclusion:

The present research aimed also at investigating the significance of temperature in the process of incremental forming. The investigations assessed some conclusions:

- No correlation between fracture and temperature in the incremental forming process.
- Increase in temperature is due to friction and large contact area between the tool and the sheet.
- The temperature ranges between a slightly lower than 45°C and little above 60°C.
- Temperature has no effect on the material properties of the part due to low level of temperature.

It is recommended to investigate further in terms of temperature effect using different materials mainly materials that have high strength.

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