Superplastic Forming using Pulse Current

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***Abstract*— Superplastic forming is a manufacturing process which makes use of the characteristic of certain metals when heated and stretched to undergo elongation of several hundred percent without failure. Superplastic forming using pulse current is developed due to lower energy consumption and higher efficiency. The objective of this project is to study about superplastic deformation using pulse current. Using the pulse current, the sheet metal can be heated and can be deformed. Selecting the materials of aluminum alloys among the series of 5xxx, 6xxx or 7xxx which finds wide application in domestic as well as automobile industries and also based on their availability and cost. Conduct experimental work on the selected aluminum alloys with different pressure rate in pulse current assisted Superplastic forming by different pulse current density. Study the stress and deformation for different set of pressure rate. In this process, the metal sheet is designed in series in a pulse current circuit and heated directly by the pulse current. Heated superplastic material is deformed using gas pressure which forces the material into a die cavity.**

Keywords — Superplastic, aluminium alloy, pulse current, deformation, stress.

I. INTRODUCTION

A. Superplasticity

Superplasticity is the capability of certain fine-grained polycrystalline materials to undergo extensive tensile plastic deformation under specific temperature and load conditions without the formation of a neck prior to failure.

Superplastically deformed material gets thinner in a very uniform manner, rather than forming a "neck" that leads to fracture. For superplastic forming the material must have an ultra-fine grain size. It is then heated up to promote superplasticity. For aluminium alloys it is between 450–520 °C.

B. Aluminium

Aluminium is a chemical element (symbol Al) with an atomic number of 13. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Alloys composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal skinned aircraft.

C. Aluminium alloy

Aluminium alloys with a wide range of properties are used in engineering structures. Alloy systems are classified by a number system or by names indicating their main alloying constituents. The strength and durability of aluminium alloys vary widely, not only as a result of the components of the specific alloy, but also as a result of heat treatments and manufacturing processes.

II. PULSE CURRENT GENERATION

A. Pulse Current

Pulsed power deals with the generation of extremely high power, short duration impulses. Peak powers typically range from megawatt (MW) to terawatt (TW) levels, and pulse durations from nanoseconds to milliseconds.

A booster converter circuit is used to generate the pulse current. A boost converter is a DC-to-DC power converter with an output voltage greater than its input voltage.

B. Operating Principle Of Booster Circuit

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage.

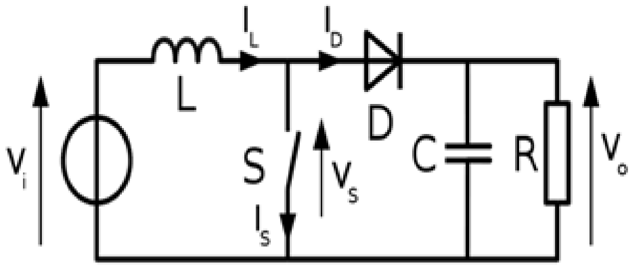

Figure 1. Booster Converter

Vi – input voltage

Vs – voltage through switch

L – inductor

D – diode

Il – current through inductor

Id – current through diode

S – Switch

C – capacitor

Is – current through switch

R – load

When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

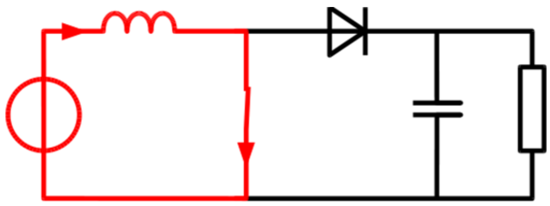

Figure 2. Close Switch Booster Convertor

When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed. As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

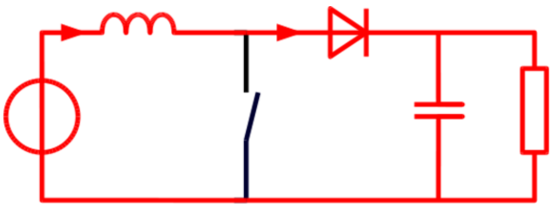

Figure 3. Open Switch Booster Convertor

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage.

When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

The basic principle of a Boost converter consists of 2 distinct states:

1. in the On-state, the switch S (see figure 1) is closed, resulting in an increase in the inductor current.

2. in the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. This results in transferring the energy accumulated during the On-state into the capacitor.

III. PROBLEM DEFINITION

In traditional method, the sheet metal to be deformed in kept inside the die and the die is heated up by keeping it inside a furnace. During this process, first the die is getting heated and then the sheet metal is heated. Because of this the time taken for deformation increases and the elongation is not linear. The elongation near the neck will be higher than the elongation at the other surfaces because the temperature of the die increases the elongation near the die.

IV. EXPERIMENT PROCEDURE

A. Experimental Setup

The experimental setup for superplastic forming using pulse current consists of a rectangular sheet metal placed in a die and pressed tightly by a hydraulic unit to ensure sealing conditions between the sheet metal and the lower die. Before mounting, the sheet is acid washed by hydrochloric acid to remove the oil on the surface in case of oxidization during heating process.

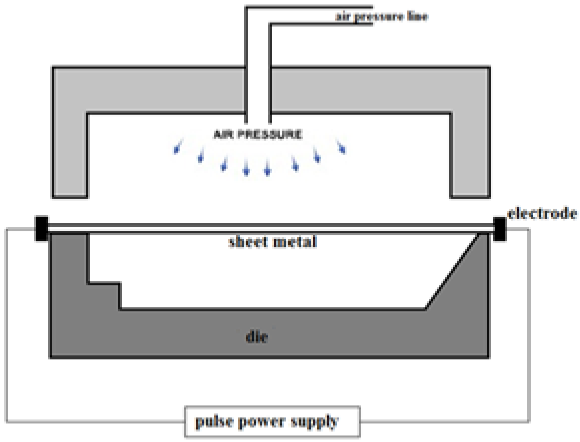

Figure 4. Experimental Setup

The two edges of the sheet are held between two electrodes and enough pressure is applied to get sufficient contact between the sheet and electrode for the electrifying. During heating process, the middle part of the sheet gets higher temperature and the deformation will be higher than that of the two sides near the electrodes. During this deformation the elongation will be higher and the deformation will not be linear. In order to overcome this, air pressure is applied through a air pressure line that will help linear deformation.

B. Hot Gas Blow Forming

When the sheet metal is heated to the desired temperature of hot forming, the pulse current should be adjusted to keep the temperature steady, and the inactive gas is filled in to apply forming pressure. The rate of pressurization is an important parameter to the gas blow forming process, since the strain rate influences the formability of the material significantly.

The pulse power supply is turned off as soon as the sheet is formed to the desired shape. Due to the low temperature of the surroundings, the temperature of the sheet drops to room temperature.

V. RESULT

A. 5053 – H32 Alloy

Yield strength = 195.0 N/mm² (MPa)

Maximum Pressure applied = 28 psi

Stress developed =196.5 N/mm² (MPa)

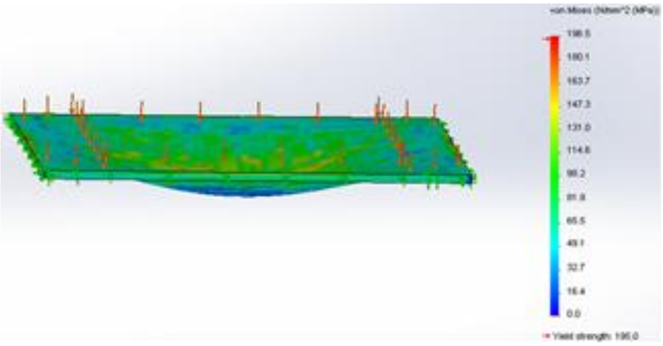

Figure 5 Maximum stress of 5053 – H32 alloy

Maximum Deformation = 0.461mm

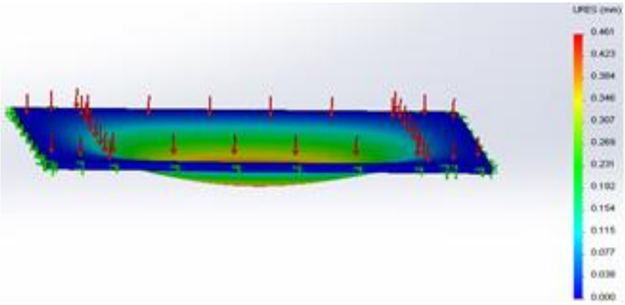

Figure 6 Maximum Deformation of 5053 – H32 alloy

Table 1 Deformation and Stress by varying Pressure of 5053 – H32 alloy

PRESSURE in psi	DEFORMATION in mm	STRESS in N/mm²MPa
1	0.018	146.0
5	0.084	146.8
10	0.166	148.1
20	0.331	170.2
25	0.414	185.9
28	0.461	196.5

B. 6061 – T6 alloy

Yield strength = 275.0 N/mm² (MPa)

Maximum Pressure applied = 36 psi

Stress developed = 272.5 N/mm² (MPa)

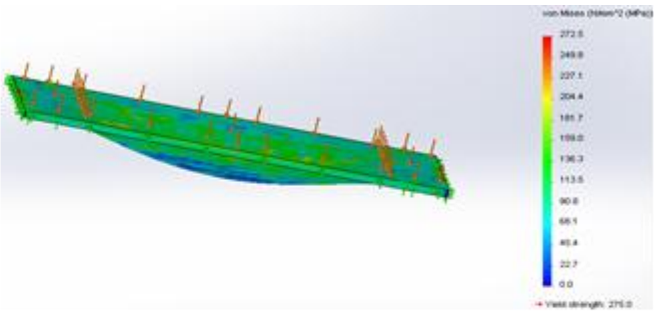

Figure 7. Maximum stress of 6061 – T6 alloy

Deformation = 0.601mm

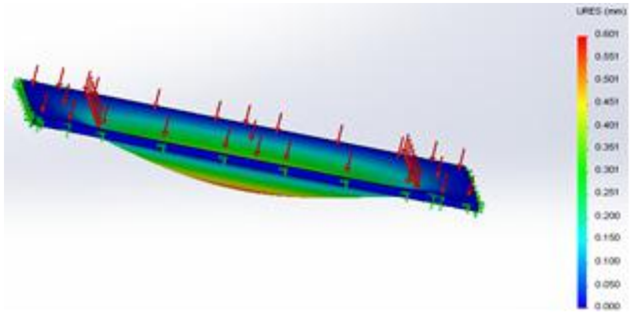

Figure 8 Maximum Deformation of 6061 – T6 alloy

Table 2 Deformation and Stress by varying Pressure of 6061 – T6 alloy

PRESSURE in psi	DEFORMATION in mm	STRESS in N/mm²MPa
1	0.017	217.5
10	0.167	218.1
20	0.334	231.6
30	0.501	254.1
36	0.601	272.5

C. 7075 – T6 alloy

Yield strength = 505.0 N/mm² (MPa)

Maximum Pressure applied = 100 psi

Stress developed = 508.2 N/mm² (MPa)

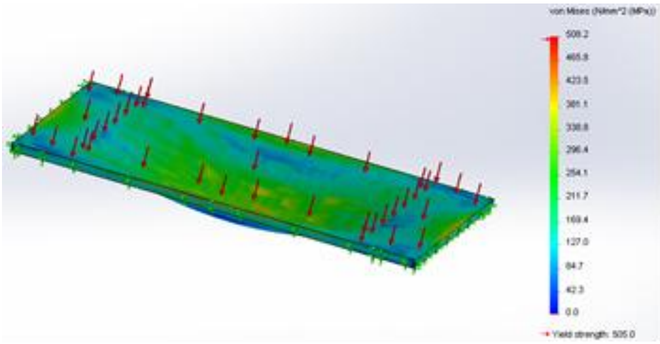

Figure 9. Maximum stress of 7075 – T6 alloy

Maximum Deformation = 1.603mm

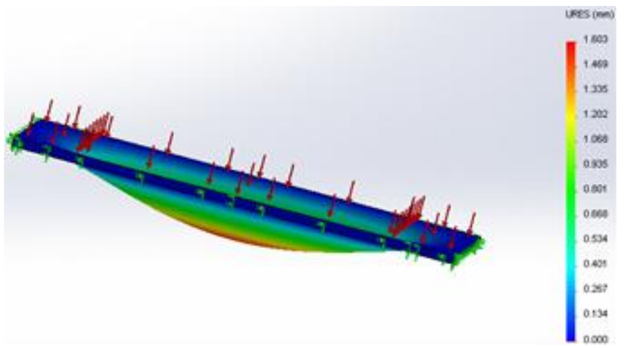

Figure 10. Maximum Deformation of 7075 – T6 alloy

Table 1 Deformation and Stress by varying Pressure of 7075 – T6 alloy

PRESSURE in psi	DEFORMATION in mm	STRESS in N/mm²(MPa)
1	0.017	223.2
10	0.160	223.8
30	0.480	258.7
60	0.961	361.8
90	1.422	471.3
100	1.603	508.2

VI. CONCLUSION

From the above analysis it is clear that the maximum stress and the maximum deformation we got is in 7075 – T6 aluminium alloy. The other two alloy of 5053 - H32 and 6061 T6 alloys have low yield strength and also have less deformation.

Table 4 Maximum stress and maximum deformation

ALLOY	YIELD STRENGTH in N/mm²(Mpa)	MAXIMUM PRESSURE in psi	MAXIMUM STRESS in N/mm²(Mpa)	MAXIMUM DEFORMATION in mm
5053 – H32	195.0	28	196.5	0.461
6061 – T6	275.0	36	272.5	0.601
7075 – T6	505.0	100	508.2	1.603

VII. FUTURE WORKS

The amount of current density required to heat the material can to be determined by doing experimentally. The pulse power generation is a difficult process for high current applications. The metal which is to be experimented is heated using pulse current. When the metal is heated, its conductivity and resistivity will change for every degree rise in the temperature. So the pulse current that we are giving as input may increase the rate of heating the metal.As the input current heats the metal before the estimated time, the hot gas blowing should be done at the exact time when the metal reaches its superplastic forming state. If the hot gas is not blown at the exact time the metal will lose its superplastic ability, and the metal will reach its melting point. In order to avoid this, the pulse current should be controlled for each degree rise in temperature of the metal. The pulse current can be controlled by using a controller and programming with the equation that relates between pulse current and temperature rise.

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