# Liquid Impact Sheet Metal Deformation of Superni (Inconel) 718 using Inclined Edge (Conical) DIE

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Received: 04 November 2023/ Revised: 16 November 2023/ Accepted: 21 November 2023/ Published: 30-11-2023


***Abstract—*** *Liquid/Hydraulic impact forming is a sheet metal forming process in which a dead weight drop freely from a certain height over a piston working inside a cylinder containing liquid or hydraulic fluid, generates shock waves which reach the sheet metal kept at a lower part of the cylinder and deforms it to the shape of the die placed below the sheet metal. In the present work Taguchi design of experiments (DoE) technique is used in order to find the effect of input parameters on impact force for deformation of superni (Inconel) 718 using inclined edge die. Contribution of each factor on output is determined by ANOVA (Analysis of Variance) and also an attempt is made towards green manufacturing by adopting used gear and vegetable oils as operating fluids. The outcome of this research will be very much useful for medium and small segment industries in getting the pre-form of the product with least cost.*

***Keywords— Liquid/Hydraulic Impact Forming, Taguchi Design of Experiments (DoE), Inconel 718, Green Manufacturing, Analysis of Variance (ANOVA), Hydraulic Fluid***

## I. INTRODUCTION

### 1.1 Liquid impact forming:

Oil can be considered as a homogeneous fluid incapable of supporting any shear. An impulsive load causes a rearrangement of fluid by flow through any boundary displacements caused by loading. A change in the pressure results in change in volume and a spontaneous local pressure is transmitted to other stations in the fluid through "elastic wave of disturbance" commonly called as stress waves. The stress waves are longitudinal waves and travel at the speed of sound of the particular fluid. The velocity of the stress waves is given by:

$$C = \sqrt{(k / \rho)}$$

Where k = bulk modulus of the fluid, ρ = density of the fluid

The pressure profile of a liquid hammer pulse can be calculated from the Joukowsky equation:

$$\frac{\delta P}{\delta t} = \rho a \frac{\delta \vartheta}{\delta t}$$

So for a valve closing instantaneously, the maximum magnitude of the Hydraulic liquid hammer pulse is given by:

$$\Delta P = \rho a \Delta \vartheta$$

Where ΔP is the magnitude of the pressure wave (Pa), ρ is the density of the fluid ($kgm^{-3}$), '$a$' is the speed of sound in the fluid ($ms^{-1}$), and $\Delta\vartheta$ is the change in the fluid's velocity ($ms^{-1}$). The pulse is due to Newton's laws of motion and the continuity equation as applied to the deceleration of a fluid element.

### 1.2 Superni Inconel) 718

Materials with distinctive metallurgical properties – such as an alloy of titanium, nickel, tool steel and other super alloys are primarily used for a specialized application requiring heat and corrosion resistance. These materials exhibit several key characteristics such as excellent mechanical strength, resistance to creep at high temperature, high work hardening, and corrosion resistance and thus they are the first choice of aerospace, submarine, gas turbine and nuclear industries. However, these properties are generally associated with poor machinability. Hence, machining of such difficult-to-cut materials is quite crucial for the manufacturing sector. Inconel 718 is a Ni-Cr based superalloy and has been widely used in aviation, submarine, nuclear, gas turbine, petroleum industries because of its excellent mechanical properties such as high strength, strong creep resistance, superior wear resistance, resistance to chemical degradation and low thermal conductivity. However, the machining of Inconel 718 using conventional machining process like turning, grinding, broaching or milling is very difficult because of its work-hardening nature, retention of high tensile strength at elevated temperature and low thermal conductivity. The chemical composition of Superni 718 (sheet metal) which is procured for research work from Misha Dhatu Nigam Ltd., (MIDHANI) is as given in table 1. The Ni-based superalloy contains major constituent elements such as Nickel (Ni), Iron (Fe), Chromium (Cr), Molybdenum (Mo), and Cobalt (Co) with some minor elements like Aluminum (Al), Titanium (Ti), and so on. These alloying elements enhance the mechanical characteristics. Where, Ni stabilizes alloy structure and properties at elevated temperatures. Co, Mo, and W increase strength at elevated temperature, Cr, Al, Si enhances oxidation resistance and elevated temperature corrosion resistance, and Carbon (C) increases creep strength. In the present work used oils are used as working liquid for deformation of sheet metal as an approach towards green and sustainable manufacturing. Green manufacturing aims to establish a system which integrates product and process issues. Used lubricating oils, used vegetable oil based coolants, represent a serious problem for environment and human health due to the presence of highly harmful contaminants, being mandatory an adequate management based on efficient collection systems and treatment processes. In this current research work an attempt is made to use these used oils as working fluid in Hydraulic hammer forming to get the forming of Superni/Inconel 718 sheet metal.

**TABLE 1**
**CHEMICAL COMPOSITION OF SUPERNI (INCONEL) 718**

| Element | C | Mn | Si | S | P | Cr | Ni | Mo |
|---|---|---|---|---|---|---|---|---|
| Wt% | 0.08 Max | 0.35 Max | 0.35 Max | 0.015 Max | 0.015 Max | 17.0 - 21.0 | 50.0 – 55.0 | 2.80 – 3.30 |
| | | | | | | | | |
| Element | Co | Nb | Ti | Al | B | Cu | Ta | Fe |
| Wt% | 1.0 Max | 4.75 – 5.50 | 0.65 - 1.15 | 0.2 – 0.8 | 0.006 Max | 0.3 Max | 0.05 Max | Bal |

## II. OBJECTIVES AND METHODOLOGY

The investigation study is planned with the following objectives:

(a) Postulation of regression model for Impact force which is considered as output response.

(b) Adoption of two-level Taguchi design of experiments and selection of test regions for the variables (factors).

(c) Conducting the experiments as per design matrix.

(d) Estimation of coefficients of postulated model.

(e) To perform ANOVA (Analysis of Variance).

A regression model is developed using Minitab to understand the relationship between the input parameters and the target variable resultant impact that is formed due to oil impact forming technique. The process parameters shown in table 2 were taken into consideration and Taguchi Method Orthogonal Array (L8) is adopted to perform the experiment.

Taguchi DoE being most useful in terms of into provided, but don't seem to be usually practical for five or more factors because number of experiments doubles sequentially with addition of every factor. However, if experiments are cheap, easy to perform than go ahead with Taguchi design of experiments. Within the study, Taguchi design of experiments for designing the experiments has been used. The Taguchi method recommends orthogonal arrays for laying out the experiment. For design the experiment firstly select the foremost suitable orthogonal arrays (OA) and to allocate the parameters and interaction of interest to the acceptable columns.

**TABLE 2**
**INPUT PARAMETERS AND LEVELS WITH OUTPUT RESPONSE**

| Factors | Units | Designation | Test levels | | Output Response (kN) |
|---|---|---|---|---|---|
| | | | Low | High | |
| Thickness of specimen (t) | mm | t | 0.2 | 0.5 | Impact Force |
| Height of the hammer (h) | cm | h | 190 | 250 | |
| Weight of the hammer (w) | kg | b | 15 | 25 | |
| Viscosity of the Fluids (o) (o1: Viscosity of used gear oil, (o2 : Viscosity of used vegetable oil) | Poise | o | 9.9 | 11.4 | |

## III. EXPERIMENTATION & REGRESSION MODEL DEVELOPMENT

The equipment is arranged on rectangular concrete base wooden block is placed over the concrete base so as to absorb the shock load without damaging the system die holder is kept on the wooden block. Suitable die is selected and placed in the die holder over which the sheet metal (work piece) is located in the shallow counter sunk bore, of the same diameter as the specimen, on the die face. Venting is provided both in the die and die holder, to prevent spring back of the specimen due to compressing of trapped air. Now the cylinder with two 'O' rings are fixed in order to prevent leakage of the working fluid. Cylinder flange and guide bush are mounted on the cylinders in such a way that it is fixed with a m-10 Allen screw. Two swing bolts are used to clamp the cylinder flange and hold the cylinder in position. Plunger along with 'O' ring fixed on it, is inserted through the guide bush into the cylinder. The mating faces of plunger and cylinder were grinded for smooth movement. Wall bracket is fixed in the wall to support the guide mechanism. The guide mechanism comprises of a pulley for lifting the weight. The set of three guide wires are provided to guide the falling weight. The weights are fixed on a disc carrying a one end thread inside the disc and other end locked to the rope by means of an eye end. The die holder is placed on the wooden block. The surface of the die should be free from dust, dirt and other foreign materials to provide good forming. The die is placed in the holder. The specimen is located in the shallow counter sunk bore between the die face and the cylinder. The cylinder cavity is filled with Hydraulic liquid up to desired height by removing the necessary Hydraulic liquid tap screws. Cylinder flange along with the guide bush is located by means of bolts. The plunger is inserted into the cylinder with the 'O' rings in position, up to the Hydraulic liquid level. Predetermined weight is raised to the required height manually by means of the rope over the pulley. Then it is released suddenly. The deformation of the work piece takes place by the shock waves in the Hydraulic liquid generated by the impact of the freely falling weights. The swing bolt is unfastened. The wire fixed to the cylinder flange lifts the cylinder along with the plunger, guide and guide bush. The formed specimen is removed from the shallow counter sunk bore and replaced by the new specimen. The cyclic process can be repeated by varying loads, energy input and Hydraulic liquid column heights.

The Taguchi (L8) design matrix of experimentation and output are given in the Table-3

**TABLE 3**
**TAGUCHI (L8) DESIGN MATRIX WITH RESPONSE**

| Trail | Thickness of specimen (t) | Height of the hammer (h) | Weight of the hammer (w) | Viscosity of the Fluids (o) | Impact Force (F) |
|---|---|---|---|---|---|
| 1 | 0.2 | 190 | 15 | 9.88 | 11.2915 |
| 2 | 0.2 | 190 | 25 | 11.36 | 16.4345 |
| 3 | 0.2 | 250 | 15 | 11.36 | 12.7062 |
| 4 | 0.2 | 250 | 25 | 9.88 | 22.3318 |
| 5 | 0.5 | 190 | 15 | 11.36 | 13.302 |
| 6 | 0.5 | 190 | 25 | 9.88 | 20.5593 |
| 7 | 0.5 | 250 | 15 | 9.88 | 15.6123 |
| 8 | 0.5 | 250 | 25 | 11.36 | 22.0909 |

**FIGURE 1: Experimental Setup**

The experimental response values are used in Minitab and the regression equation generated is as given below.

Impact Force = -0.81 + 7.33 t + 0.0465 h + 0.7126 w - 0.889 o

Analysis of variance is done to find out the percentage contribution of each factor and relative significance of each factor for Impact force the values are tabulated in table 4.

**TABLE 4**
**ANALYSIS OF VARIANCE (ANOVA)**

| | Source | Contribution |
|---|---|---|
| **Analysis of variance (ANOVA)** | Thickness of specimen (t) | 7.25% |
| | Height of the hammer (h) | 11.64% |
| | Weight of the hammer (w) | 76.01% |
| | Viscosity of the Fluids (o) | 2.59% |
| | Error | 2.51% |

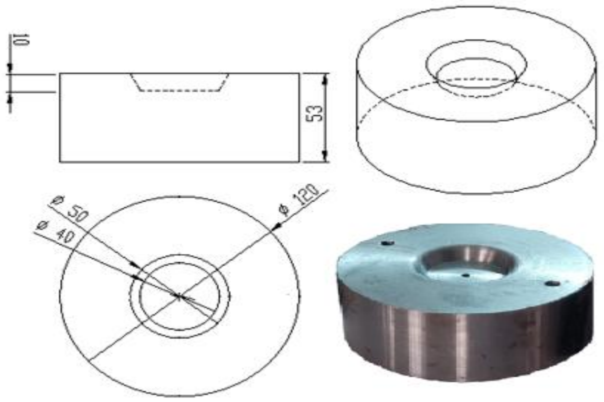


**FIGURE 2: Details of inclined edge die**

**FIGURE 3: Deformed Superni 718work pieces**

## IV. RESULTS AND DISCUSSION

- Fig.4: Demonstrated that the variation of impact is 7% ie., 28.96 kN to 31.16 kN when the thickness varies from 0.2 mm to 0.5 mm when all the remaining input parameters at low level. When input parameters are at high level the variation of force is less than 7% for change in the thickness of 0.2 mm 0.5 mm. This indicates that loading may be reached the yield phenomenon of material at higher levels of impact parameters.
- Fig.5: Indicates the variation of impact force when the height of hammer changes from 190 cm to 250 cm when input parameters are at low level the variation of force is about 7% whereas for higher level of input parameters it is 7%. This observation n establishes that at higher level of input parameters the force transmitted to the work piece is reducing which may be attributed to dynamics of fluid.
- Fig.6: Shows the variation of impact force when the weight of hammer changed from 15 Kg to 25 Kg. The variation of force when input parameters are at low level is 24% whereas for higher level is 20% this concerned that higher level of parameters considering the yield point phenomenon of work piece material.
- Fig.7: Shows that variation of impact forces when the viscosity changes of fluid from 9.88 to 11.36 Poise. When impact parameters are at low level the impact force is reduced with increase in viscosity by 1.31 kN whereas higher level of input parameters is 1.32 kN. Which may be attributed to the power transmitting ability of fluid in conical die.

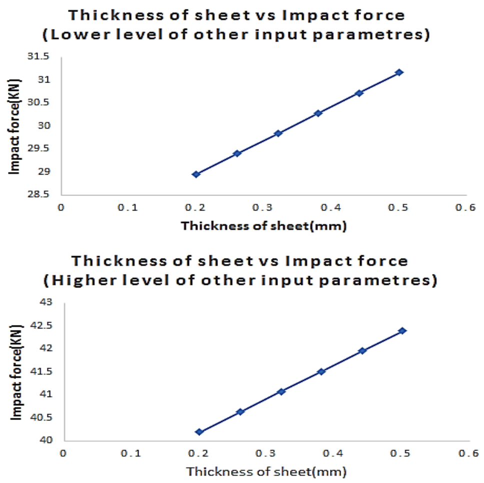


**FIGURE 4: Variation of impact with thickness**

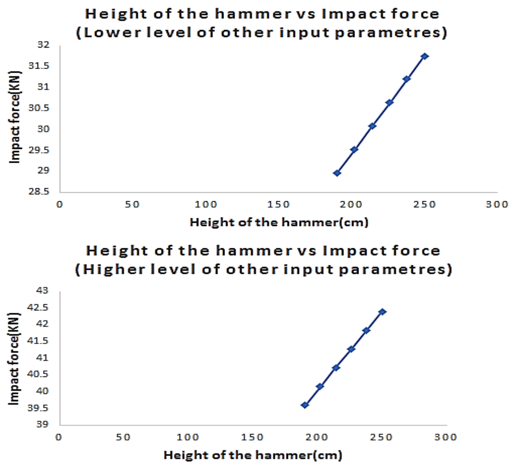


**FIGURE 5: Variation of impact with height of hammer**

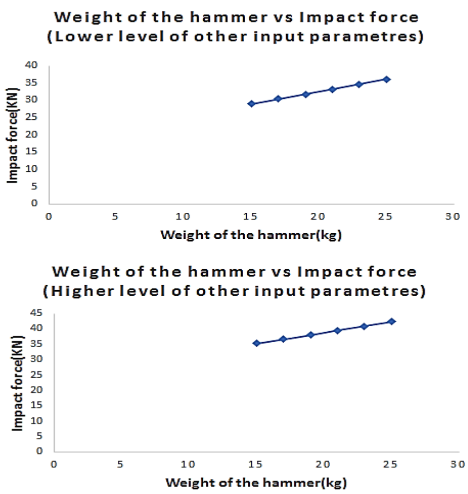


**FIGURE 6: Variation of impact with weight of hammer**

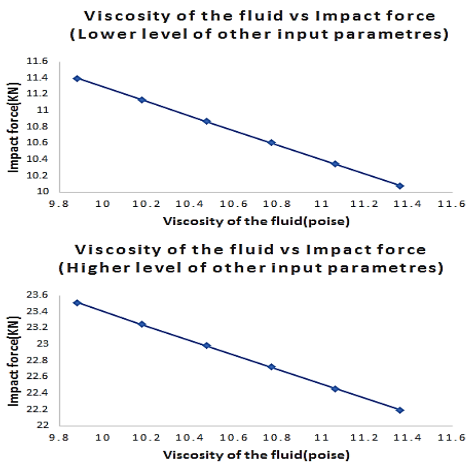


**FIGURE 7: Variation of impact with weight of hammer**

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