Green forming of superni 718 by hydraulic impact sheet metal deformation

E. Hazya[1], S. Gajanana[2], P. Laxminarayana[3], B. Ravikumar[4], B. Suresh Kumar Reddy[5]

[1]*Jawaharlal Nehru Technological University Hyderabad, Hyderabad, India*
[2,4,5]*M.V.S.R. Engineering College, Hyderabad, India*
[3]*College of Engineering, Osmania University, Hyderabad, India*

ABSTRACT

KEYWORDS

Taguchi-DOE,
ANOVA,
Hydraulic Liquid Hammer Forming,
Superni 718,
Green Manufacturing.

Hydraulic liquid hammer/impact forming is a nontraditional type of sheet metal forming technique in which a dead weight drops freely from a certain height over a plunger working inside a cylinder containing hydraulic 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 straight edge die placed below the sheet metal. Some of the important process variables that affect the deformation process are the input energy, height of the hydraulic column, and properties of the work material. The speed of deformation and pressures generated are quite low compared to other unconventional forming processes. In the present work in Taguchi DoE technique is used to find the effect of input parameters on the deformation of superni 718. and also an attempt is made towards green manufacturing by adopting used gear and vegetable oils as working fluids.

1. Hydraulic 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 changes in volume and a spontaneous local pressure is transmitted to other stations in the fluid through “the elastic wave of disturbance” commonly called stress waves. The stress waves are longitudinal waves are travel at the speed of sound of the particular fluid. The velocity of the stress waves is given by:

C = √ (k / ρ) 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}), ‘α’ is the speed of sound in the fluid (ms^{-1}), and Δ ϑ is the change in the fluid's velocity (ms^{-1}). The pulse is based on Newton’s laws of motion and the continuity equation as applied to the deceleration of a fluid element.

The impact force from the experiment is calculated as given below

F_{impact} = mgh/S

Where, m = mass of the drop hammer, g = acceleration due to gravity, h = height of drop hammer from the datum line, S = total displacement of plunger.

*Corresponding author E-mail: g_saparey@rediffmail.com

https://doi.org/10.58368/MTT.22.11-12.2023.20-29

Table 1
Chemical composition of superni 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

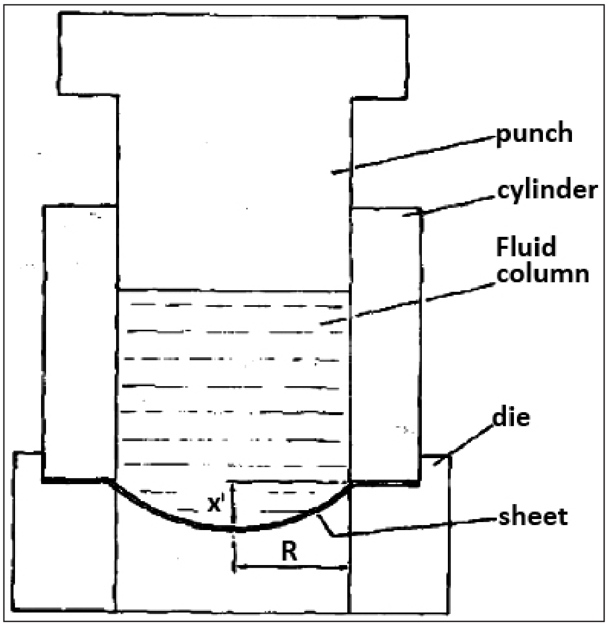

Fig. 1. Fluid column inside the cylinder.

2. Green Manufacturing

Traditional manufacturing system engages in relentless exploitation of natural resources for producing goods with the sole aim of earning profits. Such a system puts intense pressure on scarce resources available and leads to environmental degradation. In recent decades, the exponential population growth and the rapid urbanization of populations are responsible for problems such as global warming, acidification, ozone layer depletion and anthropogenic pollutants, desertification, depletion of minerals, and fossil fuels. Green Manufacturing refers to optimizing the manufacturing process and wallowing towards achieving manufacturing efficiency on hand, and avoiding unnecessary waste that pollutes the environment. The ideology of the Green Manufacturing system revolves around reducing environmental impact by reducing wastages and recycling them, which reduces harmful effects caused by the traditional manufacturing system. It helps reduce waste and manufacturing costs, but it also allows an organization to reduce costs and reap profits. Green manufacturing aims to establish a system which integrates product and process issues. In this current research work an attempt is made to utilize used lubricating oils, used vegetable oil based coolants, which are dangerous for environment and human health due to the presence of highly harmful contaminants as working fluid in Hydraulic hammer forming to get the forming of Superni/Inconel 718 sheet metal.

3. 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 is requiring heat and corrosion resistance. These materials exhibit several key characteristics such as excellent mechanical strength, resistance to creep at high temperatures, 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. Inconel 718 is a Ni-Cr based superalloy and has been widely used in aviation, submarine, nuclear, gas turbine, and 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 the process like turning, grinding, broaching or milling is very difficult because of its work-hardening nature, retention of high tensile strength at elevated temperatures 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 given in Table 1. The Ni-based superalloy contains major constituent elements such as Nickel (Ni), Iron (Fe), Chromium (Cr),

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) (o_1: Viscosity of used gear oil, o_2: Viscosity of used vegetable oil)	Poise	o	9.88	11.36	

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.

4. Objectives and Methodology

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

The investigation study is planned with the following objectives

- Postulation of regression model for Impact force which is considered as output response
- Adoption of two-level Taguchi design of experiments and selection of test regions for the variables (factors)
- Conducting the experiments as per the design matrix
- Estimation of coefficients of the postulated model
- Analysis of results: Determination of percentage contribution of each factor

4.1. Taguchi-DoE methodology

This study focuses on the optimization of process parameters and hence Taguchi's parameter design is chosen. The actual steps in using Taguchi's method of parameter design are divided into three groups: planning the experiment, performing the experiment, and analyzing the data from the experiment.

The use of Taguchi's parameter design involves the following steps.

- Planning the experiment
  - Identify the target response, side effects, and failure modes
  - Identify noise factors and testing conditions
  - Identify the quality characteristic to be observed and the objective function to be observed
  - Identify the control factors and their levels
  - Preparation of design matrix
- Performing the experiments as per the design matrix
- Analysing the results.

5. Experimentation and Regression Model Development

The equipment is arranged on a rectangular concrete base wooden block and is placed over the concrete base 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

Fig. 2. Deformed superni 718 work pieces.

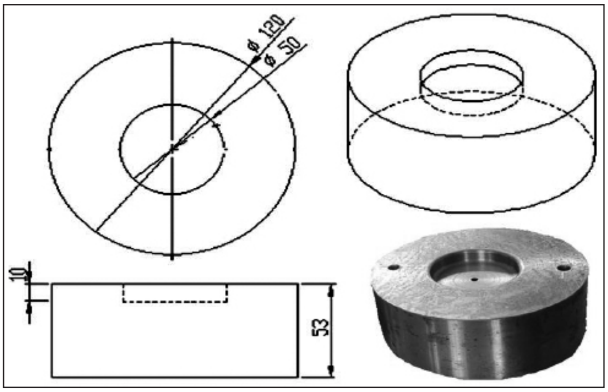

Fig. 3. Details of straight edge die.

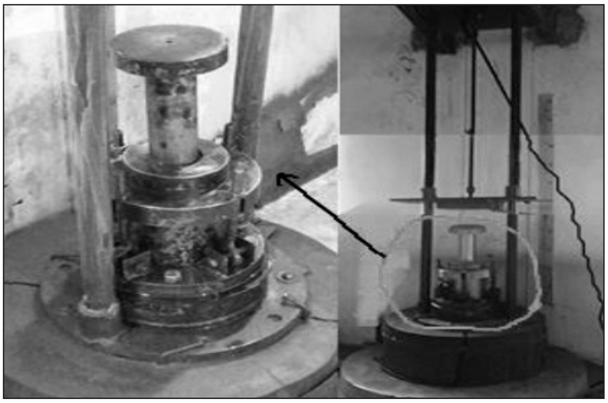

Fig. 4. Experimental setup.

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 an 'O' ring fixed on it, is inserted through the guide bush into the cylinder. The mating faces of plunger and cylinder are ginded 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 weights. The set of three guide wires are provided to guide the falling weight. The weights are fixed on a disc carrying an one-end thread inside the disc and other end is locked to the rope by means of an eye end.

Operation:

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. The 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 which is generated by the impact of the freely falling weights. The swing bolt is unfastened. The wire fixed to the cylinder flange lifts the

Table 3
Taguchi (L8) design matrix with response.

Trail	Thickness of specimen (t) mm	Height of the hammer (h) cm	Weight of the hammer (w) kg	Viscosity of the Fluids (o) Poise	Impact Force (F) kN
1	0.2	190	15	9.88	8.7510
2	0.2	190	25	11.36	19.1668
3	0.2	250	15	11.36	15.1354
4	0.2	250	25	9.88	18.1706
5	0.5	190	15	11.36	9.9659
6	0.5	190	25	9.88	19.7756
7	0.5	250	15	9.88	12.9064
8	0.5	250	25	11.36	21.7391

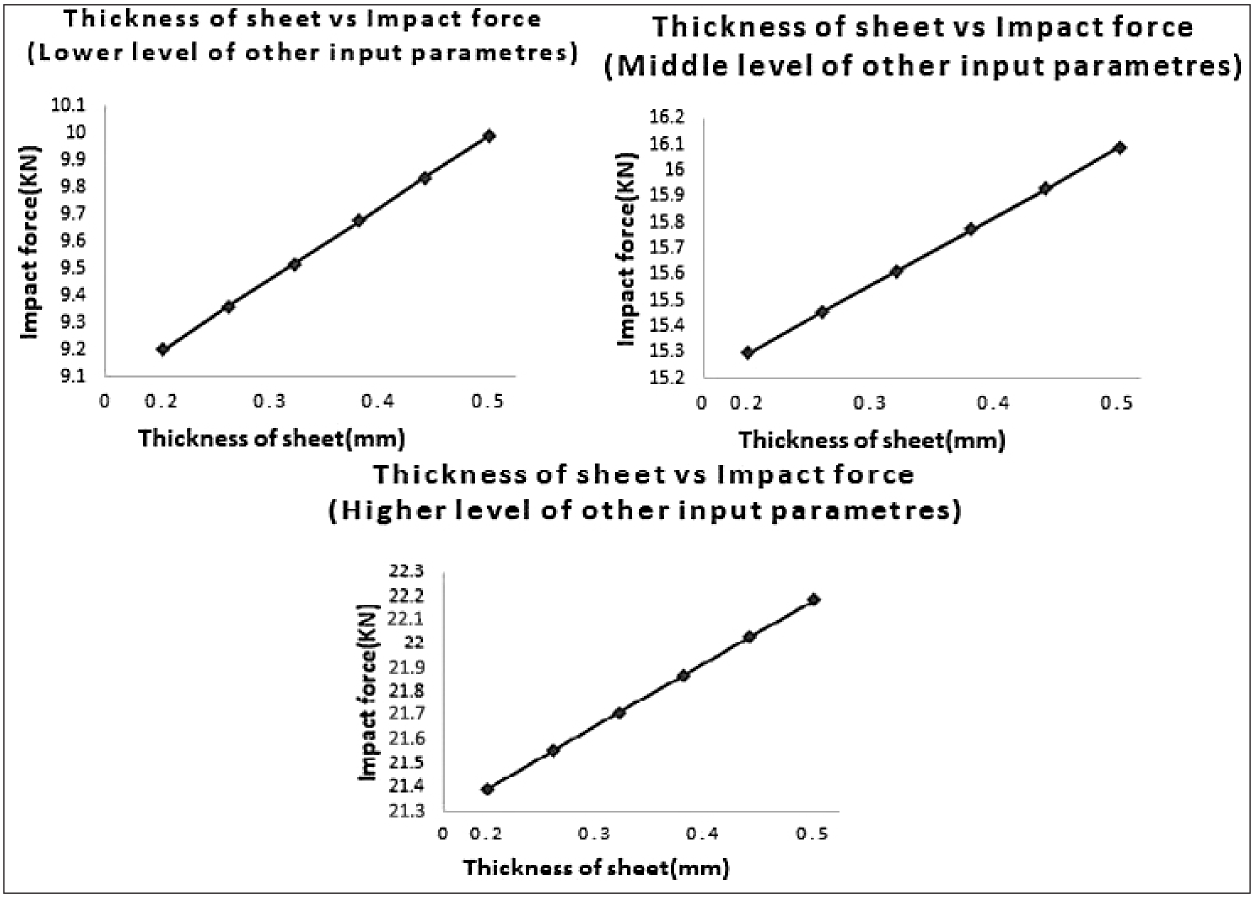

Fig. 5. Graphical relation between thickness of sheet with impact force.

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.

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

Analysis of Variance (ANOVA)	
Source	**Contribution**
t	0.78%
h	8.25%
w	80.22%
o	3.19%
Error	7.56%
Total	100.00%

Impact Force = -22.2 + 2.64 t + 0.0429 h + 0.802 w + 1.082 o

Analysis of variance is carried out to find out the percentage contribution of each factor and relative significance of each factor for Impact force.

6. Results and Discussion

Following graphical representation shows the effect input parameters on forming force.

- It is seen from graphical relation between thickness of the sheet with the impact force (Fig -5) variation of force is very less when lower-level values are taken for other input parameters when thickness of sheet is 0.2 mm the impact force is 9.19916 kN and at 0.5 mm thickness its value is 9.99116kN, similarly at middle level values of other parameters for 0.2 mm force is 15.29684kN ant at 0.5mm it is 16.08884 kN. At higher level values of other parameters for 0.2 mm force is 21.39452 kN and at 0.5mm it is 22.18652 kN. Average variation of impact force for lower, middle, higher levels of other

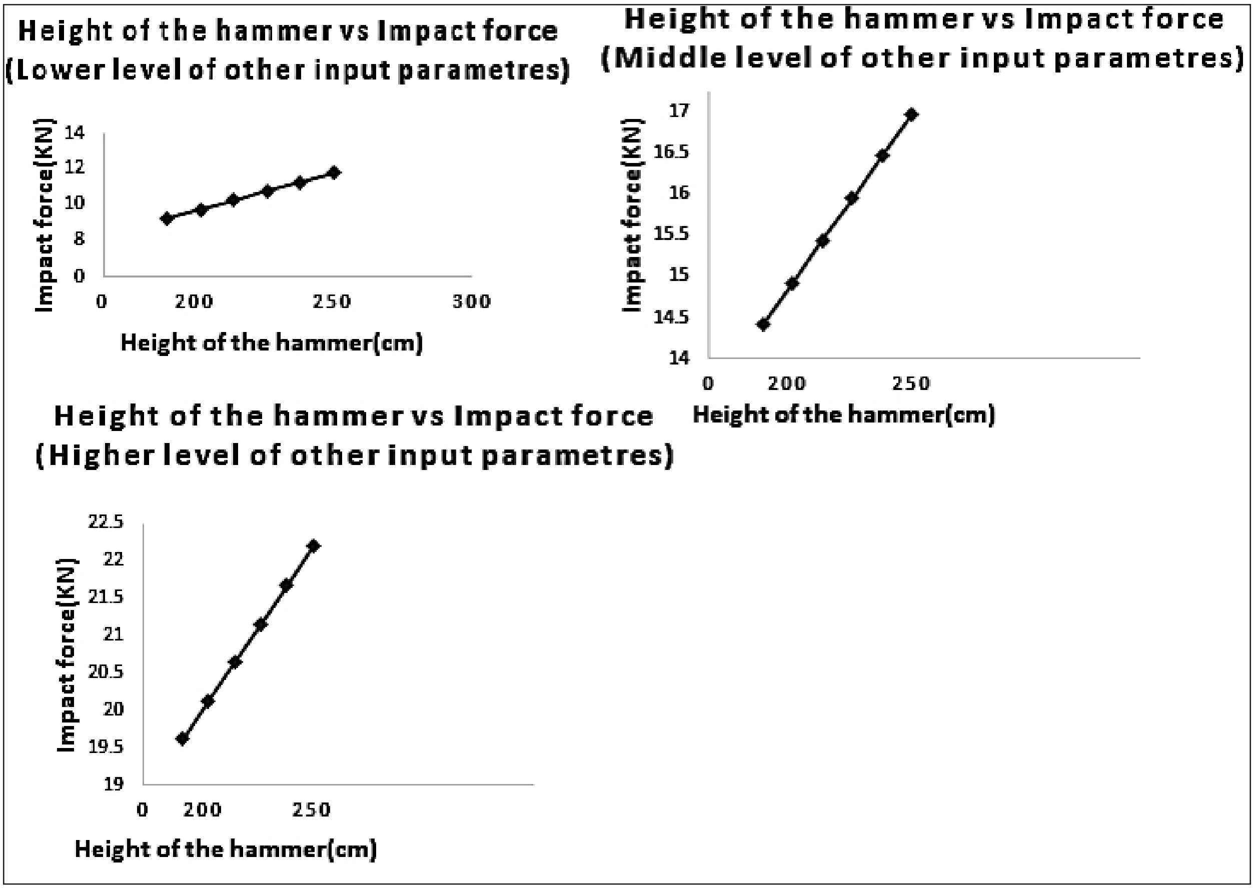

Fig. 6. Graphical relation between height of the hammer with impact force.

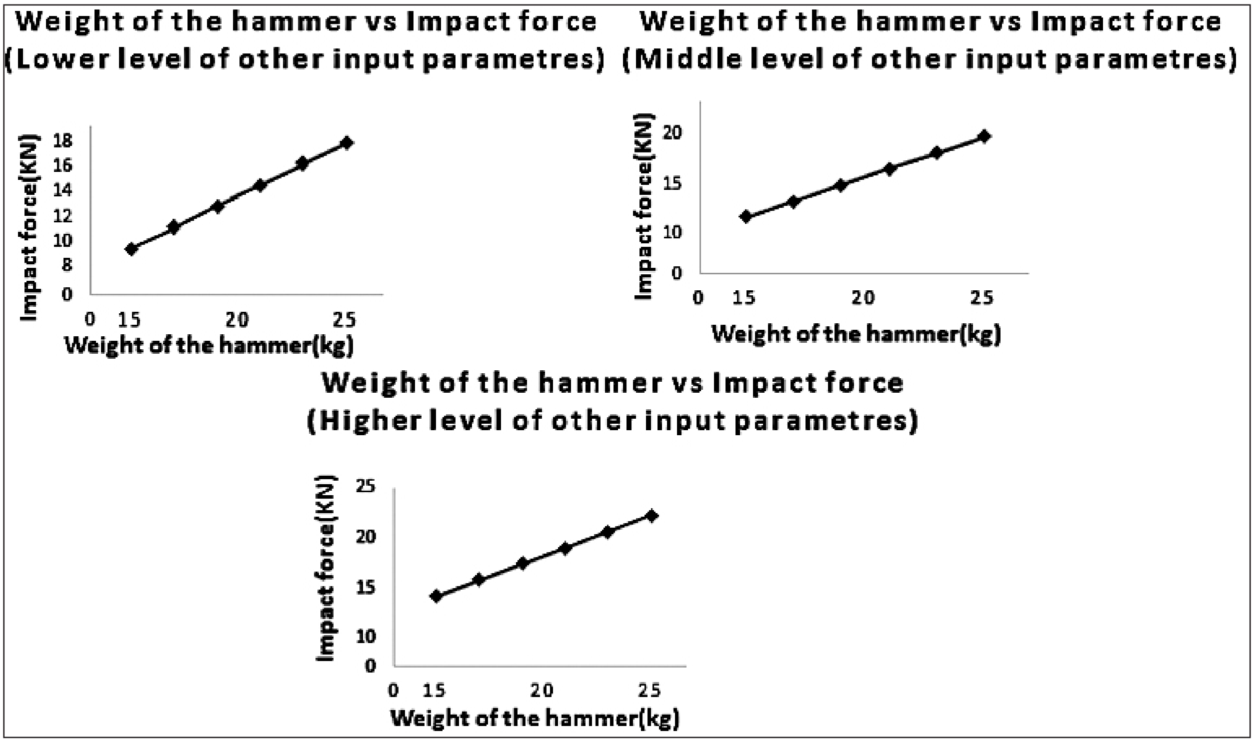

Fig. 7. Graphical relation between weight of the hammer with impact force.

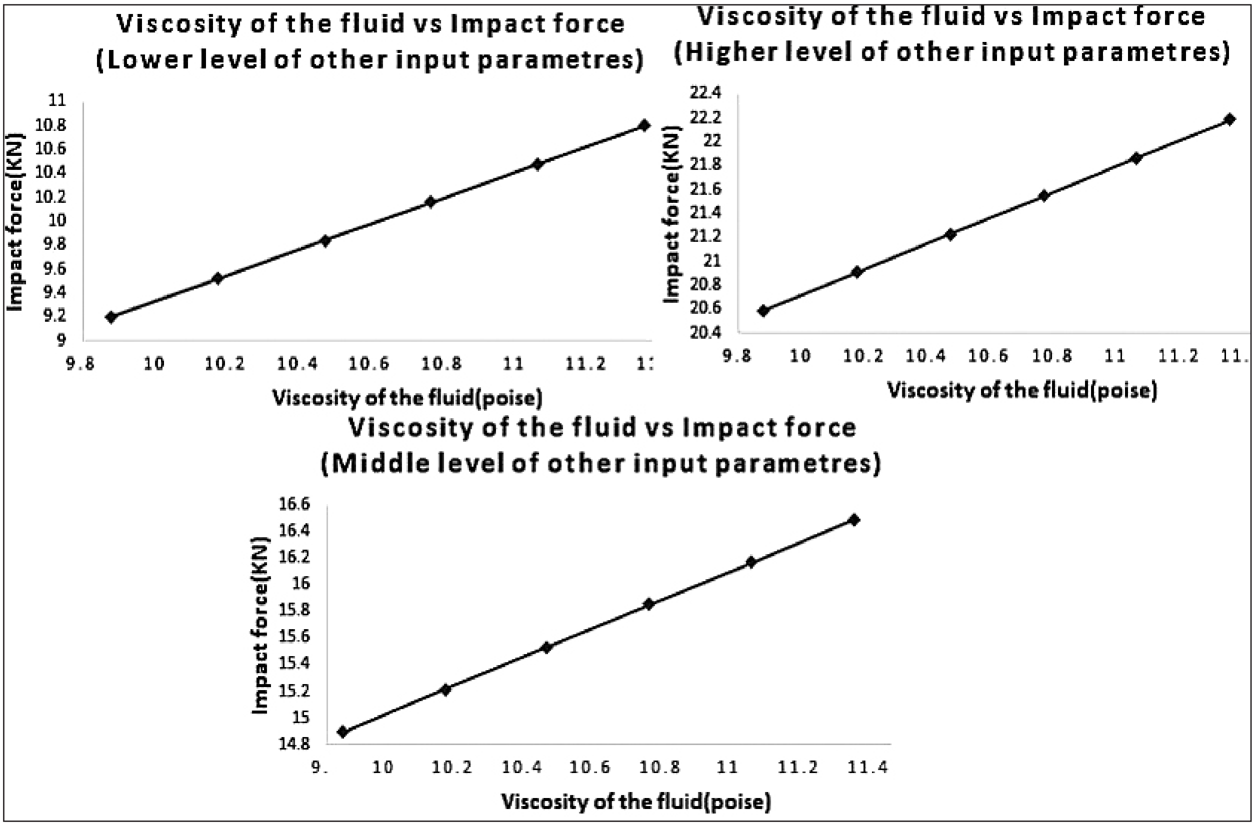

Fig. 8. Graphical relation between viscosity of the fluid with impact force.

Table 4
Validation of predicted force with respect to experimental impact force.

Parameter	Level	Experimental Force (kN)	Predicted Force (kN)	Error (kN)	% Error
t	0.2	8.75	9.19916	0.44816	5.12
t	0.5	21.7391	22.18652	0.44746	2.05
h	190	8.75	9.19916	0.44816	5.12
h	250	21.7391	22.18652	0.44746	2.05
w	15	8.75	9.19916	0.44816	5.12
w	25	21.7391	22.18652	0.44746	2.05
o	9.88	8.75	9.19916	0.44816	5.12
o	11.36	21.7391	22.18652	0.44746	2.05

input parameters is 0.792kN when a range of 0.2 to 0.5mm thickness of sheet is considered. From ANOVA also it is clear that effect of sheet thickness is very less on impact force.

- It is seen from graphical relation between height of hammer with impact force (Fig -6) variation of force is considerably high when lower-level values are taken for other input parameters when height of hammer is 190 cm the impact force is 9.19916 kN and at 250 cm height its value is 11.77316 kN, similarly at middle level values of other parameters for 190 cm force is 14.40584 kN ant at 250 cm it is 16.97984 kN. At higher level values of other parameters for 190 cm force is 19.61252 kN and at 250 cm it is 22.18652 kN. Average variation of impact force for lower, middle, higher levels of other input parameters is 2.574 kN when a range of 190 cm to 250 cm height is considered.
- It is seen from graphical relation between weight of hammer with impact force (Fig -7) variation of force is considerably high when

lower-level values are taken for other input parameters when weight of hammer is 15kg the impact force is 9.19916 kN and at 25kg weight its value is 17.21916 kN, similarly at middle level values of other parameters for 15kg force is 11.68284 kN ant at 25kg it is 19.70284 kN. At higher level values of other parameters for 15kg force is 14.16652 kN and at 25kg it is 22.18652 kN. Average variation of impact force for lower, middle, higher levels of other input parameters is 8.02 kN when a range of 15kg to 25kg weight is considered.

- It is seen from graphical relation between viscosity of fluid with impact force (Fig - 8) variation of force is considerably high when lower-level values are taken for other input parameters when viscosity of fluid is 9.88 poise the impact force is 9.19916 kN and at 11.36 poise viscosity its value is 10.80052 kN, similarly at middle level values of other parameters for 9.88 poise force is 14.89216 kN ant at 11.36 poise it is 16.49352 kN. At higher level values of other parameters for 9.88 poise force is 20.58516 kN and at 11.36 poise it is 22.18652 kN. Average variation of impact force for lower, middle, higher levels of other input parameters is 1.60136 kN when a range of 9.88 poise to 11.36 poise weight is considered. From ANOVA also it is clear that effect of viscosity of fluid is very less on impact force.
- A conclusion may be drafted from the results that hydraulic impact sheet metal deformation can be successfully employed for Superni 718 material with green manufacturing concept. Which is very much useful for Small & Medium scale industries where power fluctuations are more and cost viability is the constraint.

References

Alder, I. P., & Markova, E. V. (1975). *The design of experiments to find optimal conditions: A programmed introduction to the design of experiments.* MIR Publications, Moscow.

Barzegar, M., Rasi, R. E., & Niknamfar, A. H. (2018). Analyzing the drivers of green manufacturing using an analytic network process method: a case study. *International Journal of Research in Industrial Engineering, 7*(1), 61-83.

Botas, J. A., Moreno, J., Espada, J. J., Serrano, D. P., & Dufour, J. (2017). Recycling of used lubricating oil: Evaluation of environmental and energy performance by LCA. *Resources, Conservation and Recycling, 125,* 315-323. https://doi.org/10.1016/j.resconrec.2017.07.010

Davis, R., & Austin, E. R. (1970). *Developments in high-speed metal forming*, Machinery Publishing.

Gajanana, S. (2002). Development of mathematical model for maximum punch force. *Proceeding of National Conference on Advanced Trends in ME Research and Development, 21st Dec, JNTU College of Engineering, Ananthapur.*

Gajanana, S. (2007). Development of mathematical model for EDM using two factorial design of experiments. *XXIII National Convention of Mechanical Engineers and National Seminar On Emerging Trends In Manufacturing Systems and Technologies*, Hyderabad, September 10-12.

Gajanana. S. (2006). Optimization of process parameters for hero honda exhaust valve using design of experiments. *Proceeding of National Conference on Recent Advances in Computer Aided Engineering, 3-4 March, Osmania University, Hyderabad.*

Grieve, R. J., & Wambugu, N. W. (1981). Some aspects of sheet-metal forming using impact loading through water columns. *Experimental Mechanics, 21*(8), 302-308. https://doi.org/10.1007/bf02325770

H.M.T. (1988). *Production Technology.* TMH, New Delhi.

Jie, X. (2017). Research on green manufacturing innovation based on resource environment protection. *IOP Conf. Series: Earth and Environmental Science, 94,* 012112.

Kumar, R., & Sharma, A. K. (2012). Analysis of water hammer forming on the sheet metal. *Journal of Information Engineering and Applications, 2*(1).

Mahalle, G., Kotkunde, N., Gupta, A. K., & Singh, S. K. (2020). Prediction of flow stress behaviour by materials modelling technique for Inconel 718 alloy at elevated temperature. *Advances in Materials and Processing Technologies, 6*(2).https://doi.org/10.1080/2374068X.2020.1728649

Mahalle, G., Morchhale, A., Kotkunde, N., Gupta, A. K., Singh, S. K., & Lin, Y. C. (2020). Forming and fracture limits of IN718 alloy at elevated temperatures: Experimental and theoretical investigation. *Journal of Manufacturing Processes, 56,* 482-499. https://doi.org/10.1016/j.jmapro.2020.04.070

Montgomery, D. C. (2005). *Design and analysis of experiments. Germany:* John Wiley & Sons.

Nallusamy., Dinagaraj, G. B., Balakannan, K., & Satheesh, S. (2015). Sustainable green lean manufacturing practices in small scale industries - A case study. *International Journal of Applied Engineering Research. 10,* 143-146.

Niknamfar, A. H., Barzegar, M., & Rasi, R. E. (2018). Analyzing the drivers of green manufacturing using an analytic network process method: A case study. *The International Journal of Industrial Engineering: Theory, Applications and Practice, 7*(1), 61-83.

Rabiee, N., Sharma, R., Foorginezhad, S., Jouyandeh, M., Asadnia, M., Rabiee, M., Akhavan, O., Lima, E. C., Formela, K., Ashrafizadeh, M., Fallah, Z., Hassanpour, M., Mohammadi, A., & Saeb, M. R. (2023). Green and sustainable membranes: A review. *Environmental Research, 231*, 116133.

Shahzad, M., Qu, Y., Rehman, S. U., & Zafar, A. U. (2022). Adoption of green innovation technology to accelerate sustainable development among manufacturing industry. *Journal of Innovation & Knowledge. 7*(4). 10.1016/j.jik.2022.100231.

Shen, Y., & Zhang, X. (2023). Intelligent manufacturing, green technological innovation and environmental pollution. *Journal of Innovation & Knowledge, 8*(3). 100384.

Singh, M., Singh, K., & Sethi, A. P. S. (2020). An empirical investigation and prioritizing critical barriers of green manufacturing implementation practices through VIKOR approach. *World Journal of Science, Technology and Sustainable Development, 17*(2), 235-254. https://doi.org/10.1108/WJSTSD-08-2019-0060

E. Hazya is presently working as Assistant Professor (C), Mechanical Engineering Department, JNTU, Hyderabad. He did his B.E in Mechanical Engineering, Master's Degree in Production Engineering from Osmania University, Hyderabad. Currently he is pursuing his Ph.D from Osmania University in field of Metal forming. (E-mail: hazyanaik@gmail.com)

Dr. S. Gajanana presently working as Professor in Mechanical Engineering, MVSR Engineering College, Hyderabad. He did his B.Tech in Mechanical Engineering from S. K. University, Anantapur. Master's Degree in Mechanical Engineering Specialization in Production Technology from Karnatak University, Dharwad. Ph.D from S. V. University, Tirupati in the year 2007. Currently he is guiding 9 PhDs, 4 Ph.Ds are awarded and published more than 75 research papers in various International & National journals and International & National Conferences. He also completed one research project, sponsored by UGC. He served as Head, Department of Mechanical Engineering, and Director (SA) at MVSR Engineering College. Currently discharging the duties of Controller of Examinations, MVSR Engineering College (Autonomous), Hyderabad.

Dr. P. Laxminarayana presently working as Professor in Mechanical Engineering, College of Engineering, Osmania University, Hyderabad. He did his B.E in Mechanical Engineering from Osmania University, Hyderabad. Master's Degree in Mechanical Engineering Specialization in Production Engineering from Osmania University, Hyderabad. Ph.D from Osmania University in the year 2003. Currently he is guiding 8 Ph.Ds, 13 Ph.Ds are awarded and published more than 110 research papers in various International & National journals and International & National Conferences. He served as Head, Department of Mechanical Engineering, Chairman-Board of Studies, Dean (Faculty of Engineering), OU and many more.
(E-mail: laxp@osmania.ac.in)

Dr. B. Ravikumar presently working as Assistant Professor in Mechanical Engineering, MVSR Engineering College, Hyderabad. He did his B.Tech in Mechanical Engineering from JNTU, Hyderabad. Master's Degree in Mechanical Engineering Specialization in Production from JNTU, Hyderabad. Ph.D from JNTU, Hyderabad in the year 2021. He has published more than 15 papers in national and international journals and conferences.
(E-mail: brkmvsr@gmail.com)

Dr. B. Suresh Kumar Reddy presently working as Assistant Professor in Mechanical Engineering, MVSR Engineering College, Hyderabad. He did his B.Tech in Mechanical Engineering from S. K. University, Anantapur. Master's Degree in Mechanical Engineering Specialization in Materials Engineering from NITK, Suratkal. Ph.D from Osmania University, Hyderabad in the year 2022. He has published more than 15 papers in national and international journals and conferences.
(E-mail: bsuresh_mech@mvsrec.edu.in)