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EXPERIMENTAL INVESTIGATION AND FINITE ELEMENT ANALYSIS OF SHEET METAL FOR OPTIMUM FORMING PROCESS

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ABSTRACT:
The effects of numerous parameters like different material thickness, velocity, and stress on the bending process of Sheet metal are comprehensively studied at the same time for a single component. This research work describes about the experimental investigation and finite element analysis of the bending process for stainless steel, aluminum and brass materials. Simulations are conducted with the help of simulation software to investigate the influence of process variable on stress produced while bending. Response Surface methodology is used for Optimization in order to find optimum parameters. The paper reveals the comprehensive study on the variation of stress with Punch Velocity and thickness of Sheet metal for different materials considered in the research work.
Keywords: Sheet Metal Thickness; Velocity; RSM; FEA; Simulation.

1. INTRODUCTION:

Bending is the cold working process involving plastic deformation in which the total surface area remains constant .In bending outer fibers of the metal are in tension while the inner fibers are in compression. Bending process involves bending of metal by plastically deforming the matter and altering its form. As a fundamental and traditional process in metallic forming technologies, sheet metal forming is widely being employed in almost all industrial fields. U bending process can be considered as two steps of loading and unloading. In the first step there is a complete bending of die into the die until complete down movement of punch. In this step there is an elasto plastic deformation and temperature increases due to frictional resistance. In the second step there is an ejection of sheet metal from die[1]. Major defect produced in the bending process is spring back. Min Kuk Choi & Hoon Huh[2] presents effect of punch speed on amount of spring back for u bending dies. Result shows that effect of punch speed on spring back is very less. In this research work experimental and Finite Element Analysis on effect of punch velocity and material thicknesses of aluminum, stainless steel and brass on stress produced in U bending process are presented. Wang et al. investigated the effects of forming speed on the deformation characteristics for adhesively bonded aluminum blanks by doing V – bending experiments and conducting numerical simulations with various punch speeds at the room temperature[3].

2. EXPERIMENTAL WORK:

A universal testing machine (UTM), also known as a universal tester materials testing machine or materials test frame, is used to test the tensile stress and compressive strength of materials. Experiments are performed on Universal Testing Machine HL 591.15 model by vary materials, plate thickness and at a fixed punch velocity of 1.2 mm/s to analyze the bending process. The experimental set-up is shown in Fig. 1.
The Punch set has been machined using a CNC Machine for the standardization purpose. The dimensions for Die and Punch set are also listed in the Table1.Amir Atrian et al. have also performed experiments using a 600kN Instron Testing Machine with a 0.5mm/sec displacement rate[4].

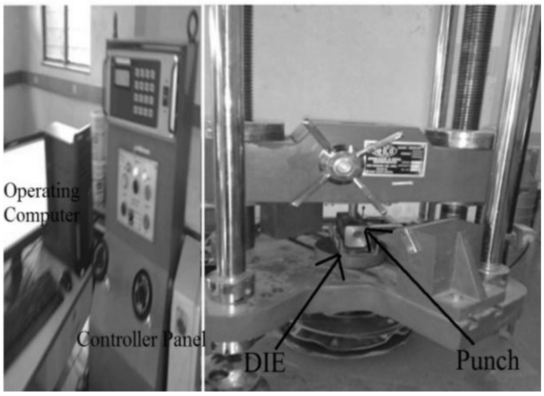

Fig. 1 Actual experimental set-up

Table 1 Dimensions for punch and die

Sr. No.	Name of Component	Length (mm)	Width (mm)	Height (mm)
1	Punch	150	60	60
2	Die	190	95	50

2.1 EXPERIMENTAL RESULTS:

By varying the thickness of Stainless steel and Galvanized iron metal sheet, following results are obtained and is shown in Table 2.

Table 2 Experimental Results

Sr. No.	Blank Sheet Material	Initial Thickness (mm)	Velocity (mm/s)	Load (KN)	Displacement (mm)
1	Galvanized Iron	1.5	1.2	18.33	35.67
2	Galvanized Iron	1.2	1.2	15.23	43.73
3	Stainless Steel	1.2	1.2	14.4	43.1
4	Stainless Steel	1.5	1.2	15.13	43.95

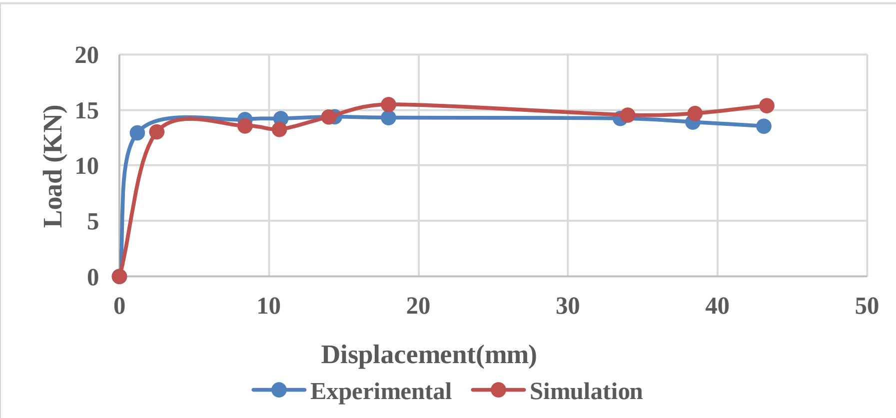

Fig. 2 Variation of Load against Displacement for Stainless Steel with 1.2 mm thickness and 1.2mm/sec Velocity

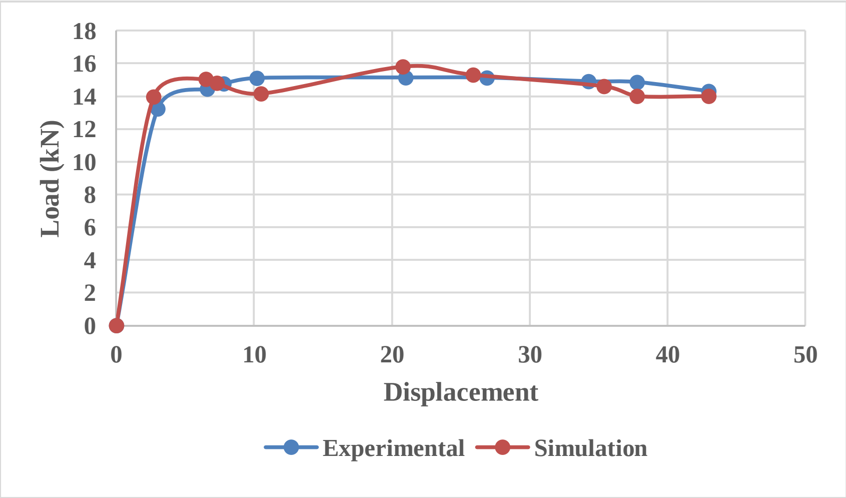

Fig. 3 Variation of Load against Displacement for Stainless Steel with 1.5 mm thickness and 1.2 mm/sec Velocity

For validation of experimental results, simulations are performed in DEFORM 3D. Experimental results are compared with simulations performed in DEFORM 3D for stainless steel sheets of thickness 1.5 mm and 1.2 mm with a velocity of 1.2 mm/s. Experimental and simulation results are plotted in same graph of Load Vs. Displacement. Experimental and simulation results are shown in Fig. 2 and Fig. 3. Both are approximating same.

3. SIMULATIONS AND FINITE ELEMENT ANALYSIS:

Due to the result of types of shapes and increase in the production rate of sheet metal products, traditional trial and error methods have lost their feasibility in the design of sheet metal forming processes. In order to address this issue and to capture the complexities of the real process a more organized method is needed. From last few years computational methods have been developed and computer simulations can be anticipated to play a significant role in the mechanized world. The first numerical simulation for sheet metal forming operations was performed by Woo[5]. Simulation will be performed in DEFORM-3D software due to provision of incredible flexibility to manufacturing engineers, metallurgists and process scientists to design tools, optimize current production methods, troubleshoot and also undertake fundamental development in metal forming and heat treatment. For getting the accurate results the DEFORM - 3D has been also being extensively used by Sung – Bo Sim et Al[6].

3.1 SIMULATION RESULTS FOR ALUMINUM BLANK MATERIAL:

Simulations has been performed on 1.5 mm, 1.2 mm and 0.8 mm thickness of Aluminum material with punching velocity of 100 mm/s, 150 mm/s and 200 mm/s in DEFORM 3D. The stress variation results are shown in Fig. 4 and Table 3.

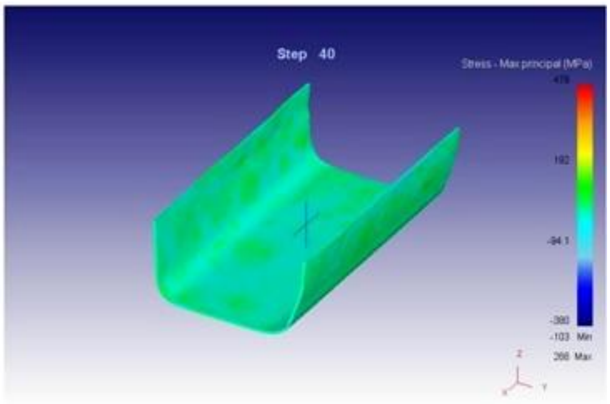

Fig. 4 Stress variations in aluminum of 1.5 mm thickness and 100 mm/s velocity

Table 3 Maximum principal stress generated in Aluminum

Sr. No.	Thickness (mm)	Punch Velocity (mm/s)	Maximum Principal Stress Generated (MPa)
1	1.5	100	266
2	1.2	100	202
3	0.8	100	131
4	1.5	150	154
5	1.2	150	173
6	0.8	150	118
7	1.5	200	178
8	1.2	200	296
9	0.8	200	204

Fig. 5 shows graphical representation of Stress vs. Thickness with 100 mm/s, 150 mm/s and 200 mm/s velocity. Stress reduces with increase in velocity from 100 mm/s to 150 mm/s and it further increases for velocity 200 mm/s. For velocity of 100 mm/s and 150 mm/s, as thickness increases stress also increases. For velocity of 200 mm/s after increases in stress for increase in thickness of 0.8 mm to 1.2 mm, stress decreases for 1.5 mm thickness. Minimum stress value occurs for 150 mm/s and Maximum stress value occurs for 200 mm/s.

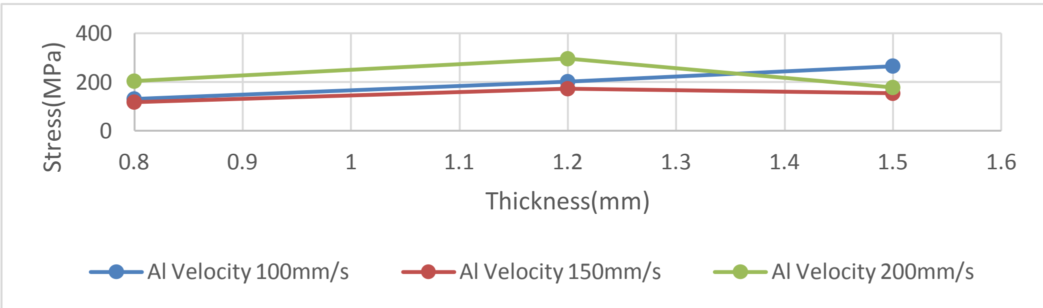

Fig. 5 Effect of Blank Thickness on stress for aluminum material with change in different velocities

3.2 SIMULATION RESULTS FOR STAINLESS STEEL BLANK MATERIAL:

Simulations has been performed on 1.5 mm, 1.2 mm and 0.8 mm thickness of Stainless steel material with punching velocity of 100 mm/s, 150 mm/s and 200 mm/s in DEFORM 3D. The stress variation results are shown in Fig. 6 and Table 4.

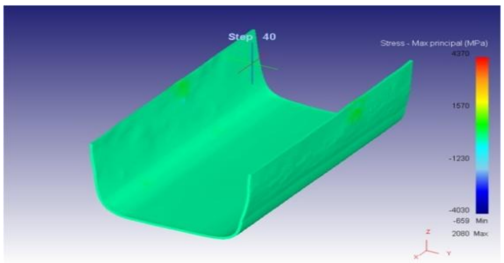

Fig. 6 Stress variations in stainless steel of 1.5 mm thickness and 100 mm/s velocity

Fig. 7 shows graphical representation of Stress vs. Thickness for stainless steel with 100 mm/s, 150mm/s and 200mm/s velocity. It can be conclude that Stress reduces with increase in velocity from 100 mm/s to 150 mm/s and it further increases for velocity 200 mm/s. Minimum stress value occur for 150 mm/s and Maximum stress value occurs for 200 mm/s. For 100 mm/s punch velocity, very small amount of change in stress with increase in thickness. For 150 mm/s and 200 mm/s punch velocity stress increases with increase in thickness.

Table 4 Maximum principal stress generated in Stainless steel

Sr. No.	Thickness (mm)	Punch Velocity (mm/s)	Maximum Principal Stress Generated (MPa)
1	1.5	100	2080
2	1.2	100	1120
3	0.8	100	1560
4	1.5	150	1200
5	1.2	150	1170
6	0.8	150	1310
7	1.5	200	2070
8	1.2	200	1640
9	0.8	200	1340

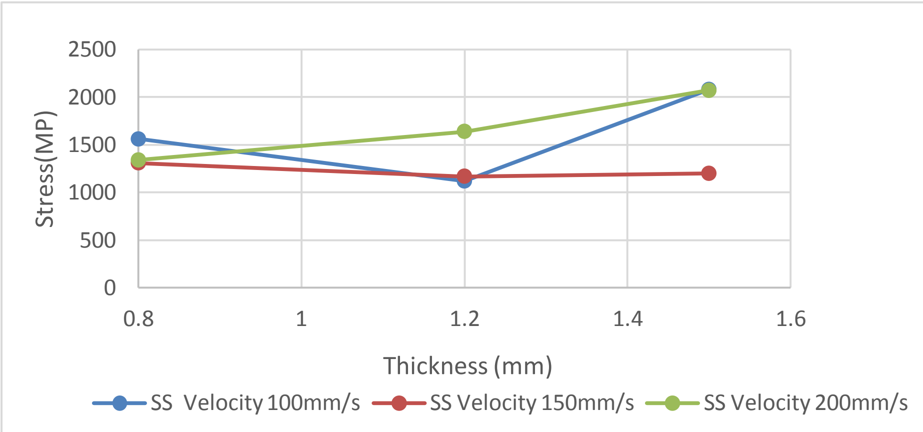

Fig. 7 Effect of Blank Thickness on stress for Stainless Steel material with change in different velocities

3.3 SIMULATION RESULTS FOR BRASS BLANK MATERIAL:

Simulations has been performed on 1.5 mm, 1.2 mm and 0.8 mm thickness of Brass material with punching velocity of 100 mm/s, 150 mm/s and 200 mm/s in DEFORM 3D. The stress variation results are shown in Fig. 8 and Table 5.

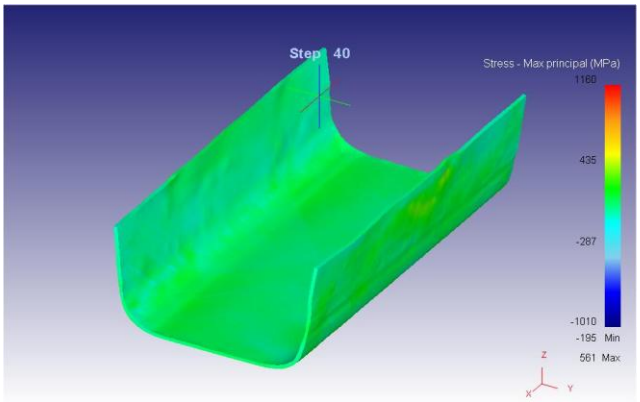

Fig. 8 Stress variations in stainless steel of 1.5 mm thickness and 100 mm/s velocity

Table 5 Maximum principal stress generated in Brass

Sr. No.	Thickness (mm)	Punch Velocity (mm/s)	Maximum Principal Stress Generated (MPa)
1	1.5	100	561
2	1.2	100	499
3	0.8	100	779
4	1.5	150	710
5	1.2	150	553
6	0.8	150	546
7	1.5	200	665
8	1.2	200	775
9	0.8	200	559

Fig. 9 shows graphical representation of Stress vs. Thickness with 100 mm/sec, 150 mm/sec and 200 mm/s velocity. Stress increases with increase in velocity. For velocity 100 mm/s and 200 mm/s stress reduces with increase in thickness. For 150 mm/s velocity stress increases with increase in thickness. Here both maximum and minimum value of stress occurs at 100mm/s punch velocity.

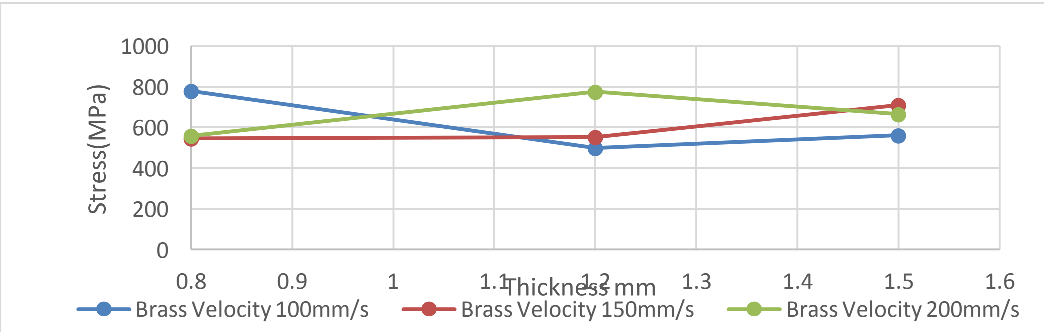

Fig. 9 Effect of Blank Thickness on stress for brass material with change in different velocities

4. OPTIMIZATION METHODOLOGY:

Now a day's one of the core research topics in the field of automobile is about optimization carried for the forming processes expected at the production of desired and precise components with high resistivity. As a trustworthy methodology, design of experiments and Response Surface Methods are useful for the optimization of sheet metal forming problems[7].

In order to The Response Surface Method (RSM) is a statistical and mathematical method which gives an effective and practical means for design optimization. Here objective is to find the optimum parameters which affect the responses[8]. A general Second-order polynomial response surface mathematical model is used to analyze the effect of various parameters on response and is given by

$$y_u = \beta_0 + \sum_{i=1}^{k} \beta_i x_{iu} + \sum_{i=1}^{k} \beta_{ii} x_{iu}^2 + \sum_{i<j} \beta_{ij} x_{iu} x_{ju} + e_u \qquad \textbf{(4.1)}$$

Here y_u is a response for stress. x_{iu} is the coded value of the i^{th} parameter of the u^{th} experiment, k is the number of parameters and β_i, β_{ii}, β_{ij} are 2nd order regression coefficients, the residual e^u is a measure of experimental error of the uth observation.

Here k=2 (Thickness, Velocity). Thus,

$$y_u=\beta_0+\beta_1x_1+\beta_2x_2+\beta_{11}x^2{}_1+\beta_{22}x^2{}_2+\beta_{12}x_1x_2 \qquad \textbf{(4.2)}$$

Coded values are calculated using equation

$$X_{ij} = \frac{X_{ij} - [(\max X_{ij} + \min X_{ij})]/2}{[(\max X_{ij} - \min X_{ij})]/2} \quad \textbf{(4.3)}$$

Where X_{ij} is the ith natural variable for the j^{th} experimental run.
Here i=1, 2,
X_1 =Thickness, x_1 = Coded Value of thickness
X_2=Velocity, x_2 = Coded value of velocity

Coded Values of thickness, $x_{1j} = \frac{X1j - [\frac{1.5+0.8}{2}]}{\frac{1.5-0.8}{2}} = \frac{X1j-1.15}{0.35}$ **(4.4)**

Coded Values of Velocity, $x_{2j} = \frac{X2j - [\frac{20+10}{2}]}{\frac{20-10}{2}} = \frac{X2j-15}{5}$ **(4.5)**

Table 6 Response values of variables for different process

Sr. No.	A (Coded Values of thickness)	B (Coded Values of Velocity)	Thickness (X_1)	Velocity (X_2)	Stress (Response)- Y_{Stress}
1	1	-1	1.5	100	266
2	0.142857	-1	1.2	100	202
3	-1	-1	0.8	100	131
4	1	0	1.5	150	154
5	0.142857	0	1.2	150	173
6	-1	0	0.8	150	118
7	1	1	1.5	200	178
8	0.142857	1	1.2	200	296
9	-1	1	0.8	200	204
10	1	-1	1.5	100	2080
11	0.142857	-1	1.2	100	1120
12	-1	-1	0.8	100	1560
13	1	0	1.5	150	1200
14	0.142857	0	1.2	150	1170
15	-1	0	0.8	150	1310
16	1	1	1.5	200	2070
17	0.142857	1	1.2	200	1640
18	-1	1	0.8	200	1340
19	1	-1	1.5	100	561
20	0.142857	-1	1.2	100	499
21	-1	-1	0.8	100	779
22	1	0	1.5	150	710
23	0.142857	0	1.2	150	553
24	-1	0	0.8	150	546
25	1	1	1.5	200	665
26	0.142857	1	1.2	200	775
27	-1	1	0.8	200	559

Coded Values of thickness and velocity are calculated using above equations and is shown in table 6 as symbol A and B respectively. Estimated Regression Coefficients for stress using data in un-coded units is shown table 7.

Table 7 Estimated regression coefficients for stress using data in un-coded units

Coded values	Coefficient
β_0=588.345	β_0
A=74.2778	β_1
B=27.5169	β_2
A*A=100.155	β_{11}
B*B=169.833	β_{22}
A*B=39.3119	β_{12}

Thus,

$$y_u = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x^2_1 + \beta_{22} x^2_2 + \beta_{12} x_1 x_2 \quad \textbf{(4.6)}$$

So, Final Equation of Response is given by

$$Y_{stress} = 588.345 + 74.2778*A + 27.5169*B + 100.155*A2 + 169.833*B2 + 39.3119*A*B \quad \textbf{(4.7)}$$

Thus, by putting the values of thickness and velocity i.e. A and B in above equation response values has been obtained by which contour plot has been generated and is shown in Fig. 10.

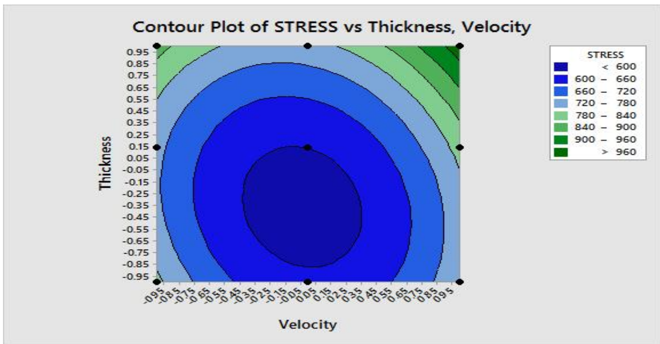

Fig. 10 Contour Plot of variation of Stress against change in thickness and Velocity

Contour plot shows that lowest stress occurs in the region of velocity from -0.4 to 0.35 i.e. velocity from 13 to 16.7 mm/s and thickness from -0.85 to 0.1 i.e. thickness from 0.85 mm to 1.18 mm. Contour plot also shows that stress decreases with increase in velocity from 100 mm/s to 150 mm/s and from 150 mm/s to 200 mm/s stress increases. In case of thickness, up to thickness of -0.35 i.e. 1.02 mm stress decreases with increase in thickness and above this value stress increases with increase in thickness. Thus, parameters velocity of 15 mm/s and thickness of 1.02 mm these are the values below which stress decreases with increase in value and above these values stress increases with increase in these values.

5. CONCLUSION:

This investigation has been carried out to analyze and optimize the performance parameters of metal sheets. In aluminum metal sheets lowest stress values are obtained, brass sheets have higher stress values than aluminum and in case of stainless steel highest stress values have been obtained due to material properties of metal sheets. Finite element simulations has been performed to analyze the effect of performance parameters i.e. thickness and velocity on stress. Optimization results indicate that parameters with velocity of 150 mm/s and thickness of 1.2 mm these are the values below which stress decreases with increase in value and above these values stress increases with increase in these values.

5.1 RESULTS AND DISCUSSION FOR ALUMINUM:

In aluminum stress first decreases with increase in velocity from 100 mm/s to 150 mm/s and then increases with increase in velocity from 150 mm/s to 200 mm/s. Here highest amount of change in stress and overall change in stress is described below for constant velocity and constant thickness.

5.1.1 CONSTANT VELOCITY:

1. For constant velocity of 100 mm/s highest amount of stress change is increment of 50.7% with increment in thickness from 0.8 mm to 1.5 mm.
2. For constant velocity of 150 mm/s highest amount of stress change is increment of 31.8% with increment in thickness from 0.8 mm to 1.2 mm and 23.4% stress increment is achieved for increment in thickness from 0.8 mm to 1.5 mm.
3. For constant velocity of 200 mm/s highest amount of stress change is reduction of 12.7% with increment in thickness from 0.8 mm to 1.5 mm.

5.1.2 CONSTANT THICKNESS:

1. For constant thickness of 1.5 mm highest amount of stress change is reduction by 42.1% with increment in velocity from 100 mm/s to 150 mm/s and reduction by 33% stress change is achieved for increment in velocity from 10 mm/s to 20 mm/s.
2. For constant thickness of 1.2 mm highest amount of stress change is increment of 41.5% with increment in velocity from 150 mm/s to 200 mm/s and reduction of 31.7% stress change is achieved for increment in velocity from 100 mm/s to 200 mm/s.
3. For constant thickness of 0.8 mm highest amount of stress change is reduction by 42.1% with increment in velocity from 150 mm/s to 200 mm/s and increment of 35.8% stress change is achieved for increment in velocity from 100mm/s to 200mm/s.

5.2 RESULTS AND DISCUSSION FOR BRASS:

Stress produced in brass is higher than aluminum due to its material properties. Here highest amount of change in stress and overall change in stress is shown below for constant velocity and constant thickness.

5.2.1 CONSTANT VELOCITY:

1. For constant velocity of 100 mm/s highest amount of stress change is increment of 11% with increment in thickness from 1.2 mm to 1.5 mm and 27.9% stress reduction is achieved for increment in thickness from 0.8 mm to 1.5 mm.
2. For constant velocity of 150 mm/s highest amount of stress change is increment of 23.1% with increment in thickness from 0.8 mm to 1.5 mm.
3. For constant velocity of 200 mm/s highest amount of stress change is reduction of 27.9% with increment in thickness from 0.8 mm to 1.2 mm and 15.9% stress increment is achieved for increment in thickness from 0.8 mm to 1.5 mm.

5.2.2 CONSTANT THICKNESS:

1. For constant thickness of 1.5 mm highest amount of stress change is increment of 20.9% with increment in velocity from 100 mm/s to 150 mm/s and increment of 15.6% stress change is achieved for increment in velocity from 100 mm/s to 200 mm/s.
2. For constant thickness of 1.2 mm highest amount of stress change is increment of 35.6% with increment in velocity from 100 mm/s to 200 mm/s.
3. For constant thickness of 0.8 mm highest amount of stress change is reduction of 29.9% with increment in velocity from 100 mm/s to 150 mm/s and reduction of 28.2% stress change is achieved for increment in velocity from 100 mm/s to 200 mm/s.

5.3 RESULTS AND DISCUSSION FOR STAINLESS STEEL:

Stress produced in stainless steel is higher than brass and aluminum due to its material properties. Here highest amount of change in stress and overall change in stress is discussed below for constant velocity and constant thickness.

5.3.1 CONSTANT VELOCITY:

1. For constant velocity of 100 mm/s highest amount of stress change is increment of 46.1% with increment in thickness from 1.2 mm to 1.5 mm and 25% stress increment is achieved for increment in thickness from 0.8 mm to 1.5 mm
2. For constant velocity of 150 mm/s highest amount of stress change is increment of 10.7% with increment in thickness from 0.8 mm to 1.2 mm and 8.4% stress increment is achieved for increment in thickness from 0.8 mm to 1.5 mm.
3. For constant velocity of 200 mm/s highest amount of stress change is reduction of 35.3% with increment in thickness from 0.8 mm to 1.5 mm.

5.3.2 CONSTANT THICKNESS:

1. For constant thickness of 1.5 mm highest amount of stress change is reduction of 42.3% with increment in velocity from 100 mm/s to 150mm/s are achieved.
2. For constant thickness of 1.2 mm highest amount of stress change is reduction of 31.7% with increment in velocity from 100 mm/s to 200 mm/s are achieved.
3. For constant thickness of 0.8 mm highest amount of stress change is reduction of 16% with increment in velocity from 100 mm/s to 150 mm/s and reduction of 14.1% stress change is achieved for increment in velocity from 100 mm/s to 200 mm/s.

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