

MULTISTAGE WIRE DRAWING PROCESS ANALYSIS AND OPTIMIZATION OF PROCESS PARAMETERS

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Abstract:- Aluminium multistage wire drawing process is challenging in the surface as the wire is hard and abrasive and the dust and powder generation is higher. A lower tensile strength requires accurate tension control to avoid lack of roundness of the finished wires in reels. Here Deform 3DVer.10.2 application software was used to optimize the process parameters, unnecessary tension which cause damage in the Al 1080A wire was analysed and load and amount of strain generation was also evaluated so that a high strength wire production was possible. Thesis work was carried out to develop new process design by optimization of process parameters for aluminium 1080A. The work aim was to analyse and numerically study the process parameters using finite element model and also to investigate the effect of loads on drawing of wire and other process parameter on drawing process.

In experimental methodology, first step was to find out the drawbacks in existing multistage wire drawing process, second step was various cause for low strength in the wire. So a new process design was carried out with optimized process parameters by use of hit and trial method. A shop floor experiment takes lots of time and cost. So simulation was done with use of DEFORM 3D Ver.10.2 application software, where post processing results was analysed and finally optimized new design of process parameter was obtained by hit and trial method.

In this work the effect of speed drawing (1mm/sec) kept constant only die diameter was changed to see the effect of other parameter. Shear friction is 0.2, reduction of die was taken 15% for three stages of drawing. All stages were compared with each other and analysis was done on load, force, stress effective, strain effective, stress max principal and damage in the wire. A tensile stress produced desired is as needed so strength of wire become high. By hit and trial method an optimized data is obtained for wire drawing process design. Only dimension of dies were changing by 15% to obtain desired diameter of wire 1.8 mm of original diameter 3 mm.

On the basis of analysis of the results. It was concluded that the friction coefficient and drawing speed also kept constant for all stages of drawing. Finally optimised process parameter design was obtained for multistage wire drawing.

Keywords: Wire drawing, Load value Multistage Wire Drawing, Drawing Speed, Die angle, Reduction ratio, Load, Stress- Effective, Strain-Effective, Strain Rate –Effective, Damage

1. Introduction

The primary goal of this study was to access the optimum process parameters which was necessary for the achievement of both quality and productivity. The optimized setting should ensure best outcome. The feeding system must be properly designed in order to have defect free wire.

Multistage wire drawing process is a process in which work piece is pulling through the dies, which reduces the cross section area of the work piece, it may be solid or hollow. Dies used in multistage wire drawing process are fixed and work pieces are plastic in nature. Steel, Al and Cu are the common material used as a work piece in multistage wire drawing process. Common die material is Steel for bar, rod and tube drawing. Nitriding is done after hardening to increase the wear resistance. Diamond dies are used for small diameter reduction with high wear resistance. The reduction in area varies from 10% to 40% for any wire drawing process. The geometry of dies affects the output responses such as effective strain, stress effective and load etc. Generally angle of dies are taken in between 4° to 12° for multistage wire drawing process. The reduction and friction condition for multistage wire drawing process depends on value of the die angle. In multistage cold wire drawing process drawing speed varies from 0.4m/s to 40m/s and load is not affected by speed.

2. Literature Review

Eiji et al. [1] analyzed the metallurgy simulation for the metal drawing process optimization by using two scale finite element methods. Two scales FE analysis procedure developed based on the crystallography homogenization method by considering the hierarchical structure of poly-crystal Al alloy metal. Micro polycrystalline structure modeled as a three dimensional representative volume element. This FE analysis code predicted the deformation strain, stress evaluations in the wire drawing process in micro scales. They analyzed the texture evaluations in the wire drawing process by two scale FE analysis code under conditions of various drawing angles of dices. They evaluated the surface texture and clarified the effects of the processing conditions on the texture evaluation.

Gawali et al. [2] investigated the effect of high speed drawing (25m/sec) on mechanical and technological properties of high carbon steel wire. Wire rod 5.50mm from steel grade 0.46% carbon and 0.71% carbon were drawn to 1.35mm in 13 draws and two speeds 8m/sec and 25m/sec. After each draw the following properties were determined; tensile strength (Ts), temperature (T), number of twists (Nt), number of bends.

Centinarslan [3] studied the ferrous metal cold drawing process for process optimization of process parameters. Material used for studies are C45, C63, C 65, C70. Here compare the all results of different material and effect in change in process parameter were analysed. Various reduction ratio and speed of drawing was selected for different material and investigate the output response and analysed the results. Torsional and strength test was carried out to investigate the process parameters. C presented also affect the drawing process for steel of different compositions, tensional test and tensile test also affected by carbon content in ferrous metal. Statically analysis and experimental analysis was done to see the results and output response. Reduction ratio and speed were changing for different material. After investigation it was observed that drawing speed and reduction ratio affected the tensile test with torsion test.

Hassan et al. [4] analysed the drawing parameters using a 3D finite element model and the effect of these parameters on drawing force. The results showed that the optimum die angle depends on reduction in area. The drawing forces estimated from finite element results was compared with that of analytical results. The drawing velocity has significant effect on drawing force, when the drawing velocity increases the drawing force decreases and the increase of bearing length causes an increase in drawing force, to avoid the increase of drawing force, the reduction in area and friction coefficient should be small with a large die angle. DEFORM-3D was successfully used to simulate the wire drawing process. The adopted model showed a desirable agreement with the results of the analytical method with a maximum error of 4%.

Haddi et al.[5] analyzed the temperature and speed effect on drawing stress for improving the wire drawing process. Thermocouple and load cell system are used to measure the temperature rise and drawing stress for different drawing speed. The result obtained show that drawing stress and temperature rise vary during the drawing process. From the experimental results a relationship between temperature rises, friction co-efficient and drawing stress was build up. A modification of the Avitzur's model was presented. This new model provided the process parameters which satisfy the condition of minimum drawing stress for copper material. A new approach had been developed to characterize interface condition between copper (Cu) wire and the die. Maximum plastic deformation and friction phenomenon causes maximum temperature near the wire –die interface. Study were shown die semi angle, friction coefficient, length of bearing part of the die, temperature had significant effect on drawing process. A comparative study had been done between analytical method and finite element method (FEM). Two materials Cu and steel had been tested under different friction condition. They observed that optimum die angle sligh.

Lee et al. [6] analysed design of multistage wet wire drawing process for improving drawing speed for high carbon (0.72 % C) steel wire. In this study wire temperature variations observed. After that no of passes executed for preventing the rise in wire temperature. A new machine designed to implement the new pass schedule at high speed for improvement of productivity. The no of passes can be increase from 24 to 29 in order to increase the final drawing speed from 1100 m/min -2000 m/min. Wire temperature calculation model for wet wire drawing process was used and appropriate pass schedule was also considered. Finally the final drawing speed was doubled with respect to current drawing process.

Karbayama et al. [7] analysed influence of die geometry on stress distribution by experimental and FEM simulation on electrolytic copper wire drawing. The experimental results showed that the friction coefficient decreases as the wire drawing speed is increases. The simulation showed a variation in the radial and axial tension. Influence of die geometry on the drawn wire was clarified. Capstan machine applied the tensile stress and the compression stress applied by the deformation zone of the die. The wire force and the friction coefficient value decreased while the velocity increases. Distribution of residual stress in drawn wires is predicted by finite element method.

Masse et al. [8] investigated optimal die semi angle concept in wire drawing examined using automatic optimization techniques. In the investigation of concept of optimal dies semi angle in wire drawing used coupling of evolutionary algorithms with Meta model of damage simulation optimization of damage and wire drawing forces suggested a refined vision of optimal dies semi angle concept. It presented that a die semi angle slightly above the optimum. In this paper meta model base evaluation algorithm that demonstrate their robustness and efficiency to analytical problem and complex forming process used, in order to precise the optimal die angle concept in the wire drawing. The optimal die angle minimized the non dimensional drawing stress. It increased reduction ratio and friction factor experimentally. Optimization provided different optimum die semi angle depending on the objective function.

Lee and Tarnq [9] evaluated drawing parameters selection for maximizing production rate or minimizing production cost in multistage drawing process. This paper investigated about drawing parameter for maximum production rate or minimum production cost in multistage wire drawing process. A polynomial network constructed to develop relationship

between parameter such as speed and wire drawing performance such as applied force, die angle etc. The optimal drawing parameter subjected to an objective function of maximum production rate or minimum production cost with constraint of permissible limit of surface roughness, forces and feasible range of drawing parameters. In this study drawing parameters considered the economics of multistage operation.

Domiaty et al. [10] investigated temperature rise in wire drawing. The work objective focussed on the practical knowledge area. The result obtained were used by design manufacturing to select the process which satisfied the condition of minimum temperature rise and maximum energy saving for ten different materials. Comparison between predicted temperature rise and experimental results were shown. The rise in temperature during wire drawing greatly affected the lubrication conditions, tool life and properties of final product. The use of proper lubricant techniques reduces the heat generated during drawing and energy consumption. Process parameter dies angle, friction, force, speed reduction ratio calculated for different ten materials. The predicted value of temperature rise compared with the experimental finding in literature to examine the validity of prediction techniques.

3. Material Used

This simulation was done for the design and analysis of process parameter on multistage wire drawing process. Al 1080A material of wire is used for simulation optimization of the process parameter of wire drawing. Properties of material Al 1080A are shown in table 1.1 given below.

Table.1.1 Properties of the Al – 1080A

S. NO.	PARAMETERS	VALUE
1	Young's Modulus	68GPa
2	Poisson's Ratio	0.33
3	Shear Modulus	26GPa
4	Fatigue strength	18 to 50 MPa
4	Specific Heat Capacity	900j/kg-K
6	Thermal Conductivity	230W/m-K

4. Computer aided simulation process

The simulation process consists of following steps:

4.1 Initial Geometry CAD model of work piece, DIES arrangement are Converted into STL files. These STL files are imported in into the pre-processor of the simulation package.

4.2 Material Data and Meshing In this step, already existing material and their material properties are assigned to imported dies diameter of 2.55 mm, 2.26 mm, 1.8 mm and work piece diameter with 3 mm diameter of Aluminum-1080A, has been chosen to carry out simulation analysis. Meshing can be done with the use of tetrahedral elements.

4.3 Applying Load Conditions Different type of boundary condition were applied for multistage wire drawing such as velocity, coefficient of friction, reduction ratio etc. Finally database file is generated and file of data is run in simulation engine. Following boundary conditions and the parts applied to them:

- **The Die Part**
Die is rigid which does not deform and contains element to the region of the part, the boundary condition applied are: zero displacement in all directions and zero rotations in all directions.
- **The Wire Part**
Since the wire is plastic which part is deforming during wire drawing .In this process a small portion of wire is inserted into the die, the boundary condition for the wire part represented by the signing the drawing velocity on the small part of the wire as shown in a figure 4, the boundary condition are zero velocity in x and y direction and 1 mm/sec on the z direction.

Finally the number of simulation steps is automatically selected to find out the number of steps required for the drawing process. After finishing the model development and applying boundary conditions, the case can be solved using simulation software. The post processor shows the results of the simulated case.

4.4 Simulation

After pre processing is done all input parameters feed correctly then simulation run is start, for successful simulation result it is necessary to feed all input details correctly. Simulation run performs after that analysis is carried out and post processing is start to see the simulation results.

4.5 Post processing

It analysis the result with help of visualised tools such as force, stress and load conditions etc. It reads the database files from simulation engines and displaying the results in graphical form and extracting the numerical data. CAE simulation reduces the time and cost of development of product and improving the safety comfort and durability of the product. A proper assumption is needed to initiate the analysis as an input.

5. Process Parameters and Material Data

The following process parameters and material data is used for simulation:

• **Die details**

Outer Diameter 12 mm
 Outer Height 10 mm
 Exit Angle 10°
 Bearing Length 1 mm

• **Wire details**

Original Diameter 3 mm
 Final Diameter 2.55 mm, 2.16 mm, 1.8 mm
 Length 150 mm

Pre processor and simulation setting

Simulation Solver = Lagrangians incremental
 Simulation Steps = 57steps
 Per Step Time Increment = 0.5 second
 Criterion = 0.7 (Relative interference)
 Iteration = (Solver = Conjugate Gradient, Method = Direct)
 Inter-object Relationship =Die and work piece shear friction = 0.2
 Tolerance Limit = 0
 Number of Mesh = 3000000
 Mesh Type = Tetrahedron

6. SIMULATION RESULTS AND DISCUSSIONS

The simulation of wire drawing process has been performed with controlled variable for different stages of wire drawing and results obtained was in the form of stress, strain, total forces, maximum principle stress, and effective strain rate and damage. These results were used to obtain the optimum process parameter of multistage wire drawing. Different control values were obtained by hit and trial method in simulation, a successful simulation was performed and analysis was done.

6.1 Load prediction

It was observed in z direction, found that as die diameter was reduced by 15% with no change in die angle of 10° with 1 mm/ sec velocity of wire drawing, load required to draw the wire was very high but when drawn wire passed through the third dies load requirement was decreasing to draw the wire, finally the work piece load value was high as compared to dies load through which wire was drawn in multistage wire drawing. The shear friction was kept constant during multistage wire drawing process. Load value was obtained through simulations was shown in table 1.2 and load graph in figure 1.1 given below.

Table 1.2 Load Values

	LOAD (N)	DIE1	DIE2	DIE3	WIRE
MULTI STAGE WIRE DRAWING	X	28.2, 5.89	28.2,0.46	28.2,1.37	28.2, 3.12
	Y	28.2,13.9	28.2, 7.85	28.2,3.78	28.2,0.517
	Z	28.2, 129	28.2, 208	28.2, 136	28.2, 496

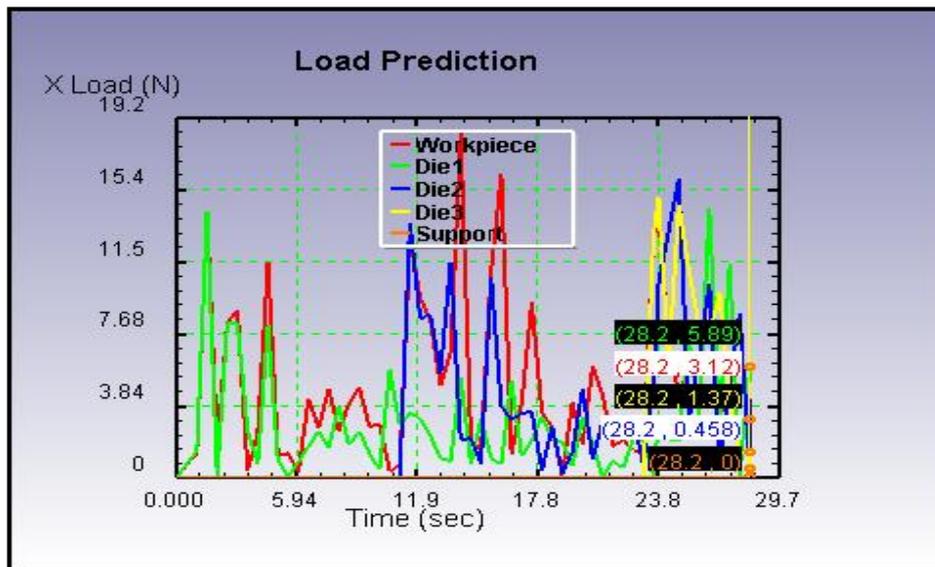


Fig. 1.1(a) X Load in Multistage Drawing

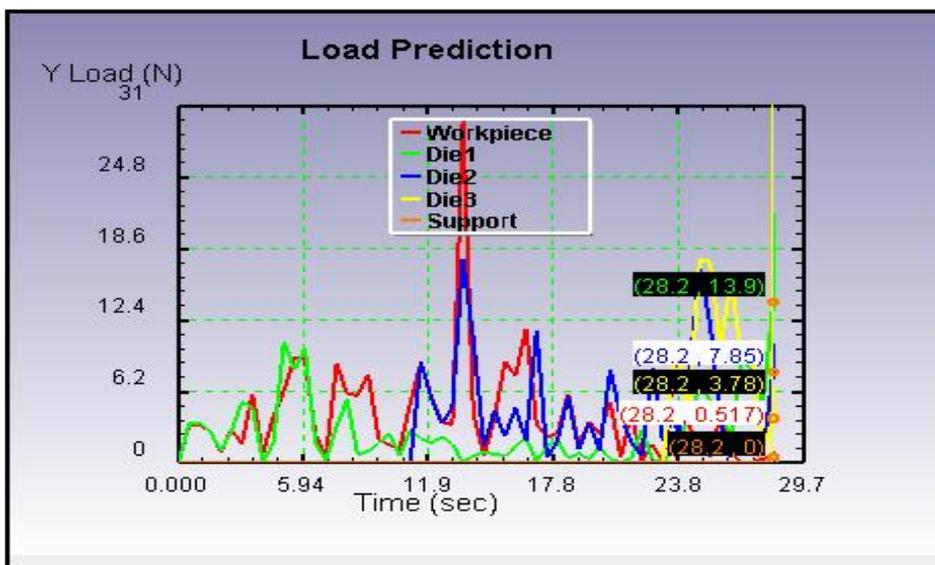


Fig 1.1 (b) Y Load in Multistage wire drawing

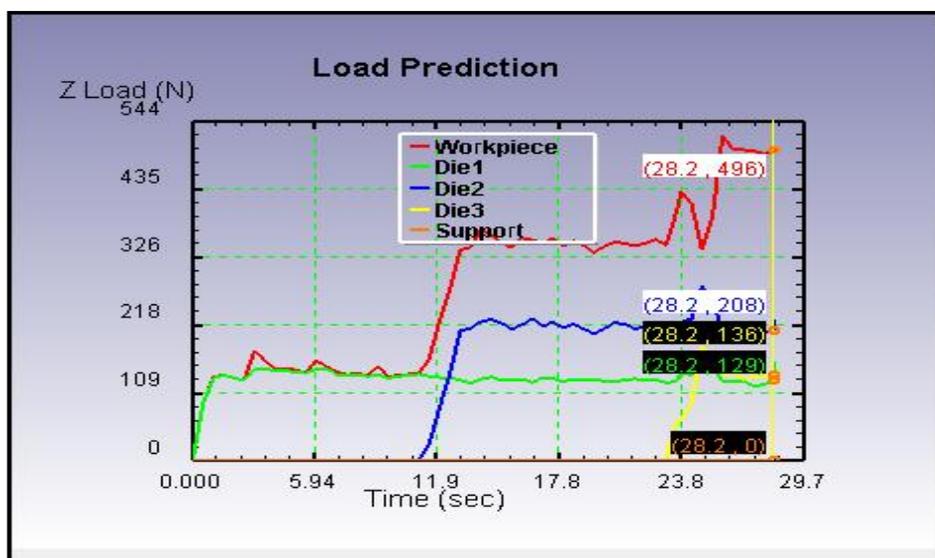


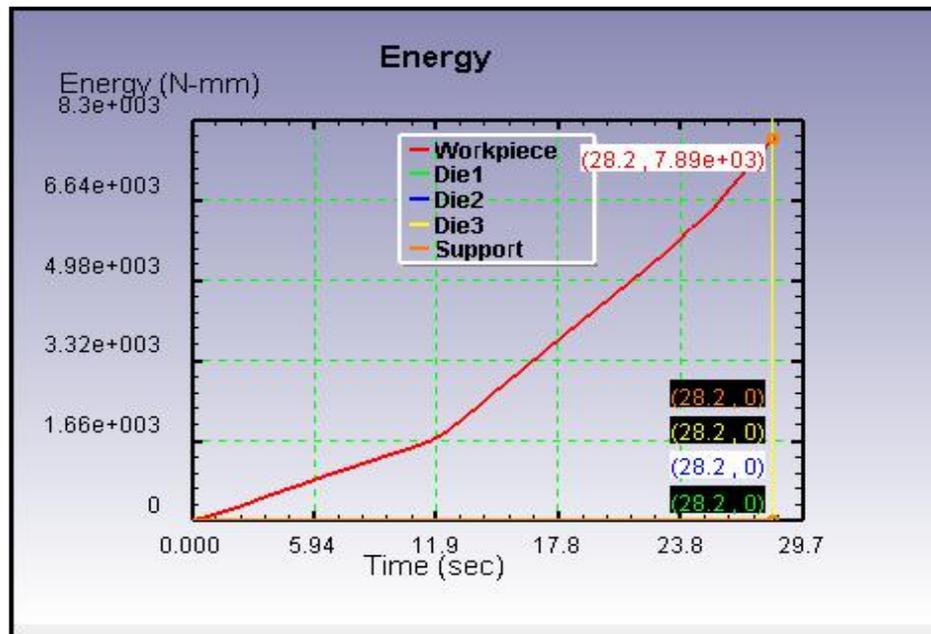
Fig 1.1(c) Z Load in Multistage wire Drawing

6.2 Energy Requirement

Comparing energy requirement of wire drawing values of drawn wire, it was found that, energy requirement is increasing as die radius was decreasing. Deformation of wire was basic alteration of the shape or size of wire, here diameter of wire was reduced by wire drawing process which required some energy to take deformation, Energy required to deform material a specific amount. In first stage wire drawing process energy required was less because deformation take place with control process parameters as slow rate to avoid any damage. Energy requirement with time for work piece was gradually increasing with rigid die but die energy shows constant value that means die is rigid no deformation take place. stage energy requirement for deformation was more because diameter of wire was reducing continually. Afterward linearly graph of energy obtain which means energy value was increasing slowly. Energy requirement of wire for deformation in all three stages wire drawing are shown in table 1.3 and energy graph figure 1.2 given below.

Table 1.3 Energy Requirement in multistage wire drawing

ENERGY (N-mm)	1 ST STAGE WIRE DRAWING	2 ND STAGE WIRE DRAWING	3 RD STAGE WIRE DRAWING
		28.0, 3.78e+03	28.5, 7.44e+03



SFig 1.2 Energy Required in Multistage wire Drawing Process

6.3 Stress - Effective

Comparing the all three stages with each other and it was found that effective stresses of drawn wire is increasing as die radius is decreasing. After applying load stress effective generated in work piece, at contact of die and work piece effective stress is very high. The range of stress value is 52MPa to 85MPa which is increasing as passing through the narrow space of die. Due to high effective stress material deformation take place uniformly in all direction. Stress – effective values are shown in table 1.4 and graph shown in figure 1.3 given below.

Table 1.4 Stress- Effective for multistage wire drawing

STRESS- EFFECTIVE	1 ST STAGE WIRE DRAWING	2 ND STAGE WIRE DRAWING	3 RD STAGE WIRE DRAWING
		48.9	100

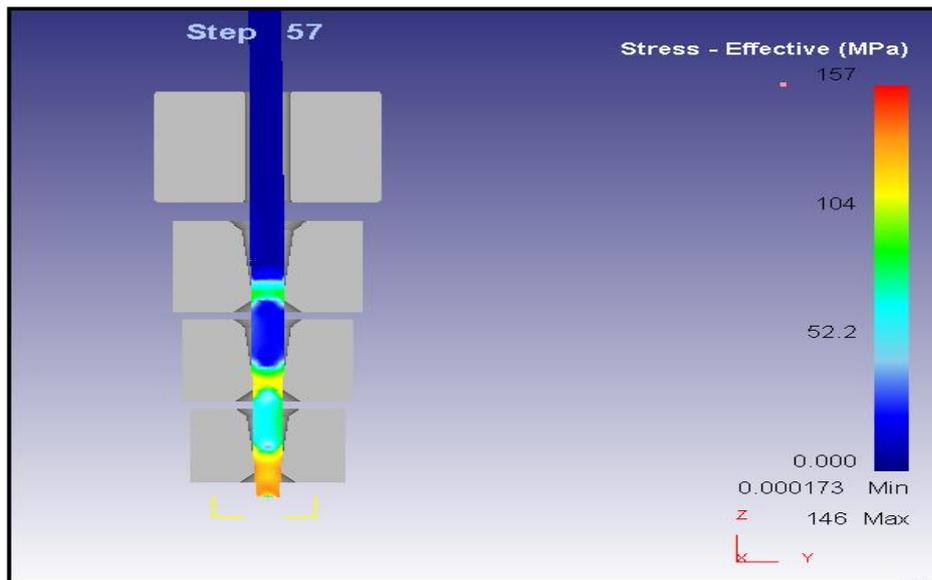


Fig 1.3 Stresse- Effective For Multistage Wire Drawing

6.4 Total Force

Comparing total forces, it was found that total forces was reducing as die radius was decreasing. As observed in the figure Total force was very low at internal surface of work piece whereas outwards forces on the work piece are negligible, which shows that overall stress is negligible no damage of work piece take place during process. Total force produces for deformation are not very high because very low deformation of work piece is required. Shear friction was kept constant for all three stages of wire drawing. The process is cold drawing process which performs at room temperature. Total force values are shown in table 1.5 and figure 1.4 given below.

Table 1.5 Total Force in multistage wire drawing

TOTAL FORCE	1 ST STAGE WIRE DRAWING	2 ND STAGE WIRE DRAWING	3 RD STAGE WIRE DRAWING
	0.2	0.08	0.05

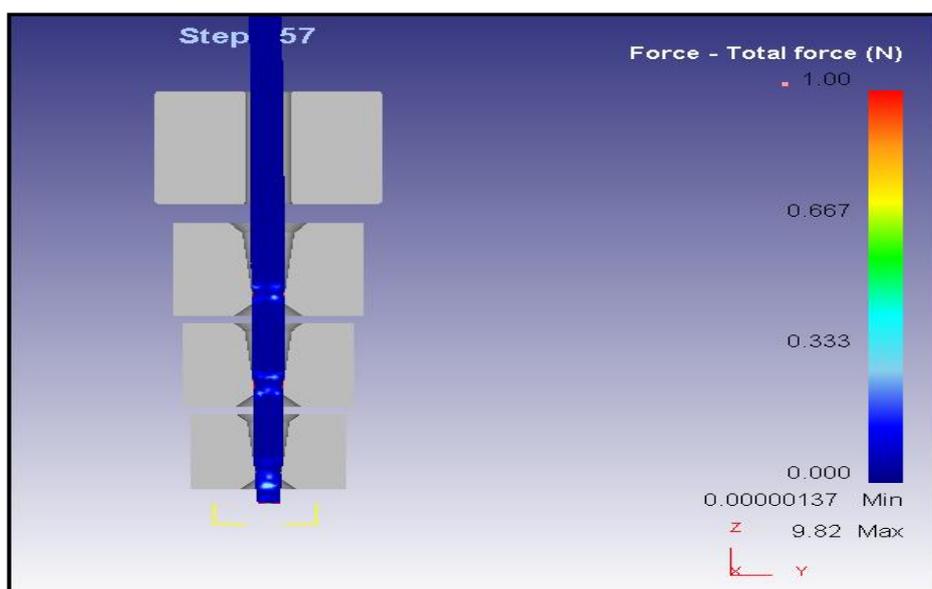


Fig. 1.4 Total Forces for Multistage Wire Drawing

6.5 Stresses-Max Principal

Comparing the Max. Principal stress value, it was found that, max. Principal stress value is increasing and last stage of wire drawing decreasing. As above die diameter reduction required large amount of load for drawing of wire, due to which stress was increased during all stages of drawing. Principal stress was defined as normal stress calculated at an angle when shear stress is zero, here both compressive and tensile stress was considered as a minor principal stress and major principal stress respectively. Where principal stresses were shown, there is no shear in work piece. The compressive and tensile stresses was observed around the contact of die and work piece. At certain point compressive stress was observed and at contact surface low tensile stress was observed after that tensile stress was very low. At contact surface of die and work piece it was observed that almost zero normal stress. Stress –max Principal for multistage wire drawing are shown in table

Table 1.6 Stress –max Principal for multistage wire drawing

STRESS-MAX PRINCIPAL	1ST STAGE WIRE DRAWING	2ND STAGE WIRE DRAWING	3RD STAGE WIRE DRAWING
	0	120	50

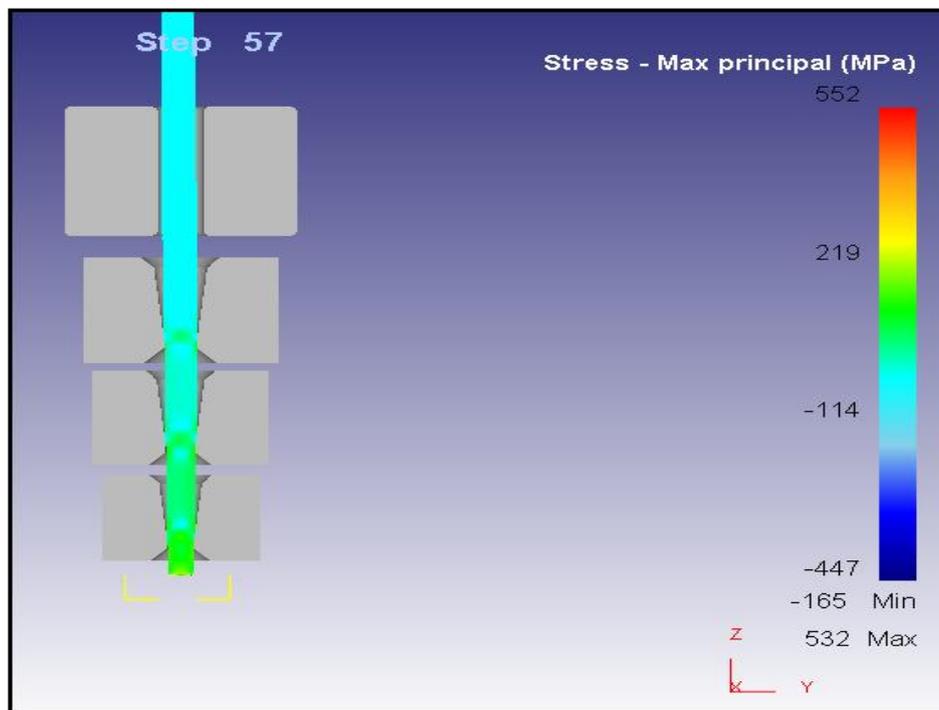


Fig. 1.5 Stress –Max Principal for Multistage Drawing

6.6 Strain – Effective

Strain Effective is the integral of the plastic component of the rate of deformation of the material. It is simulation calculation program which predict the whether any object is bending or breaking. It was observed in simulation there was no bending or breaking during wire drawing process. The strain effective values were almost negligible as observed in table 1.7 and figure 1.6.

Table 1.7 Strain – Effective for multistage wire Drawing

STRAIN RATE EFFECTIVE	1ST STAGE WIRE DRAWING	2ND STAGE WIRE DRAWING	3RD STAGE WIRE DRAWING
	0.60	0.07	0

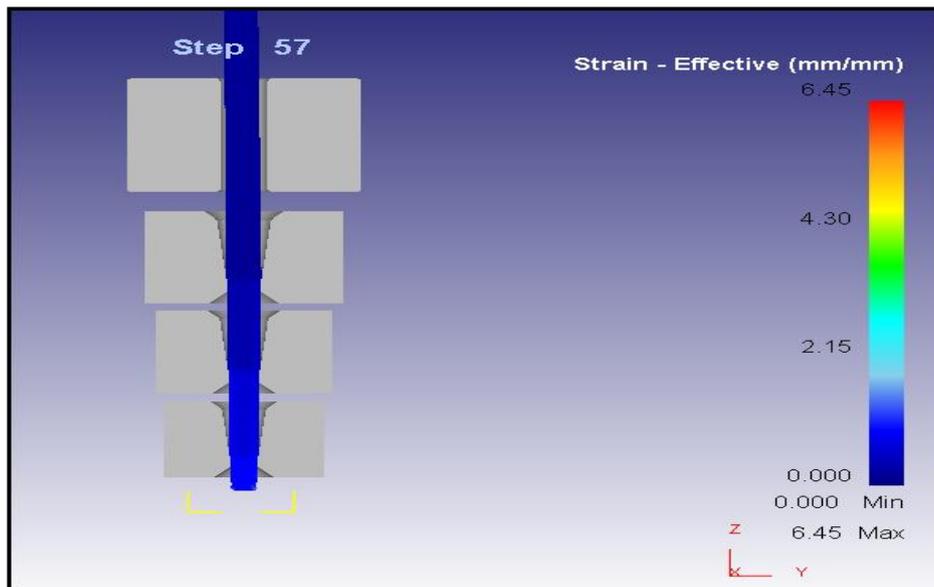


Fig. 1.6 Strain - Effective for Multistage Drawing

6.7 Strain rate - Effective

Comparing the effective strain rate value of drawn wire, it was found that, effective strain rate was decreasing as the die diameter was decreasing. Strain rate is the change in strain (deformation) of the material with respect to time. The strain rate some point within the material measures the rate at which the distance of adjacent parcel of the material change with time in the neighbourhood of that point. It was observed after simulation effective strain rate was almost zero because there is no change in distance, all particles in some region were moving with same velocity with same direction where as dies were kept constant. The effective strain rate value was considered negligible as observed in table 1.8 and figure 1.7 respectively.

Table 1.8 Strain Rate – Effective for multistage wire drawing

STRAIN RATE – EFFECTIVE	1 ST STAGE WIRE DRAWING	2 ND STAGE WIRE DRAWING	3 RD STAGE WIRE DRAWING
	0.60	0.07	0

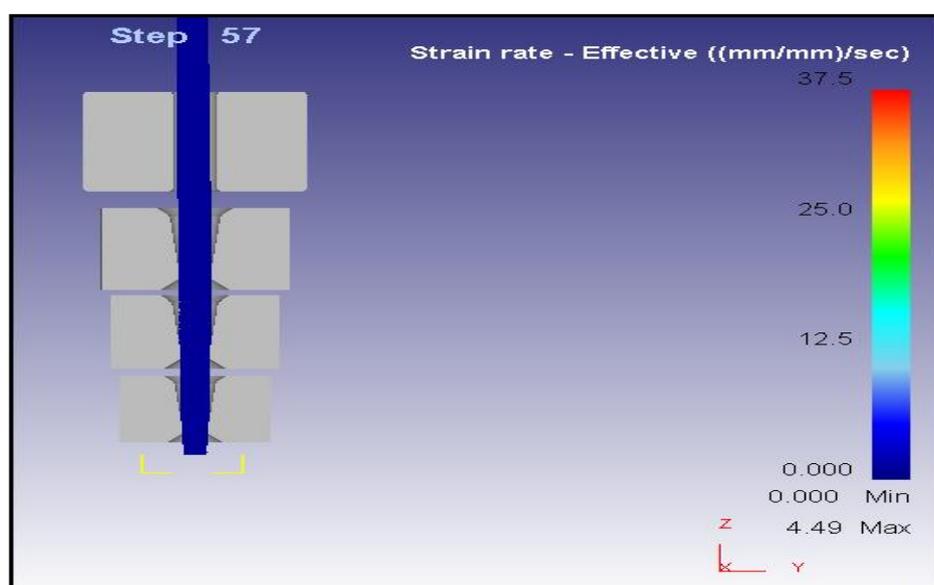


Fig 1.7 Effective Strain Rate for Multistage wire Drawing

6.8 Damage

Damage of wire and die is not occurred during process so damage in the wire is zero. The simulation run is successfully and optimised data obtained for multistage wire drawing process. Damage values are shown in table 1.9 and figure 1.8 respectively given below.

Table 1.9 Damage in multistage wire drawing

DAMAGE	1 ST STAGE WIRE DRAWING	2 ND STAGE WIRE DRAWING	3 RD STAGE WIRE DRAWING
	0.01	0.01	0.001

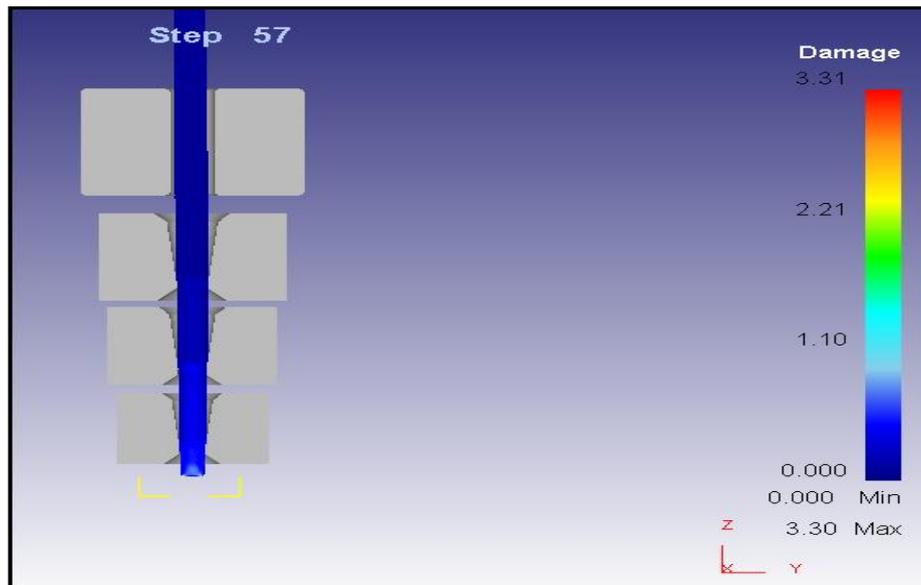


Fig 1.8 Damage in Multistage wire Drawing

From simulation performed it was proved that if reduction (constant value 15% reduction) is done in dimension of die for three stages of wire drawing

- This increase the amount of load to draw the wire material.
- The increase of load on die cause compressive stress on wire surface at contact after that compressive stress is reduced and tensile stress is generate for pulling the wire from wire dies.
- So almost negligible damage was occur during the process and strain is also zero.
- With the above results, it can be seen that the simulation was performed is validated.

7. CONCLUSIONS

Various conclusions were derived from analysis of the results the effect of change in dimension of die in different stages on wire drawing process has been done. Results obtained is concluded and discussed below;

- It has been found that as die radius was decreasing for three stages at constant reduction rate (15%) cause the load value is increases as number of pass schedule increases.
- It was observed that most dominant process parameters that affected the drawing operation were drawing force, reduction rate.
- As die radius reduces may causes distortion during wire passing through the die.
- Due to above issues, an optimum die diameter was important parameter to be obtained from the simulation studies.
- It has been found that a die diameter of 2.55 mm, 2.16 mm and 1.8 mm gave optimum deformation of wire with minimum damage of wire with constant die angle of 10°.
- The developed model, as it is validated can be used to simulate any problem in multistage wire drawing process for any material.

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