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Design and Analysis of High-Pressure Torsion Process Using Finite Element Method

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Abstract*:* *High Pressure Torsion (HPT) is a procedure that is frequently used to change the structure and characteristics of materials by using severe plastic deformation. It is widely believed that astraightforward shear causes deformation during HPT. In order to create nanocrystalline structures in metals and alloys as well as to cold weld powders, HPT is utilized. The flow kinematics and stress condition of a material under deformation dictate the HPT treatment's outcome. Recent studies have revealed that the actual plastic flow during HPT might deviate greatly from the straightforward concept.*
Based on a modification of the traditional high pressure torsion technique of severe plastic deformation, a new approach called High Pressure Torsion Extrusion (HPTE) will be proposed. A specimen will be extruded via sectional containers that will be spinning in relation to one another during HPTE. The area where the containers converge on the specimen will be exposed to shear deformation. The findings of the FEM inquiry will be presented in this report

Keywords: HPT (High-pressure torsion) , Strain , Heat Generation , Coefficients of friction, Finite Element Method (FEM) ANSYS

I. INTRODUCTION

High-pressure torsion (HPT) stands as the historical pioneer and current dominant method in Severe Plastic Deformation (SPD), crucial for creating nanocrystalline structures in metals, alloys, and enabling cold welding of powders. This technique compresses and torsional strains samples, proposed over 60 years ago, gaining significant traction only in the last 20 years due to its potential for exceptional grain refinement, often down to the nanometer scale, and resulting in remarkably high material strength.

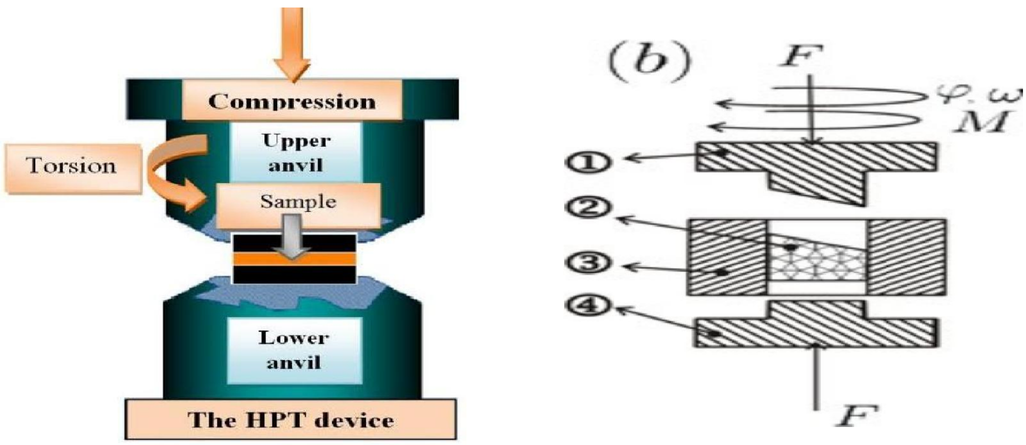

Fig.1 High-pressure torsion (HPT) setup

Its capability to produce nanostructures with high-angle grain boundaries has spurred extensive investigations, positioning the high-pressure torsion (HPT) process as a leading approach for processing nanostructured materials. Control over polycrystals' mechanical and physical properties relies significantly on grain size, known to enhance the

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strength of polycrystalline materials when reduced. Recent interest focuses on producing metals with extremely small grain sizes, establishing Severe Plastic Deformation (SPD) as the primary means of obtaining materials with ultrafine-grained (UFG) structures and outstanding mechanical traits.

The sample material is used to waste of metal by a Aluminium alloy (AA), copper and brass etc. This technique used to most useful by server plastic deformation by a waste of material used to create the new product.

1. Rotary top wedge punch
2. Sample of cylindrical wedge
3. Constraining of die and
4. Lower punch (stationary) holding sample (2) fixed at its interface with (4) due to sticking friction situation.

A high pressure torsion setup's essential elements, including the cylindrical wedge sample. The constraining die 3 processes a cylindrical sample 2. Top punch 1, which displays an excessive wedge angle, is brought into contact with the cylindrical wedge sample's top face, which is acting as an anvil. To apply Force F, lower punch 4 is brought into contact with the sample's bottom face. The primary focus on highlighting the key benefits of High-pressure torsion (HPT) in the context of recycling waste metal, specifically emphasizing cost, energy, and economic damage savings during the re-melting process. In this study used in Aluminium alloy AA6061 in workpiece material.

The main focus of this specific objectives related to the design, analysis, and data acquisition in a high-pressure torsion extrusion process. This includes obtaining the accumulated strain post-extrusion, determining heat generation concerning the revolutions per minute (rpm), and assessing the accumulated strain through elastic and plastic deformation. The creation and application of a mathematical model for understanding material flow in High-pressure Torsion (HPT) samples, considering nonzero z-axis velocity components and a kinematically admissible velocity field's influence on material flow[1].investigated by Laminar or turbulent flow of plastic can occur during HPT. Work hardening must follow a power law function in stationary laminar plastic flow[2].The experimental utilization of High-pressure Torsion (HPT) technology to transform metal chips, specifically AA 6082 alloy chips, directly into finished products. This study involves using HPT processing to convert chips into hollow ring bush components and cylindrical solid bars. The sentence details the specific parameters and characteristics of the HPT process applied to these chips, highlighting the pressure load, punch diameter, pressure, density, percentage density, and the resultant transformation of the chips into ring bush components through the HPT process[3].High-pressure Torsion's (HPT) influence on mechanical behaviors and microstructural changes in both pure and alloyed metals. It emphasizes the summary of how mechanical and microstructural characteristics evolve during the HPT process[4]. Investigation using Finite Element Modelling (FEM) to explore potential reasons for the non-uniform flow observed during High-pressure Torsion (HPT)[5].The hypothesis by determining the evolution of hardness under torsional straining in an alloy of aluminium 6061 and directly the results to those previously discovered for pure aluminium[6].The models included torsional strains up to 1.5 turns, applied pressures from 0.5 to 2.0 GPa, and friction coefficients from 0 to 1.0 outside of the depressions. materials used in the HPT process for copper [7]. The disc was processed with five revolutions at a pressure of 6 Gpa and one-fourth turn of HPT at 463 K.The outcome of the heterogeneous flow during HPT processing Discs' through-thickness direction is characterised by variations in grain structure, microhardness, and strain distribution [8]. The HPT processing, high purity aluminium discs at room temperature with an applied pressure of 6.0 Gpa and torsional straining from ¼ to 20 turns. With increasing numbers of HPT revolutions, the outcome is a progressive evolution in homogeneity such that after 20 spins, the microhardness values are saturated at a consistent value throughout the discs [9]. The microstructural evolution occurring in high-purity Al during cyclic (c-HPT).In this study, we examine the HPT processing of high purity aluminium under monotonic (m-HPT) and cyclic (c-HPT) circumstances. In compared to m-HPT, the total number of turns is the same for c-HPT [10]. Donya Ahmadkhaniha, studied deformation was applied to pure magnesium casting, and its effects on the microstructure, hardness, tensile characteristics, and corrosion resistance were assessed.HPT samples with missing orientation angles at the centre and edge after 1 and 5 revolutions. Cast pure Mg disc performed 1 or 5 passes of HPT processing at room temperature [11]. Cheng Xu, at studied investigation focused on exploring the effects of pressure and torsional straining in (HPT) processing, using tests on Al-6061 alloy. In progressive increase in hardness uniformity with the number of HPT revolutions, comparing unprocessed discs with those subjected to pressure alone and pressure combined with torsional straining, under different pressure levels [12].

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II. DESIGN OF HPT AND MESH GENERATION

Ansys produces and markets engineering simulation software that may be used across the whole product life cycle. Ansys Computer models are used to analyse the strength, toughness, elasticity, temperature distribution, fluid movement, and other attributes of structures, electronics, or machine components using mechanical finite element analysis software.

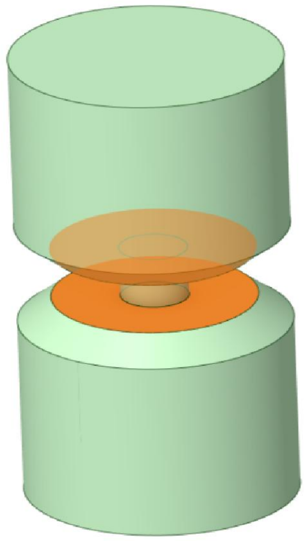
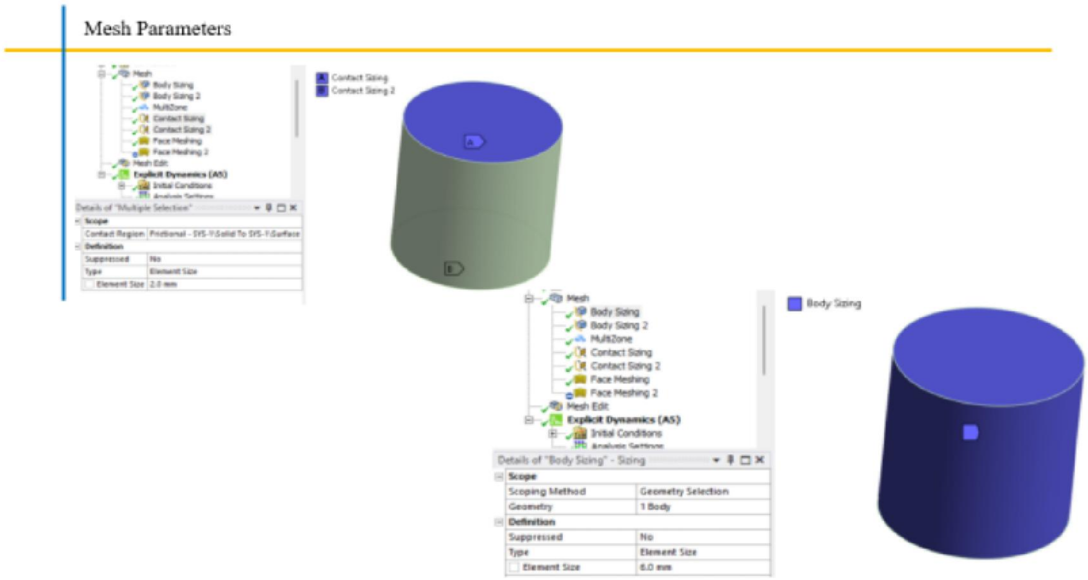


Fig. 2 Assembly of Punch and Die inHPT.

Ansys users often split down bigger structures into little components that are each designed and tested separately which is also known as Finite Element Analysis(FEA).To create the Ansys software by High-pressure torsion (HPT) in geometry of punch , sample material and Die.



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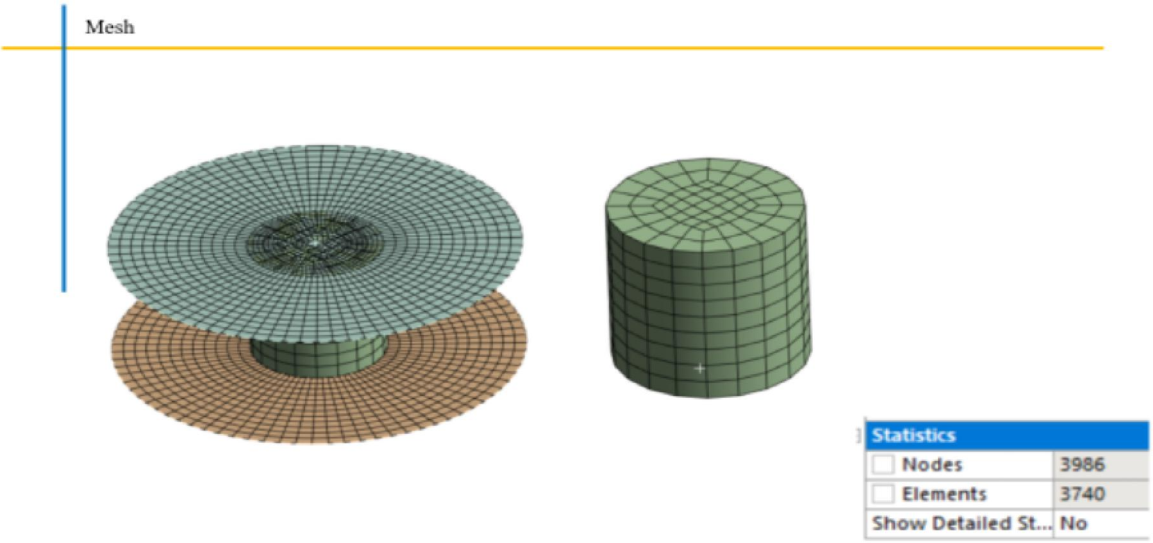


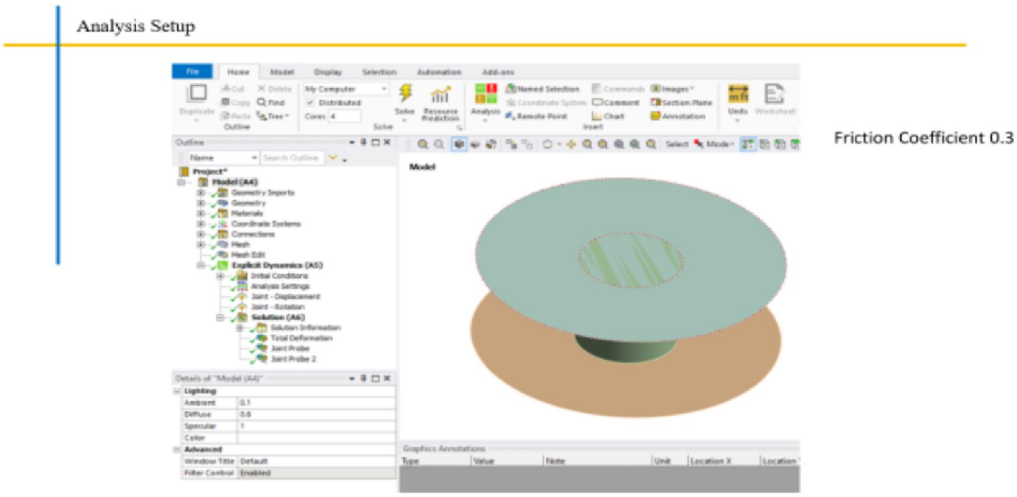
Fig.3 Meshing of Punch, Die and sample material

ANSYS's default meshing client, was used for meshing. The fine mesh with approximately 3740 elements these will serve as data points for the punch and die of the material flow during the simulation. Various combinations of automatic meshing method's developed in the programme were used to disperse the mesh elements and nodes throughout the equipment. The mesh along the wall regions was controlled and concentrated using faced body selection.

Mesh generation is performed using Ansys software. The fine mesh with approximately 3740 elements. the mesh quality statistics Number of Elements is 3740 with fine mesh size in 6.0 mm.

III. RESULTS AND DISCUSSION

Flate surface configuration, Friction coefficients 0.3



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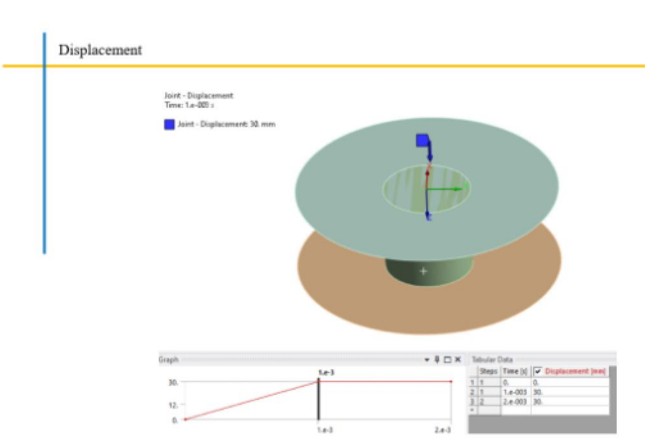
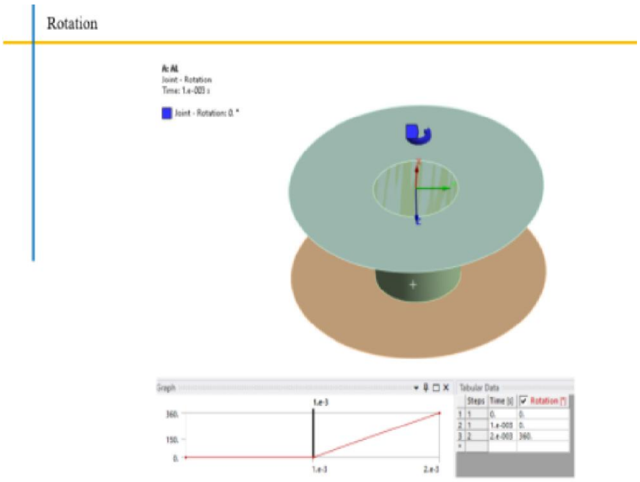
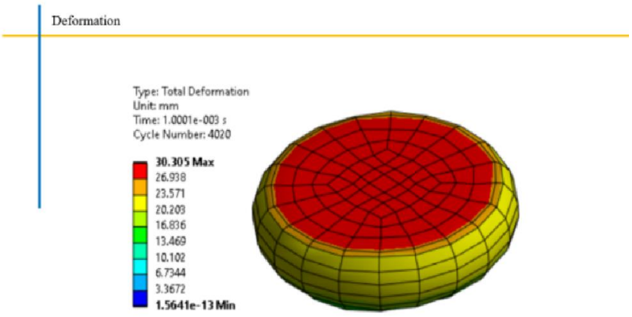


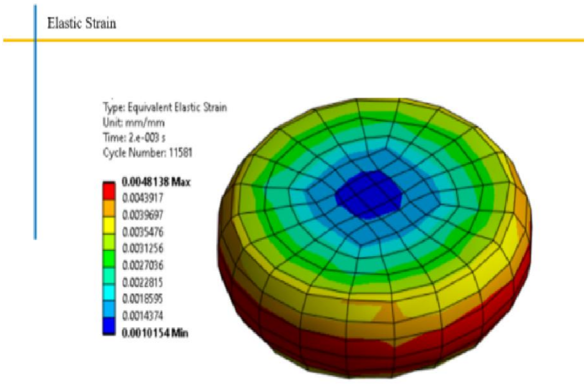


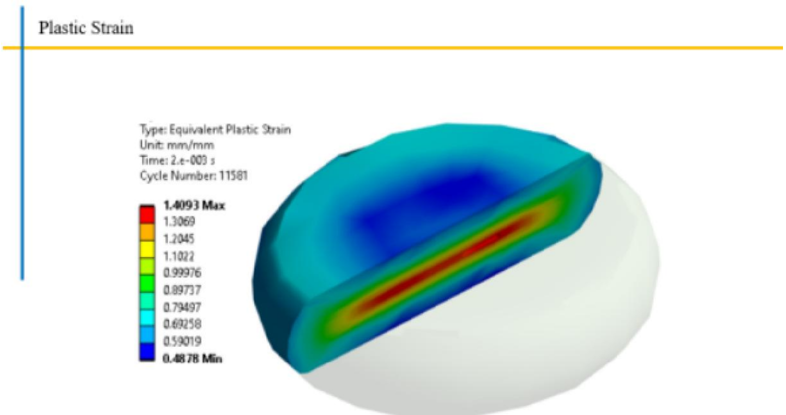
The sentences emphasize the specific analysis setup, particularly focusing on including only the contact surfaces of the rigid bodies (punch and die) with the sample, excluding the entire dies due to their rigidity. They also highlight the assigned frictional coefficient (0.3) for the contact between the rigid body and the sample's target area.

The simulation comprises two steps: initially, the punch is displaced vertically by 30 mm in the direction of gravity, and in the subsequent step, the punch's displacement is restricted, preventing movement in any direction. Each step is conducted within a time frame of 1 millisecond.

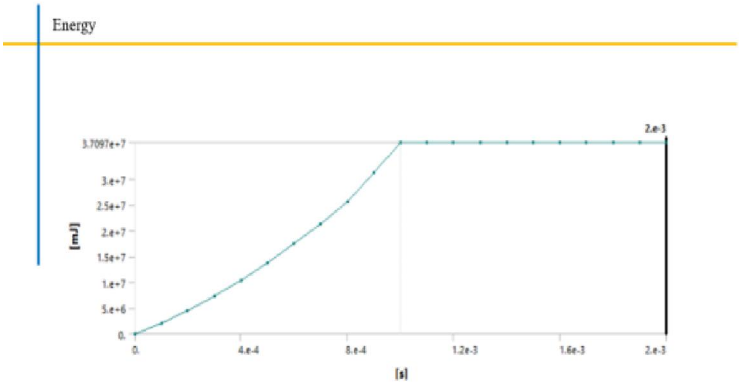
The Rotation is considered to be Radians per second (RPS) to time is considered by 360 degrees by 2 milli second. The rotational by fully of area in considered in punch by produced in material.







The compressed the sample by 30 mm and maximum you can see with red contour in this deformation. The maximum elastic strain is 0.4% is observed at the curved surface of sample. The Maximum strain is observed at outer curved surface of the sample and the minimum at top and bottom flat surface of the sample. The maximum plastic strain of 140% is observed. The maximum strain location is in the centre of the sample. You can see the maximum strain in cut section of the sample in red contour.



Fig(a). Time vs Energy

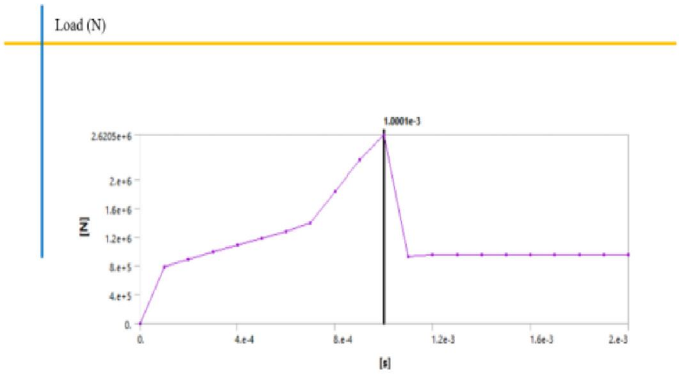


Fig (b). Time vs Load

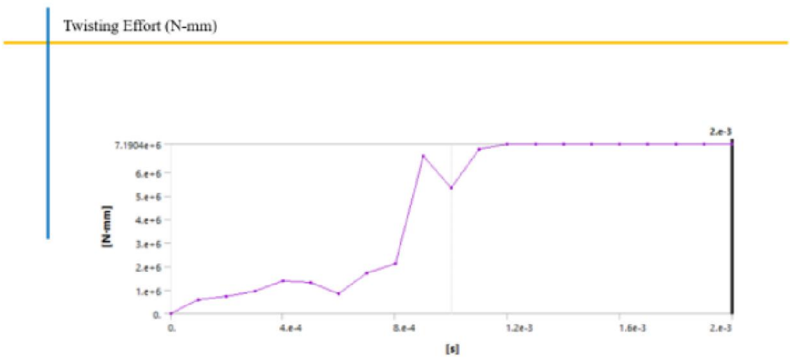


Fig (c).Time vs Twisting Effort

The energy in the sample is increasing by compressing the sample, and its value is maximum at the energy. The maximum energy stored in the sample is 3.7×10^3 mJ.

The load is suddenly reduced in the second step as material is almost in plastic zone. The maximum load is required with consideration of 0.3 coefficient of friction is 2.62×10^6 N.

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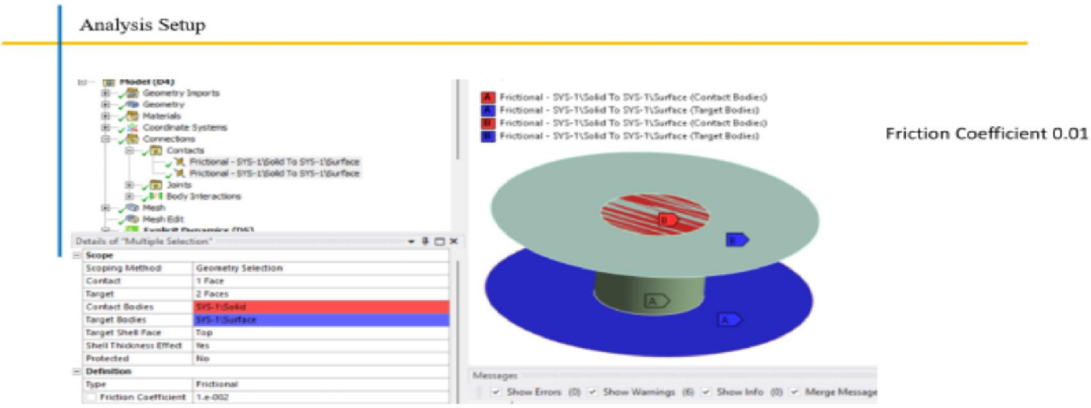
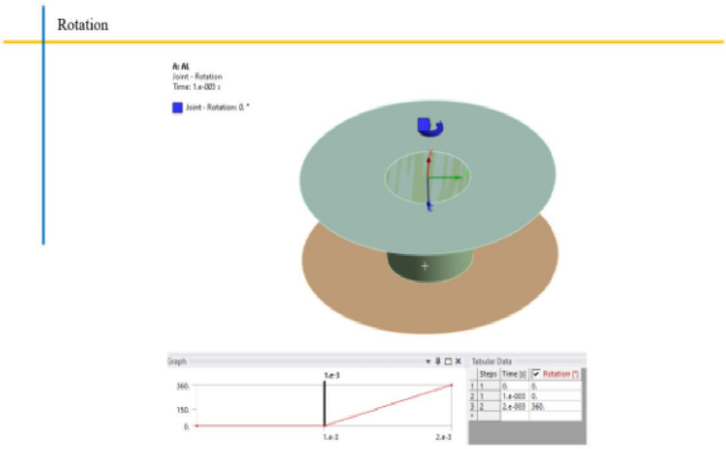
The maximum twisting required with consideration of 0.3 coefficient of friction is 7.19×10^6 N-mm. The better sample finishing will reduce the twisting torque.

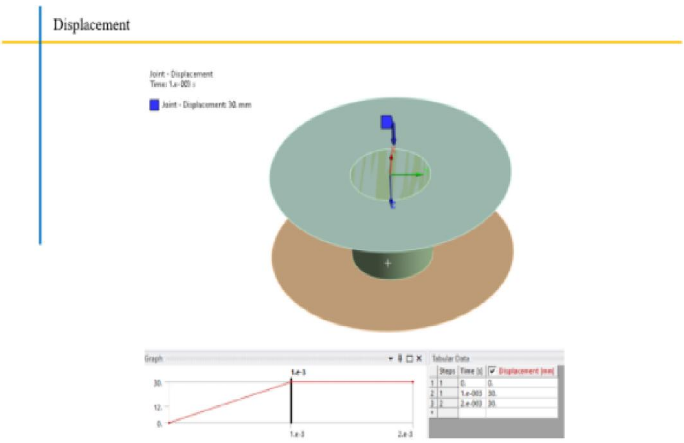
SR NO.	Input parameters		Output Parameters		
1	Friction coefficients (µ)	0.3	Load (F)		2.62×10^6N
2	Displacement Force (Df)	30mm	Strain (ε)	Elastic strain (εe)	0.40%
				Plastic strain (εp)	140%
3	Torsional Force (Tf)	7.19×10^6 n-mm	Energy (E)		3.7×10^3m J

Flat surface configuration, Friction coefficients 0.01

The rigid dies due to their excessive rigidity, varying friction coefficients were applied to the material's contact surfaces. A frictional coefficient of 0.01 was assigned between the rigid body and the sample's target area.







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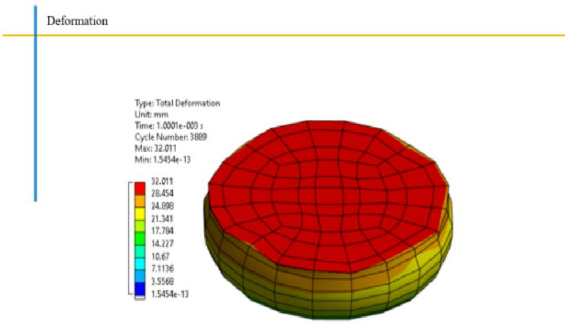
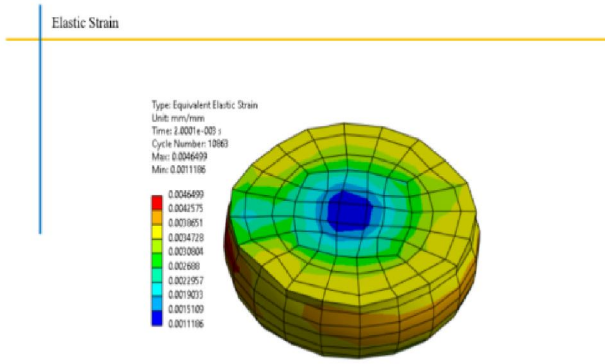
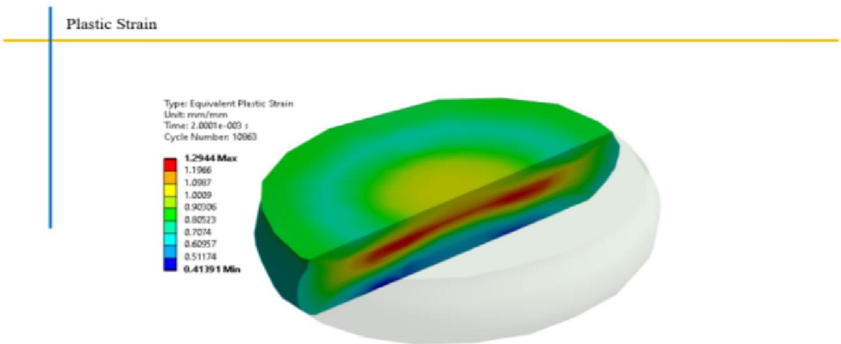
The vertical direction by 30 mm and in the next step, displacement of punch is restricted means it will not allowed to move in either direction. The both steps, time is taken as 1 milli seconds.

The Rotation is considered to be Radians per second (RPS) to time is considered by 360 degrees by 2 milli second.







The Deformation of sample 32.01 mm and maximum with red contour in the deformation. The Maximum strain is observed at outer curved surface of the sample and the minimum at top and bottom flat surface of the sample. The maximum elastic strain is 0.46% is observed at the curved surface of sample. The maximum plastic strain of 129% is observed. The maximum strain location is in the centre of the sample. You can see the maximum strain in cut section of the sample in red contour. The looking at the plastic strain value, it is cleared that material will not get its original shape after removing loads.

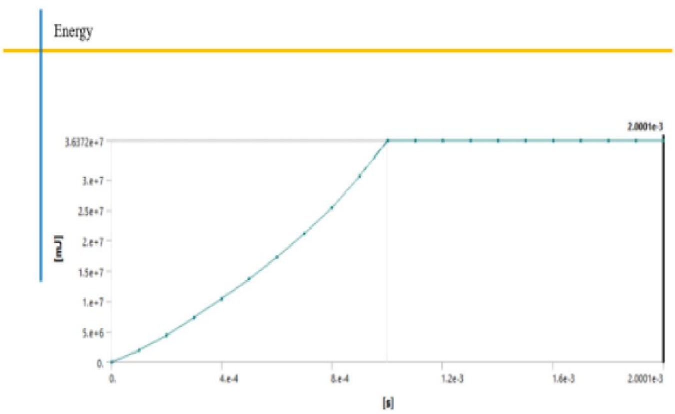


Fig (d). Time vs Energy graph

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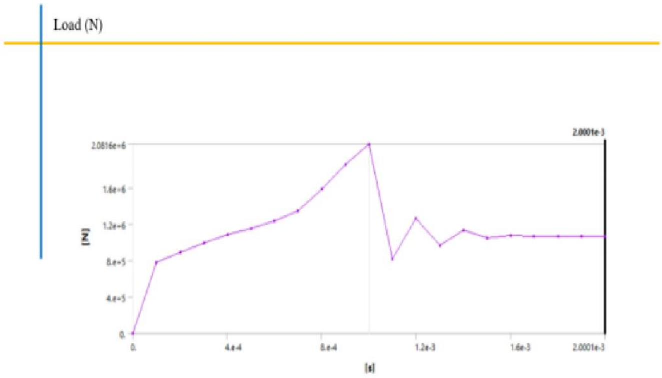


Fig (e).Time vs Load graph

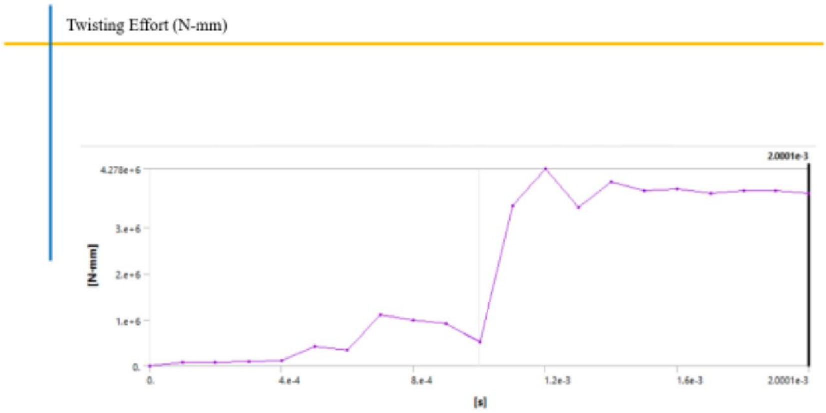


Fig (f).Time vs Twisting Effort

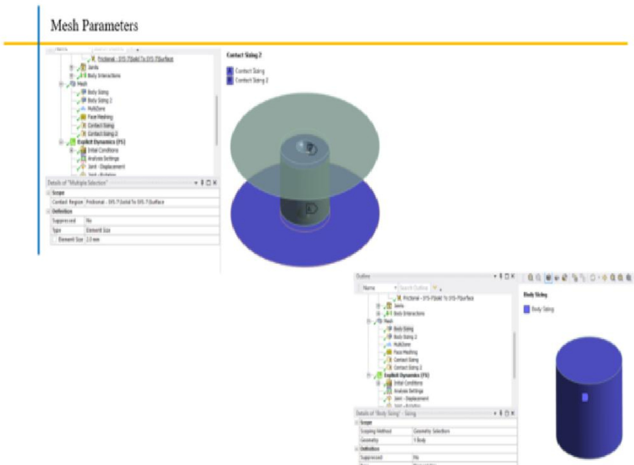
The energy in the sample is increasing by compressing the sample, and its value is maximum at the energy. The maximum energy stored in the sample is 3.7×10^3 mJ. The graph it is cleared that the newton force is required to press this sample. The selection of power press will be based on maximum value of the load. The load is suddenly reduced in the second step as material is almost in plastic zone. The maximum load is required with consideration of 0.3 coefficient of friction is 2.62×10^6 N. The maximum twisting required with consideration of 0.3 coefficient of friction is 7.19×10^6 N-mm. The better sample finishing will reduce the twisting torque.

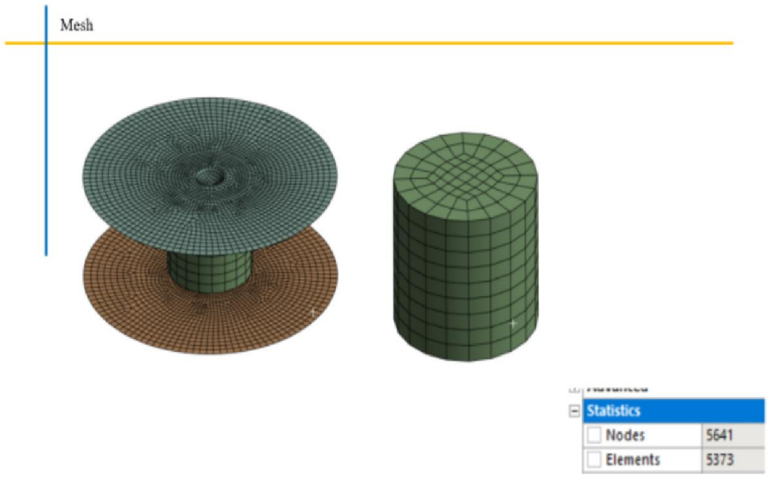
SR NO.	Input parameters		Output Parameters		
1	Friction coefficients (μ)	0.01	Load (F)		2.08×10^6N
2	Displacement Force (Df)	32.01mm	Strain (ε)	Elastic strain (εe)	0.46%
				Plastic strain (εp)	129%
3	Torsional Force (Tf)	4.27×10^6 n-mm	Energy (E)		3.63×10^3m J

Spherical configuration, Friction coefficients 0.01Coarse mesh.

A coarse mesh indicates a relatively large maximum go through size.The general word used to describe a grid with a low resolution, or one whose grid points are spread out widely. The phrase describes contrasting a grid with one that has a much better resolution.

The introduction of the sphere on both side to control the slippage, we need to provide 40 mm displacement in the first step of the analysis setup. The design of created by Spherical configuration on punch and die by contact surface. The geometry is new created on the testing of result by marital deformation effect on the process of High-pressure torsion.





ANSYS's default meshing client, was used for meshing. The fine mesh with approximately 5373 elements these will serve as data points for the punch and die of the material flow during the simulations. The total nodes in this mesh model is 5641. Total number of elements area 5373 in this mesh model.The surface elements are considered for the rigid bodies and hexahedral mesh elements are taken for the sample and good quality of mesh is obtained.

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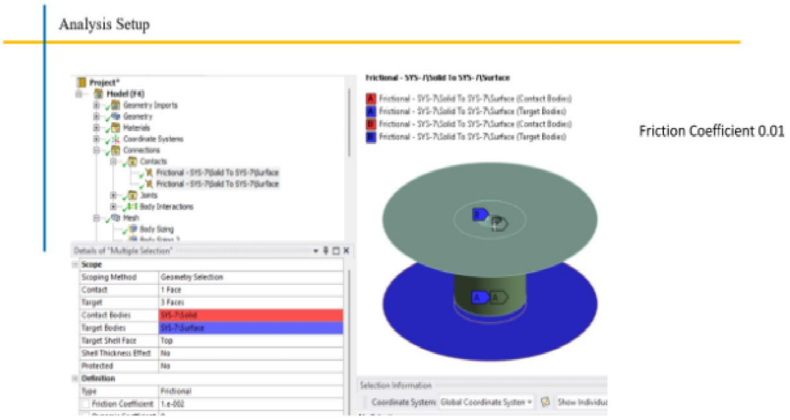
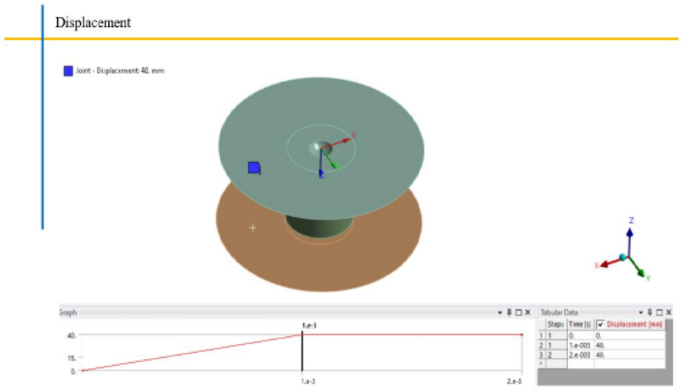
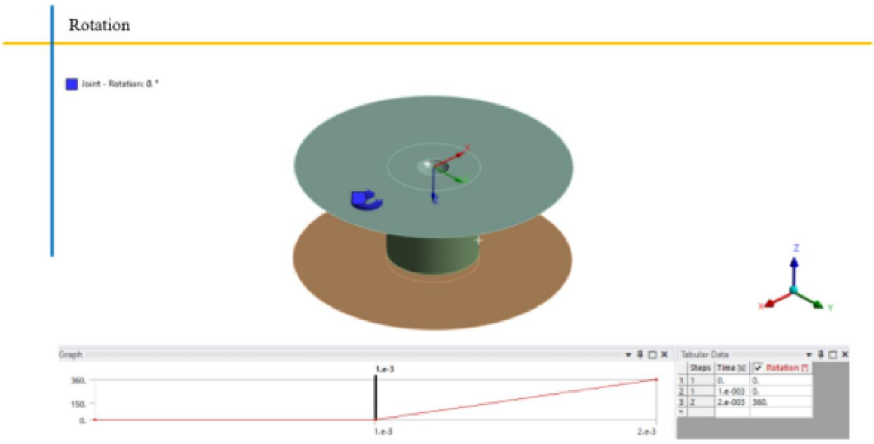
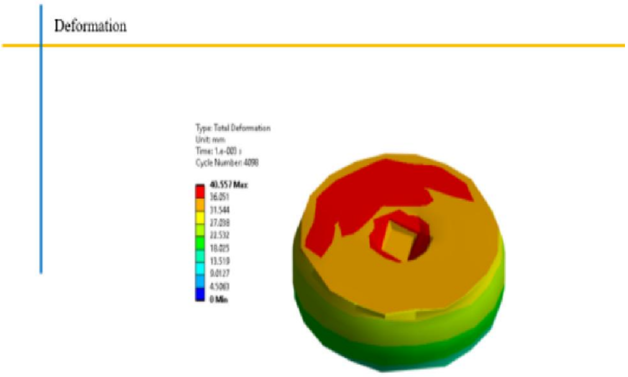
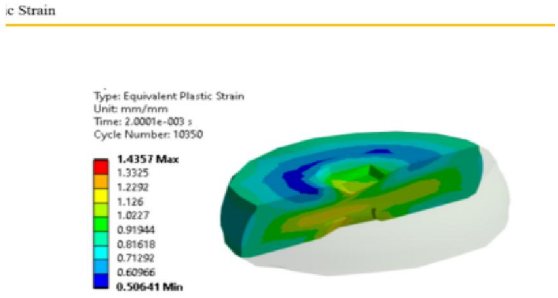
The analysis setup, we have considered the spherical contact surface of the rigid bodies i.e. punch and die with the sample only. the entire dies as the material of the same is very rigid compared to the sample. The frictional coefficient between the contact of rigid body to target of sample is considered as 0.01.punch is displaced in the direction of gravity. i.e. in the vertical direction by 40 mm and in the next step, displacement of punch is restricted means it will not allowed to move in either direction. The both steps, time is taken as 1 milli seconds. Rigid link is rotating by 360 degrees means full rotation. The time is considered the same for both steps. The Rotation is considered to be Radians per second (RPS) to time is considered by 360 degrees by 2 milli second. The rotational by fully of area in considered in punch by produced in material.

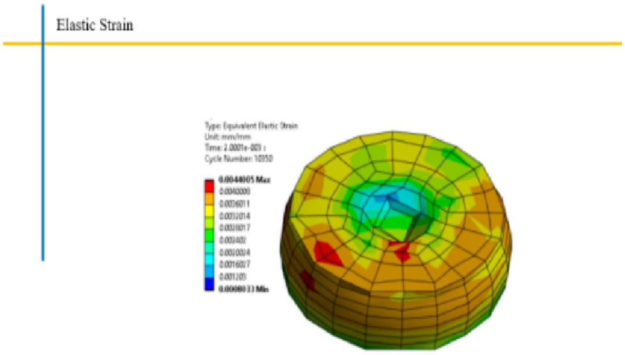












The Compressed the sample by 40.55mm and maximum with yellow and red contour in this figure. The deformation patterns looks symmetric as the load is applied constant to the entire contact area.

The Maximum strain is observed at outer curved surface of the sample and the minimum at top and bottom flat surface of the sample.The maximum elastic strain is 0.44% is observed at the curved surface of simple.

The maximum plastic strain of 143% is observed. The maximum strain location is in the center of the sample. The maximum strain in cut section of the sample in yellow and green contour.The looking at the plastic strain value, it is cleared that material will not get its original shape after removing loads from it.

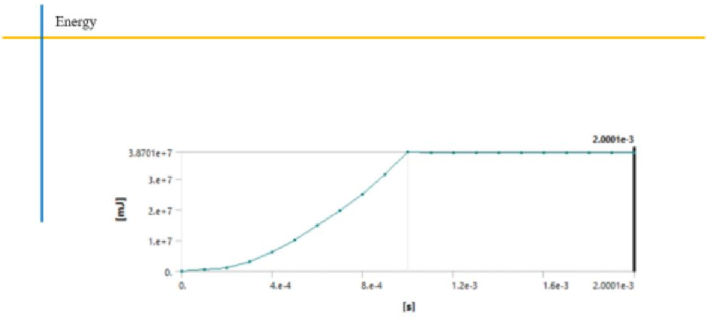


Fig (g). Time vs Energy graph

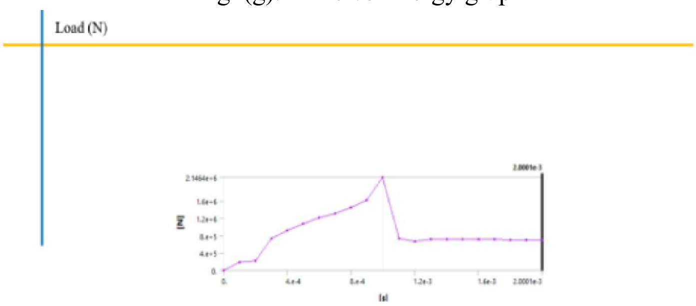


Fig (h).Time vs Load graph

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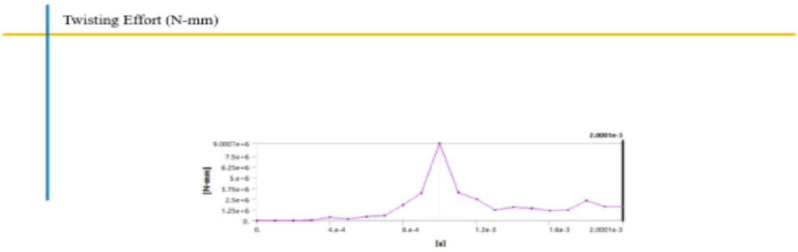

Fig (i).Time vs Twisting Effort.

The energy in the sample is increasing by compressing the sample, and its value is maximum at the energy. The maximum energy stored in the sample is 3.87×10^7 mJ.

This value shows the load application required to deform the sample.The graph shows time versus load value in newton. It indicates the value of power press capacity. The load is suddenly reduced in the second step as material is almost in plastic zone. The maximum load is required with consideration of 0.01 coefficient of friction is 2.14×10^6 N.

This figure shows the graph for time versus twisting torque requirement to twist the sample. The maximum twisting required with consideration torque 0.01 coefficient of friction is 9.0×10^6 N-mm.The better sample finishing will reduce the twisting torque.

SR NO.	Input parameters		Output Parameters		
1	Friction coefficients (μ)	0.01	Load (F)		2.14×10^6N
2	Displacement Force (Df)	40.55mm	Strain (ε)	Elastic strain (εe)	0.44%
				Plastic strain (εp)	143%
3	Torsional Force (Tf)	9.0×10^6 n-mm	Energy (E)		3.87×10^3m J

IV. CONCLUSION

The high-pressure torsion extrusion (HPTE) simulation using Ansys Explicit was performed on a sample of dimensions 50 mm in height and 50 mm in diameter. The simulations were conducted in two steps: compression and twisting. The first set of results obtained with different coefficient of friction values 0.01 and 0.3 provided insights into the material's response under varying friction conditions. The load, twisting torque, and energy graphs were reported for each simulation. The results showed that the coefficient of friction had a significant impact on the deformation behaviour. A higher coefficient of friction (0.3) resulted in higher loads and twisting torques, indicating increased resistance to deformation. Conversely, a lower coefficient of friction (0.01) led to lower loads and twisting torques, suggesting reduced resistance to deformation. The energy graphs also exhibited similar trends, with higher friction values requiring more energy for deformation.

In the second set of results, a spherical design modification was implemented in the punch to prevent slippage of the sample. This modification aimed to enhance the overall deformation process by increasing the contact area between the punch and the sample. The deformation and strain profiles were analysed for these simulations. The results demonstrated that the spherical punch design modification effectively reduced slippage and improved the deformation behaviour of the sample. The deformation and strain were more uniform and localized within the sample.

Based on these findings, it can be concluded that the coefficient of friction and punch design significantly influence the deformation behaviour and mechanical properties of AL 6061 during the HPTE process. A higher coefficient of friction increases the resistance to deformation, while a lower coefficient of friction reduces it. Additionally, the spherical punch design modification improves the deformation process by reducing slippage and promoting more uniform deformation. Further research could focus on exploring additional materials, varying sample geometries, and investigating the effects of other process parameters to expand the understanding of the HPTE technique.

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Nomenclature

- εe = Elastic Strain
- εp = Plastic strain
- Tf = Twisting Effort
- Ds = Diameter of Sample
- Dp = Diameter of Punch
- F = Compressive Force
- Df = Displacement Force
- L = Load
- μ =Coefficients of friction

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