



**MARMARA UNIVERSITY
FACULTY OF ENGINEERING**



Design and Analysis of an Extrusion Die Having Rotating Die

Hasan Baki Şahin

GRADUATION PROJECT REPORT

Department of Mechanical Engineering

Supervisor
Prof. Dr. Aykut Kentli

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**MARMARA UNIVERSITY
FACULTY OF ENGINEERING**



**Design and Analysis of an Extrusion
Die Having Rotating Die
by**

Hasan Baki Şahin

June 22, 2023,

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Signature of Author(s)

Department of Mechanical Engineering

Certified By

Project Supervisor, Department of Mechanical Engineering

Accepted By

Head of the Department of Mechanical Engineering

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Hasan Baki Şahin

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ABSTRACT

Design and Analysis of an Extrusion Die Having Rotating Die

The design and analysis of an extrusion die with a rotating die component were the main topics of this research. By forcing materials through a die, extrusion is a common manufacturing process for shaping materials. In contrast to the traditional extrusion procedure, which uses a stationary die, in this project we introduced a inventive method by including a rotating die component.

The objective of this project were to investigate the effects of a rotating die on the extrusion process and analyze its potential advantages. In order to fulfill this goal, we determined two parameters as shear friction coefficient and rotation die speed and changed these values and examined their effects on Strain rate, Max principal stress, Average velocity and Pusher load values. We interpreted these effects and determined the ideal intervals for our extrusion process.

SYMBOLS

τ : Shear friction coefficients

F : Force

V_{avg} : Average total velocity

$\dot{\epsilon}$: Strain rate

σ_1 : Maximum principle stress

V_T : Translation velocity

P : Power

E : Energy

ABBREVIATIONS

RPM	: Revolutions per minute
FEA	: Finite element analysis
CAD	: Computer-Aided Design
AISI	: American Iron and Steel Institute
MPa	: Megapascal
s	: Second
mm	: millimeter
m	: meter
N	: Newton

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1. INTRODUCTION

This research project's main emphasis is on the design and study of an extrusion die with a rotating die component. By forcing materials through a die, extrusion is a common manufacturing process for shaping materials. In contrast to the conventional stationary die method, we suggest a novel strategy in this project that involves a rotating die component. The goal is to look into how a rotating die affects the extrusion process and evaluate any potential benefits.

1.1. History and Overview of Friction Extrusion

Extrusion techniques were initially developed for the purpose of shaping lead pipes and have been used since the late 1700s. The first extrusion machine, created and patented by Joseph Bramah, used a manually controlled press to make lead or other soft metal pipes of different widths and any desired length without the need for joints. Due to its high malleability and suitability for the primitive mechanical presses at the time, lead was preferred in these early processes. Due to the commercial need, lead plumbing was the primary focus of improvements in extrusion for nearly a century. However, Alexander Dick developed "hot extrusion" in 1894, allowing the processing of tougher metals, in response to the growing demand for protective electrical insulation.[1,2,3]

Prior researchers suggested that raising the workpiece's temperature would make deformation simpler, but they struggled to create a machine that could tolerate thermal pressures and produce goods without cracks. Dick came up with a composite container with several casings that effectively dispersed heat while preserving the required stiffness. Since then, the extrusion process has been developed, making it possible to shape complex structures out of different metal alloys.[4]

There are several types of extrusion processes. However, two of them are more common and known. These are direct extrusion and indirect extrusion.[5]

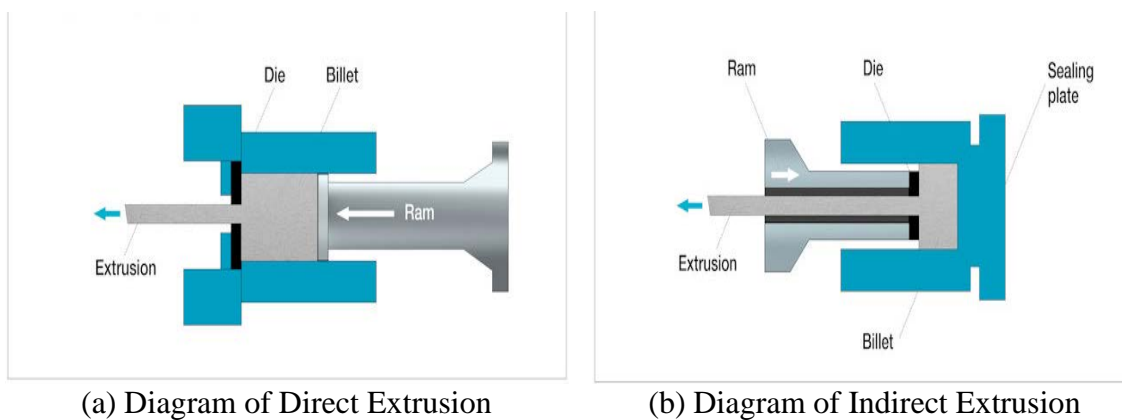


Figure 1: Diagrams of the Two Main Types of Extrusion Processes

In direct extrusion process, a billet (a cylindrical material) is pushed through a die aperture by using a ram or a screw. The substance moves in the same direction as the ram. [6,7]

Indirect extrusion involves moving the ram against the direction that the material is flowing. The die approaches the fixed billet and forces the material to flow against its natural flow. [6,8]

1.2. Project Objectives

This project's main goal is to investigate the effects and advantages of adding a rotating die component to the extrusion process.

In order to do this, we'll:

- a) **Evaluate the design of the extrusion die:** We will consider a number of elements that affect the performance of the die, including the shear friction coefficient and the die rotation speed. By taking into account these elements, we want to improve the rotating die's design and the extrusion process' effectiveness.
- b) **Conduct finite element analysis (FEA):** We will use finite element analysis to simulate and examine the extrusion process with the rotating die. FEA is a potent numerical technique that enables prediction and assessment of complex engineering problems. We can precisely simulate and predict how the extrusion die will behave under different conditions by using FEA.
- c) **Utilize the DEFORM3D program:** For the project's simulation procedures, DEFORM3D software will be used. The comprehensive tool DEFORM3D was created especially for machining and metal forming applications. It is the perfect option for our research because it offers advanced features for analyzing and optimizing the extrusion process.

2. MATERIAL AND METHOD

2.1. Material Selection

Cold drawn AISI 1035 steel will be selected as the primary material for the extrusion process in this research project. A medium carbon steel with excellent machinability, weldability, and moderate strength characteristics is AISI 1035. The material's surface finish, dimensional precision, and tensile strength are all improved by the cold drawing process. Based on its suitability for extrusion operations and the availability of pertinent mechanical characteristics data for analysis and comparison, AISI 1035 steel was chosen. [9]

One of the first quality that it effect the decision is that AISI 1035 steel can be easily worked with during the extrusion process due to its inherent properties, such as machinability and weldability. The extruded product must have this in order to have the desired shape and dimensions. [9,10]

Additionally, the surface finish, dimensional accuracy, and tensile strength of the material are all significantly enhanced by using the cold drawing process. The improvements are especially helpful when applied to the friction extrusion process, where high mechanical integrity and precision are essential. [9,11]

2.2. Design of the Extrusion Die

The extrusion die for indirect extrusion was be designed using SolidWorks, a computer-aided design (CAD) software. The die design had included the desired shape and dimensions of the die cavity to achieve the desired cross-sectional shape of the extruded part. Also, the In-direct extrusion type was used in this project and the necessary parts were designed to be suitable for this type.

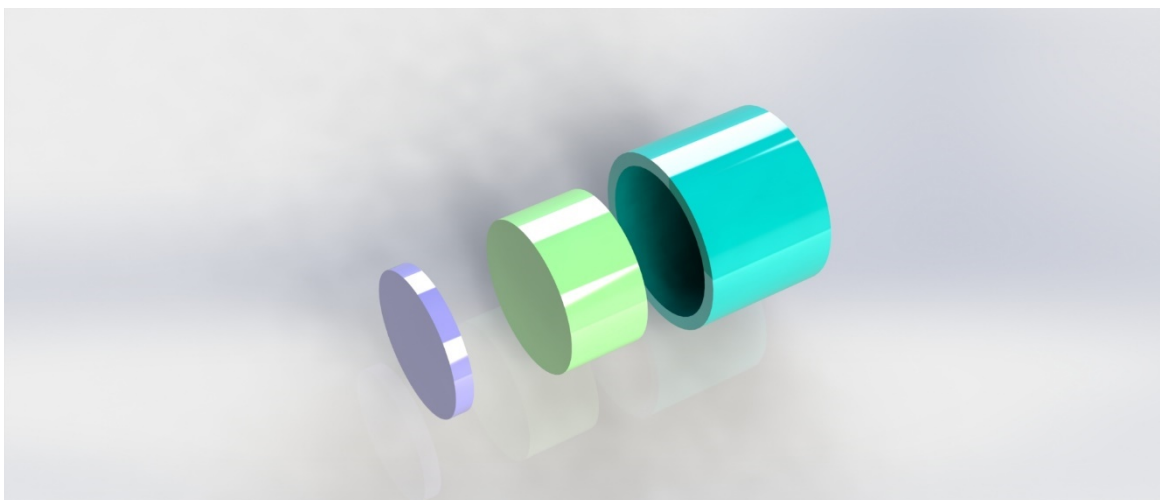


Figure 2: Pusher, Billet and Die parts CAD design

2.3. Finite Element Analysis (FEA)

The extrusion process will be simulated, and the effectiveness of the die will be assessed, using finite element analysis and the DEFORM3D tool. The extrusion process parameters, including die rotation speed, friction coefficient, and material qualities, will be set using the DEFORM3D software when the CAD model of the die is imported. Insights into the material flow, temperature distribution, and stress-strain behavior throughout the extrusion process will be provided through the FEA simulation.

2.4. Data Collection and Analysis

The cold-drawn AISI 1035 steel will be manufactured as billets, which will be put into the extrusion machine fitted with the intended die. Extrusion conditions, such as pressure, die rotation speed, and extrusion speed, will be managed and observing during the trials. Previous friction extrusion studies have been examined and it was found appropriate to take the rotation die speed value between 150-250 RPM and the shear friction coefficient value between 0.2-0.4. Thermal impacts would be ignored throughout the analysis.[12]

Data will be collected for analysis during simulations. Measurements of the extruded part's dimensions as well as parameters like Maximum principle stress, Strain rate, die rotation speed, and extrusion total speeds will be recorded. To compare the simulation results with the experimental findings, the data will be evaluated. The correctness and dependability of the simulation model will be assessed by statistical analysis and correlation investigations.

The rate of material deformation during friction extrusion is referred to as the "strain rate". The characteristics and behavior of the extruded material can be affected by the strain rate. [12]

Using a higher strain rate increases plastic deformation, allowing the material to flow more easily and fill the extrusion cavity. Additionally, higher strain rates allow the extruded material to produce a finer grain structure. This helps us to achieve higher strength and hardness values. Therefore, The higher strain rate value is the desired and ideal case for this extrusion process. [12,13,14]

The highest magnitude of stress that the material experiences at a particular location during friction extrusion is referred to as the maximum principal stress. Undesired material failure, such as cracking or fracturing, can be caused by excessively high stresses. Therefore, The lower maximum principle stress value is the desired and ideal case for this extrusion process. [15,16,17]

The combination of the linear velocity of the extruded material provided by rotation and the upper die translation velocity is called the total velocity at the critical point in the friction extrusion. A higher total velocity results in more effective material flow and better component mixing in the extruded material. Therefore, The higher total velocity value is the desired and ideal case for this extrusion process. [15,18,19]

The force used to push the material being extruded through the die is referred to as the pusher load in friction extrusion. Using lower pusher load may reduce die wear and increase tool life. Therefore, The lower pusher load value is the desired and ideal case for this extrusion process. [20]

The focus of this project's results evaluation is on the numerical data analysis from simulations to evaluate the effectiveness of the rotating die extrusion process. For the purpose of coming to useful conclusions, the collected data will be carefully examined using statistical techniques and correlation analyses.

3. RESULTS and DISCUSSION

3.1. Effects of Friction Shear Factor

This section will keep the other parameters constant by changing the shear friction coefficient values. Thus, we will be able to observe and interpret the effects of shear friction coefficient values on Strain rate, Maximum principle stress, total velocity and max load values. In order to make an accurate interpretation when performing this operation, the values of each shear friction coefficient value at the same time interval should be taken into account. In addition, it is possible to apply the method we apply in this section within other parameters.

3.1.1. For Shear at 200 RPM

Effect to Strain Rate:

Table 1: Strain rate datas for different shear rate at 200 RPM

0.2 shear (τ)		0.3 shear (τ)		0.4 shear (τ)	
Time (s)	Strain rate (mm/mm)/s	Time (s)	Strain rate (mm/mm)/s	Time (s)	Strain rate (mm/mm)/s
0.459637	2.97144	0.30195	2.59711	0.29874	2.80591
0.638620	2.25127	0.71278	2.39029	0.62900	1.90002
0.916689	2.42331	0.96415	1.90547	0.73850	2.11760
1.017606	2.28951	1.11536	1.91318	1.20531	2.18470
1.194409	2.05184	1.60877	2.15025	0.89033	2.32761
1.615872	2.98291	1.70946	2.39735	1.59391	1.77693
1.846691	2.62718	1.83677	2.09233	1.94707	1.83963
2.274386	2.95797	2.16373	2.53321	2.27444	2.08491
Mean	2.56942	Mean	2.24739	Mean	2.12966

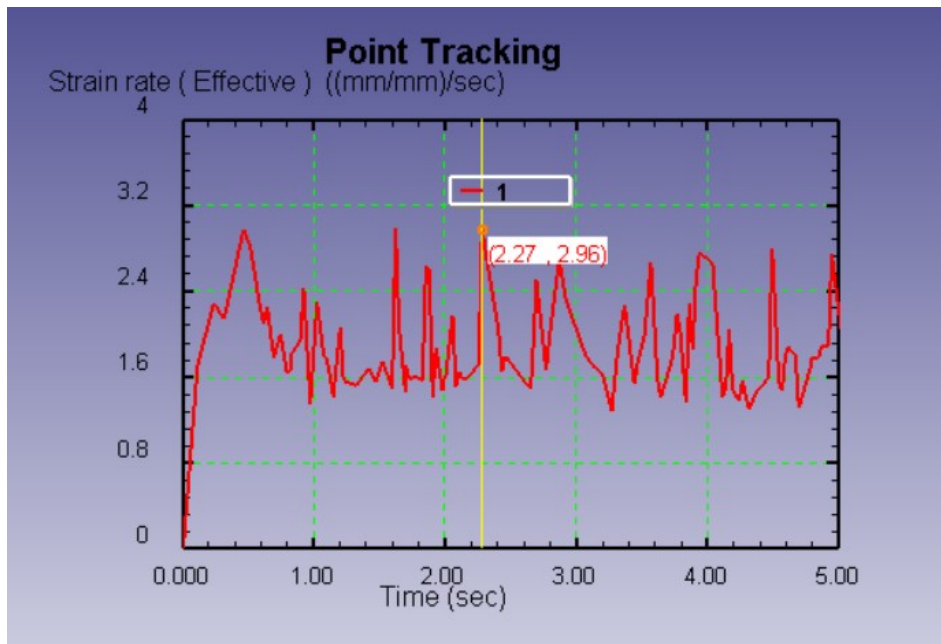


Figure 3: Strain rate vs time graph at 0.2 shear 200 RPM

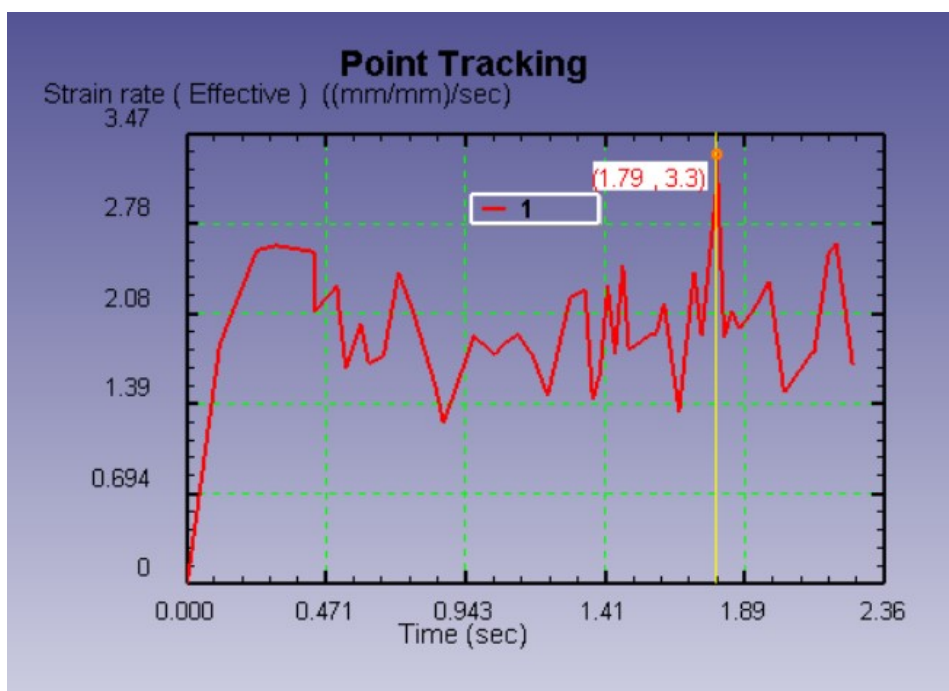


Figure 4: Strain rate vs time graph at 0.3 shear 200 RPM

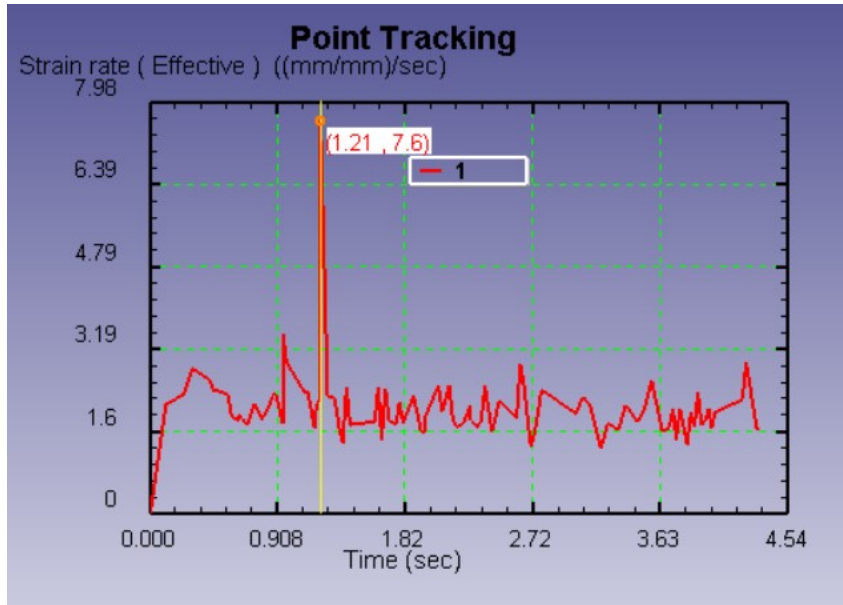


Figure 5: Strain rate vs time graph at 0.4 shear 200 RPM

Effect to Max Principle Stress:

Table 2: Max. principal stress for different shear friction coefficient values at 200 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Max principal stress (σ_1) (MPa)	1073.57	1339.32	1015.89

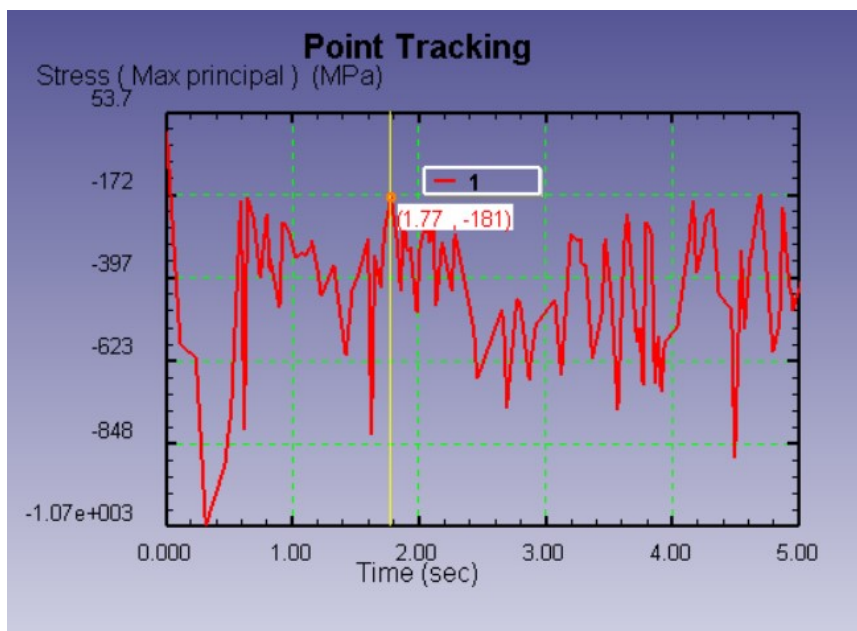


Figure 6: Maximum principal stress vs time graph at 0.2 shear 200 RPM

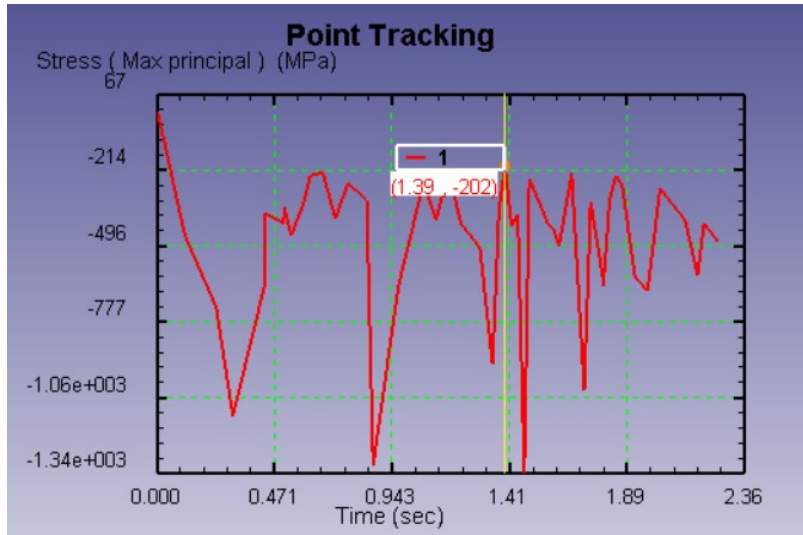


Figure 7: Maximum principal stress vs time graph at 0.3 shear 200 RPM

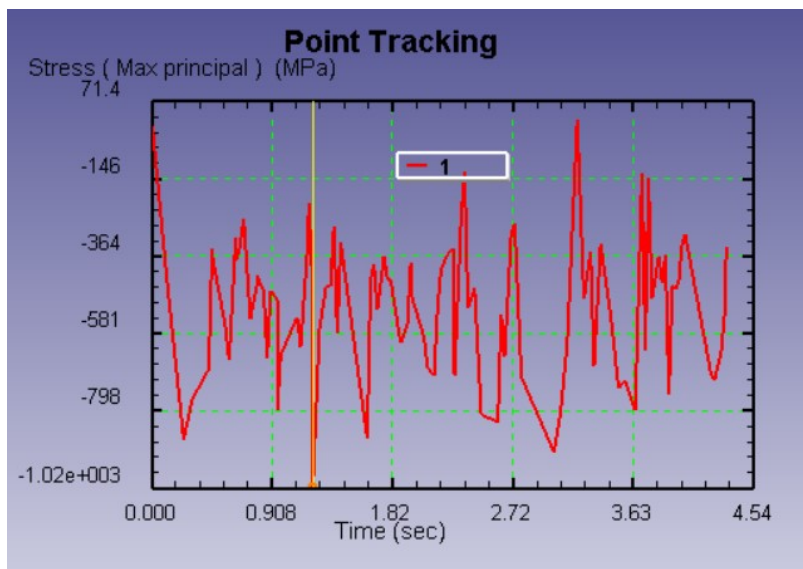


Figure 8: Maximum principal stress vs time graph at 0.4 shear 200 RPM

Effect to Velocity:

Table 3: Total Velocity for different shear friction coefficient values at 200 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Velocity (V_{avg}) (mm/s)	1716.293	1715.750	1714.799

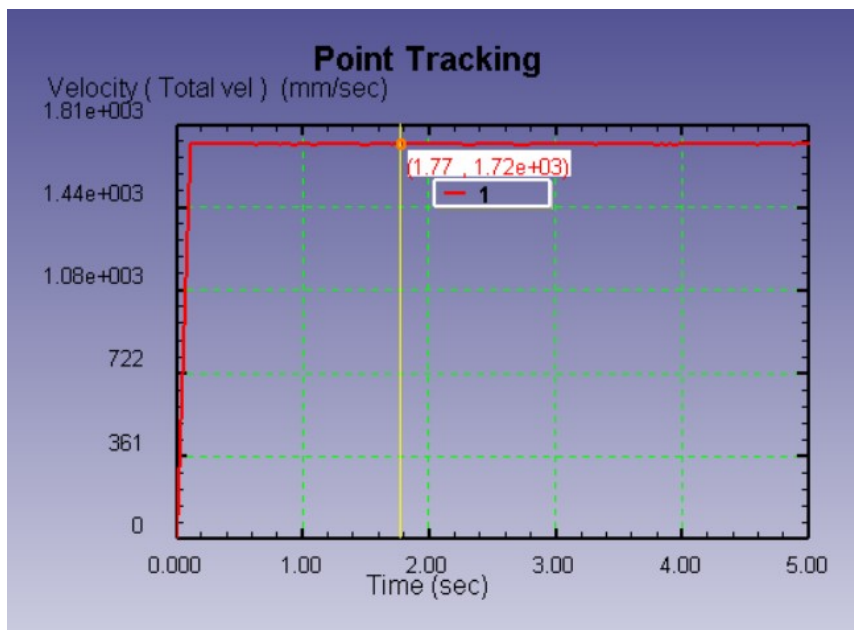


Figure 9: Total velocity vs time graph at 0.2 shear 200 RPM

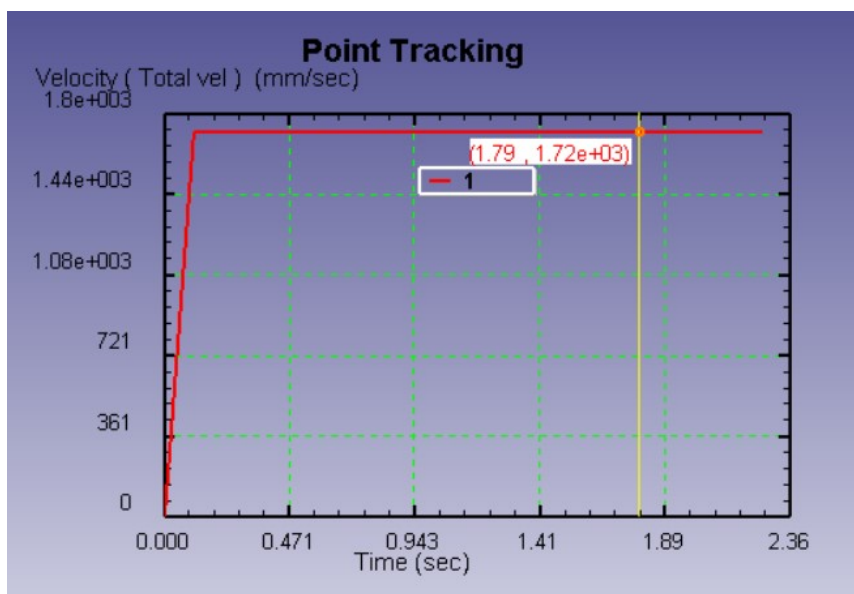


Figure 10: Total velocity vs time graph at 0.3 shear 200 RPM

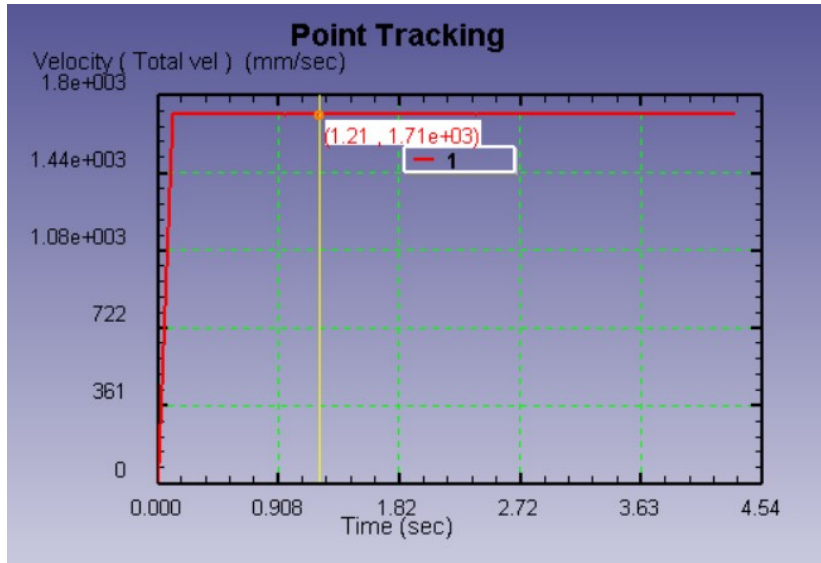


Figure 11: Total velocity vs time graph at 0.4 shear 200 RPM

Effect to Max Load:

Table 4: Max Load for different shear friction coefficient values at 200 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Max Load	65333541.77	65931977.87	73168539.79
(F)			
(N)			

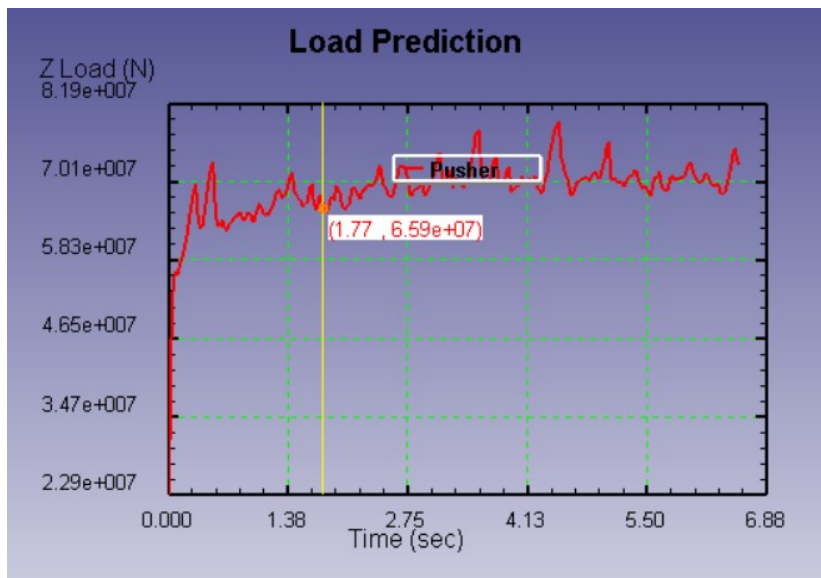


Figure 12: Pusher load vs time at shear 0.2 at 200 RPM

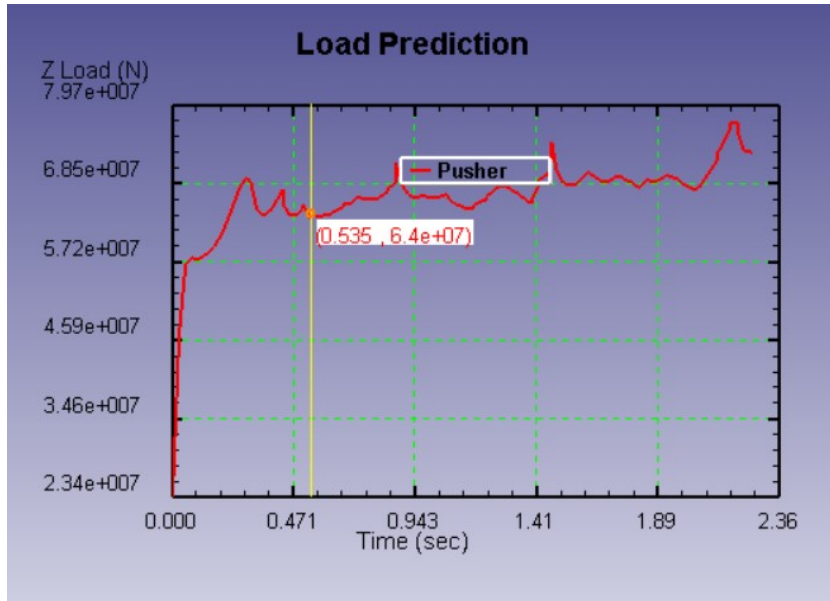


Figure 13: Pusher load vs time at shear 0.3 at 200 RPM

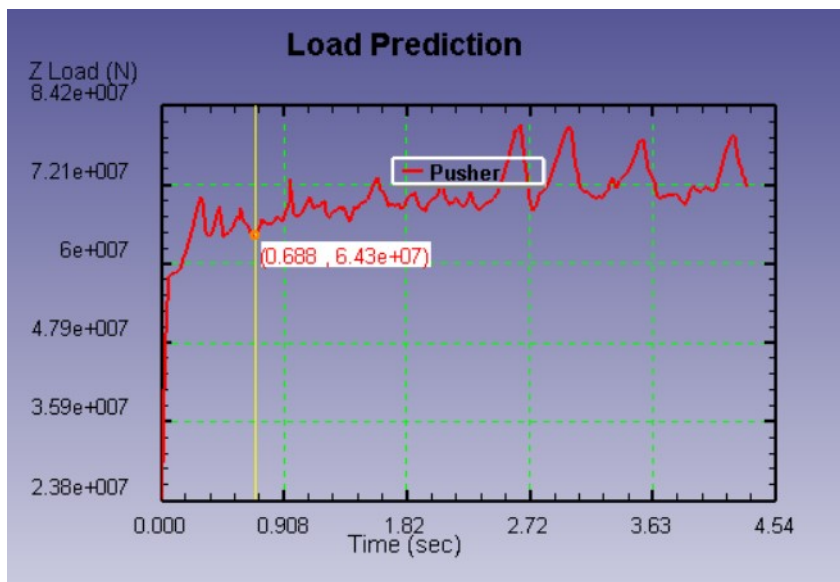


Figure 14: Pusher load vs time at shear 0.4 at 200 RPM

3.1.2. For Shear at 150 RPM

Effect to Strain Rate:

Table 5: Strain Rate for different shear friction coefficient values at 150 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Strain rate ($\dot{\epsilon}$) (mm/mm)/s	2.60944	2.46347	2.26482

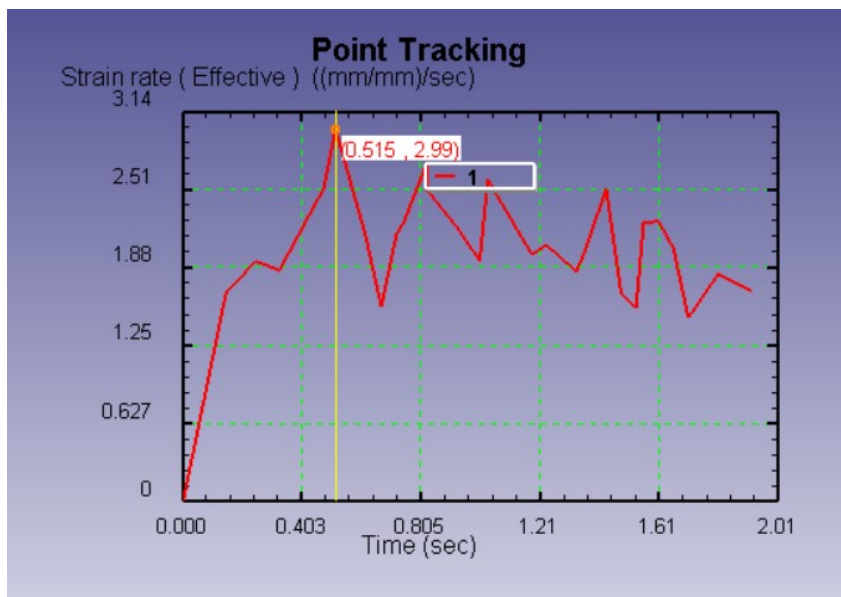


Figure 15: Strain rate vs time graph at 0.2 shear 150 RPM

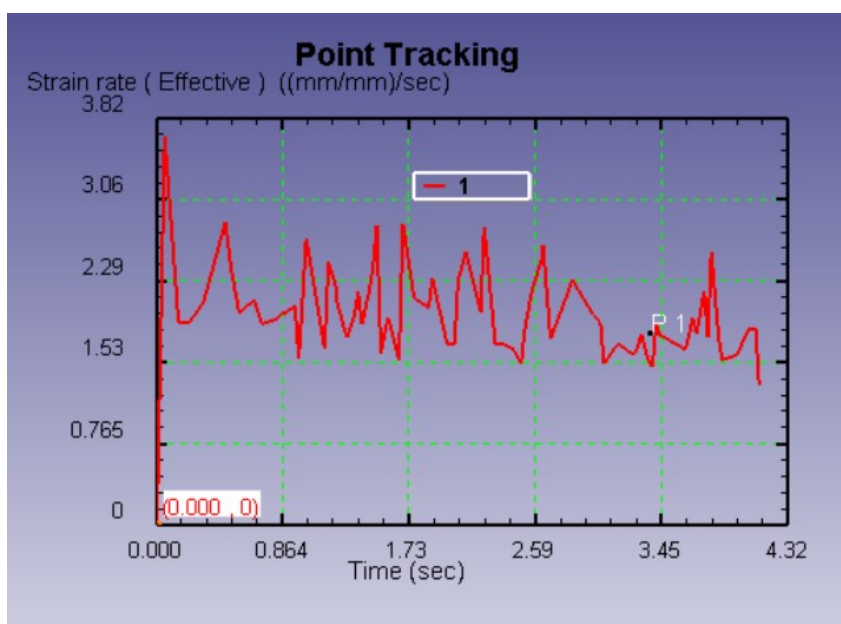


Figure 16: Strain rate vs time graph at 0.3 shear 150 RPM

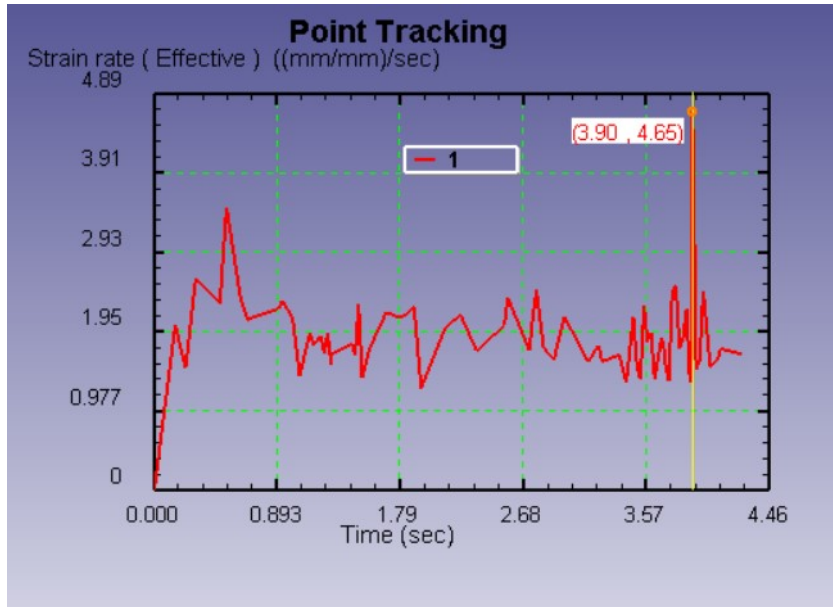


Figure 17: Strain rate vs time graph at 0.4 shear 150 RPM

Effect to Max Principle Stress:

Table 6: Max. principal stress for different shear friction coefficient values at 150 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Max principal stress (σ_1) (MPa)	1016.22	1494.54	1325.76

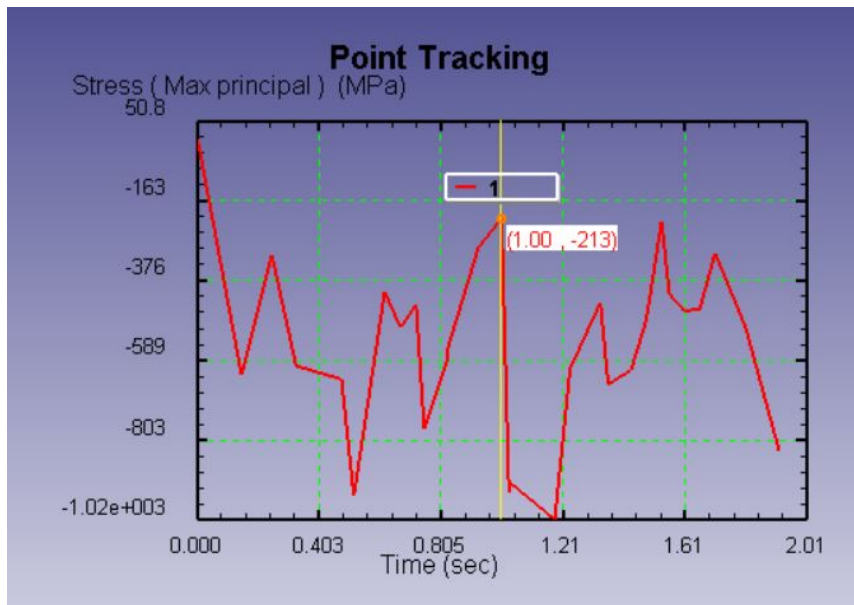


Figure 18: Maximum principal stress at 0.2 shear 150 RPM

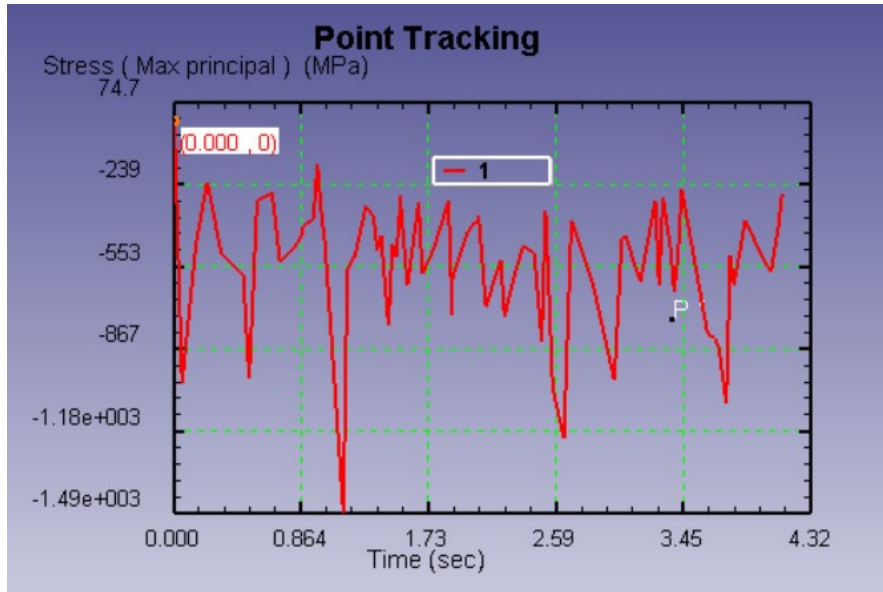


Figure 19: Maximum principal stress at 0.3 shear 150 RPM

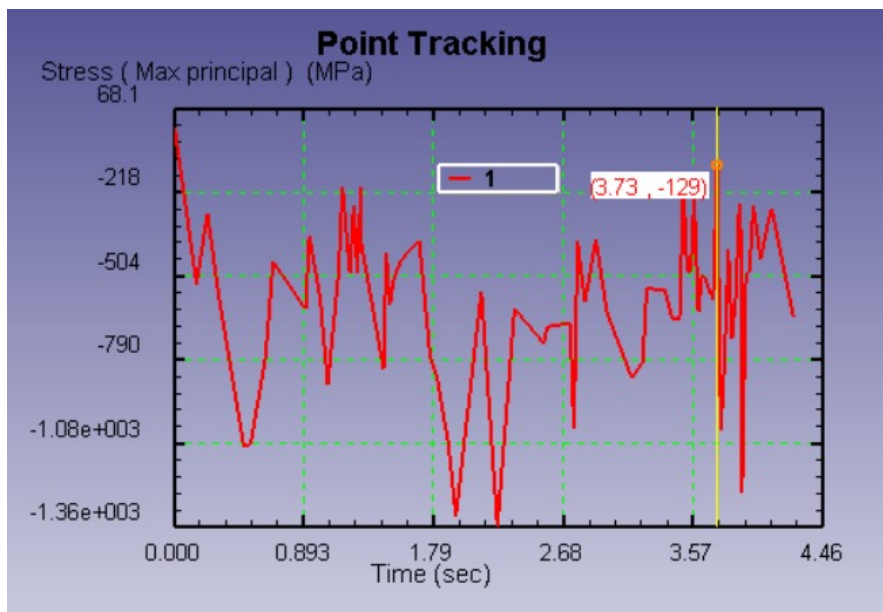


Figure 20: Maximum principal stress at 0.4 shear 150 RPM

Effect to Velocity:

Table 7: Total velocity for different shear friction coefficient values at 150 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Velocity (V_{avg}) (mm/s)	1286.855	1286.482	1285.908

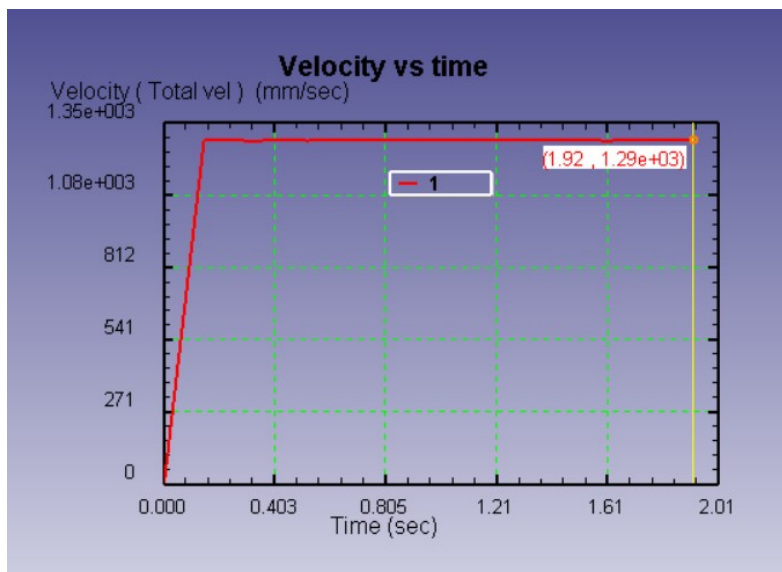


Figure 21: Total velocity vs time graph at shear 0.2 at 150 RPM

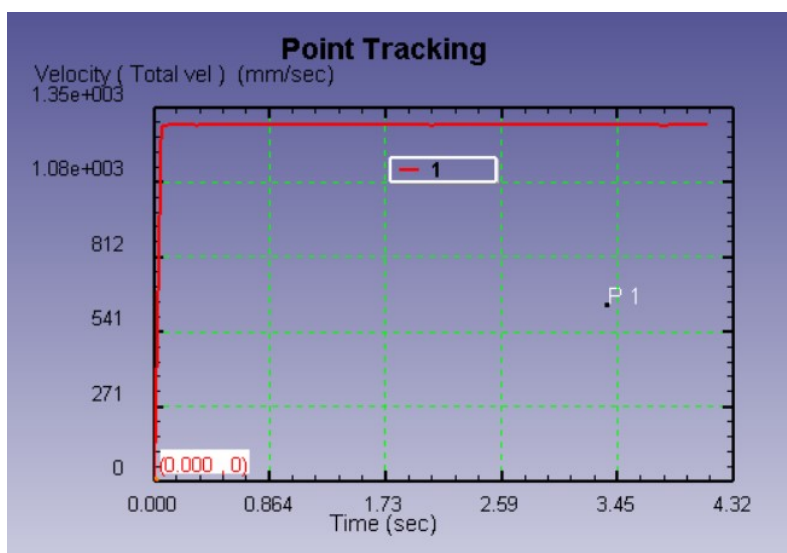


Figure 22: Total velocity vs time graph at shear 0.3 at 150 RPM

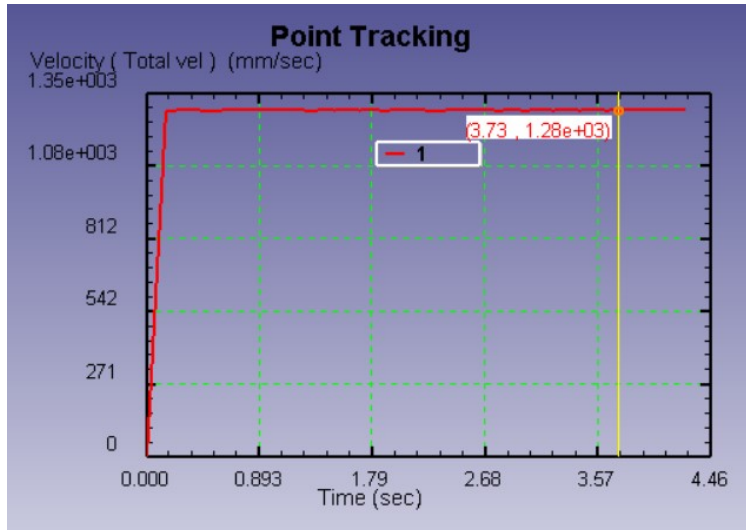


Figure 23: Total velocity vs time graph at shear 0.4 at 150 RPM

Effect to Max Load:

Table 8: Max Load for different shear friction coefficient values at 150 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Max Load	73016960.30	78278188.35	68651814.96
(F)			
(N)			

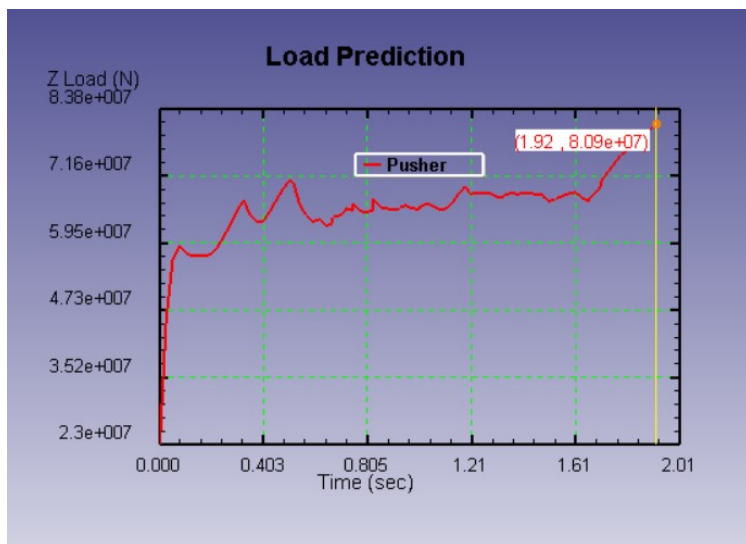


Figure 24: Pusher load vs time at shear 0.2 at 150RPM

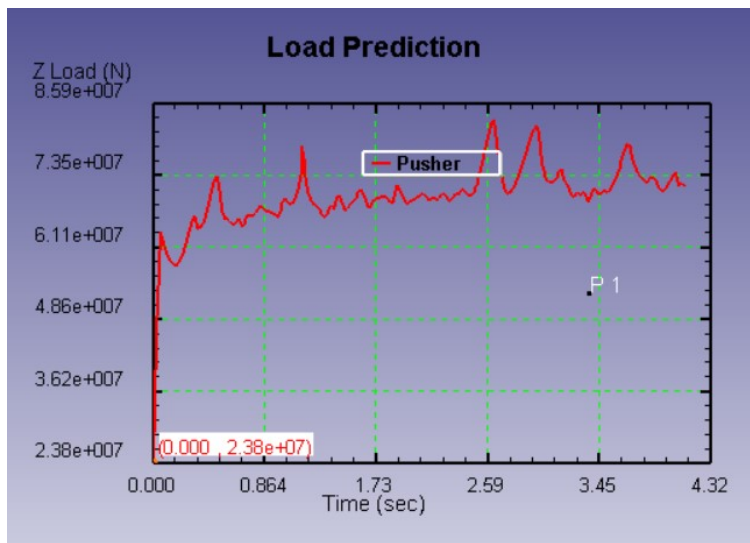


Figure 25: Pusher load vs time at shear 0.3 at 150RPM

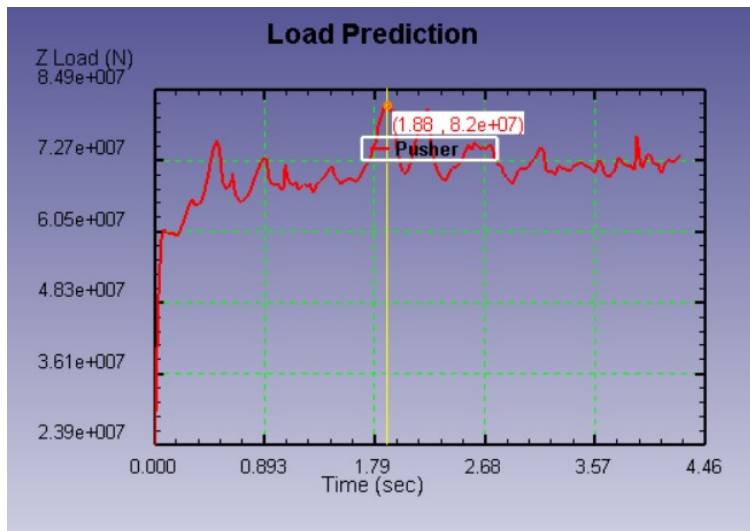


Figure 26: Pusher load vs time at shear 0.4 at 150RPM

3.1.3. For Shear at 250 RPM

Effect to Strain Rate:

Table 9: Strain rate for different shear friction coefficient values at 250 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Strain rate (ϵ') (mm/mm)/s	3.08779	2.88011	2.83363

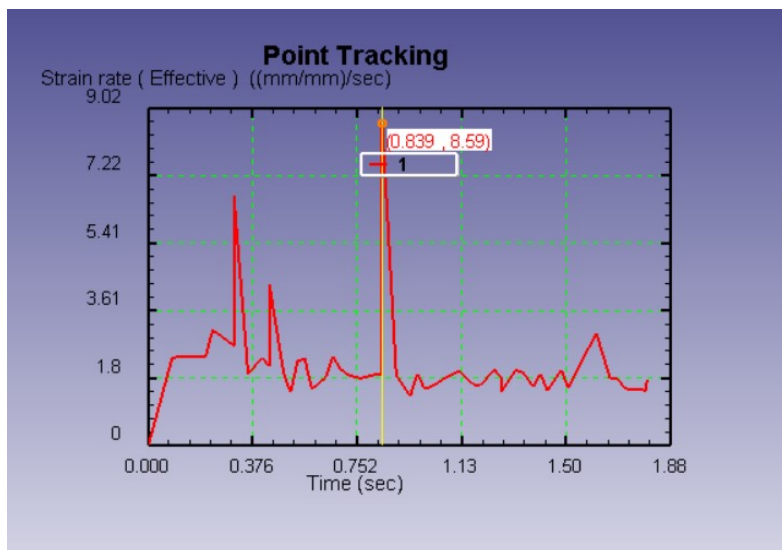


Figure 27: Strain rate vs time graph at 0.2 shear 250 RPM

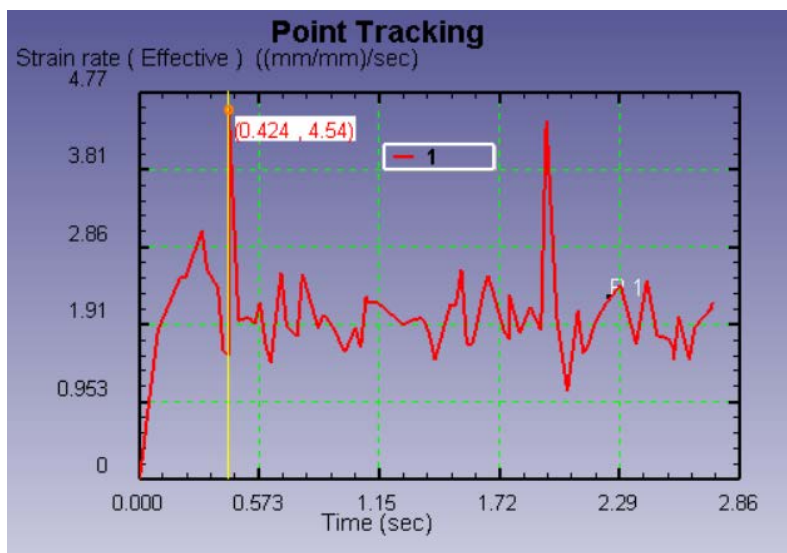


Figure 28: Strain rate vs time graph at 0.3 shear 250 RPM

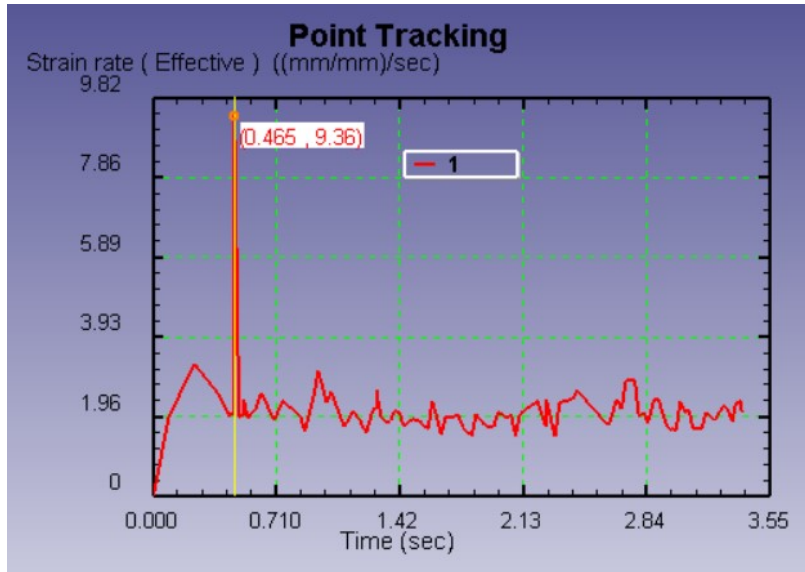


Figure 29: Strain rate vs time graph at 0.4 shear 250 RPM

Effect to Max Principle Stress:

Table 10: Max principal stress for different shear friction coefficient values at 250 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Max principal stress (σ_1) (MPa)	1054.07	850.65	1189.60

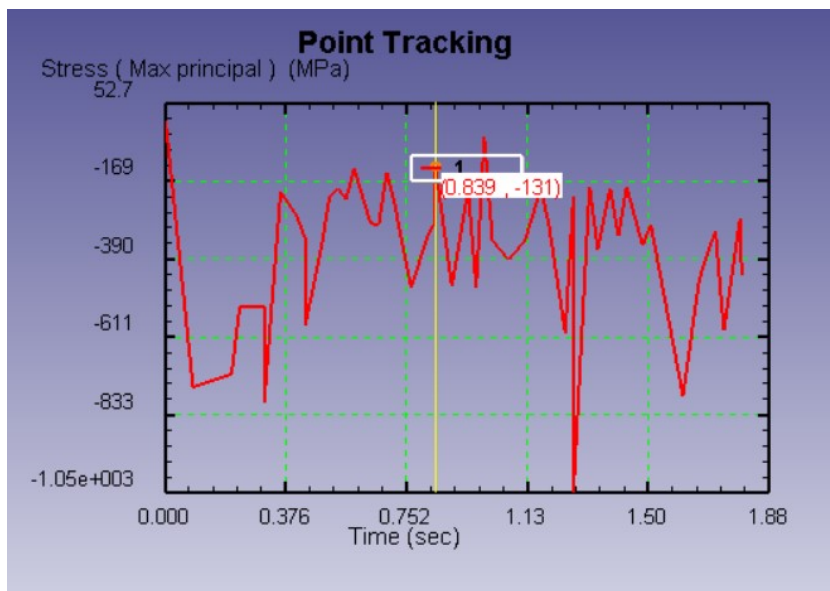


Figure 30: Maximum principle stress vs time at 0.2 shear 250 RPM

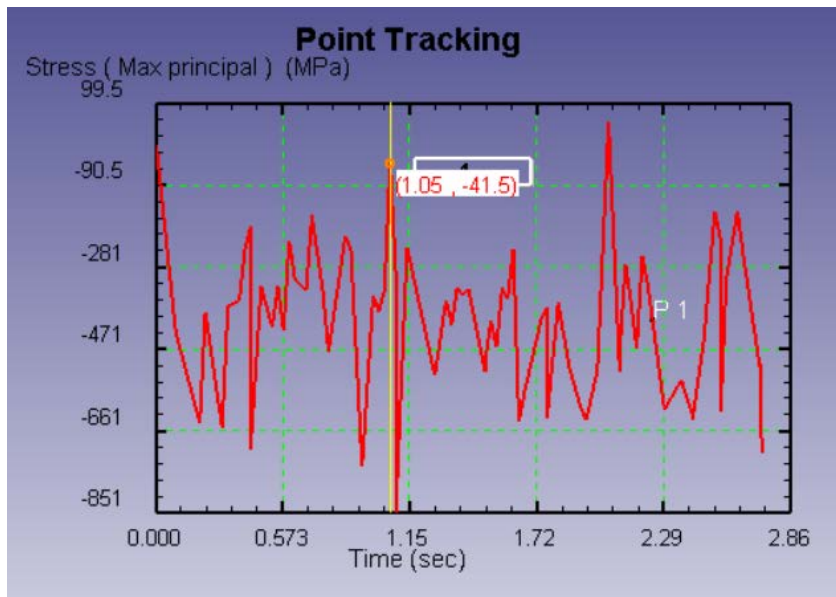


Figure 31: Maximum principle stress vs time at 0.3 shear 250 RPM

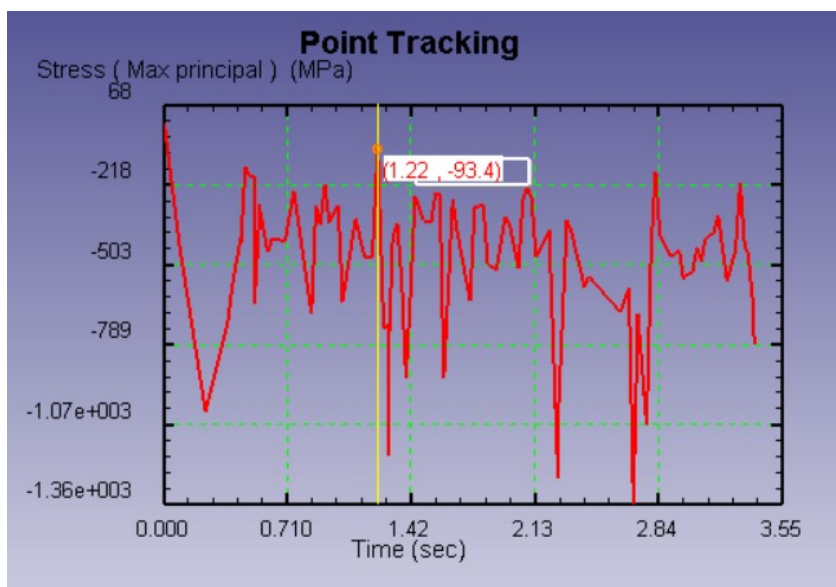


Figure 32: Maximum principle stress vs time at 0.4 shear 250 RPM

Effect to Velocity:

Table 11: Total velocity for different shear friction coefficient values at 250 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Velocity (V_{avg}) (mm/s)	2145.605	2144.908	2144.216

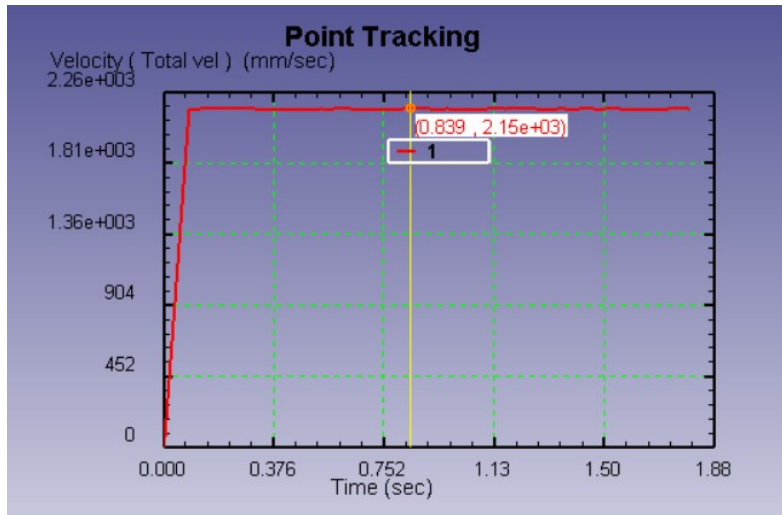


Figure 33: Total velocity vs time at 0.2 shear 250 RPM

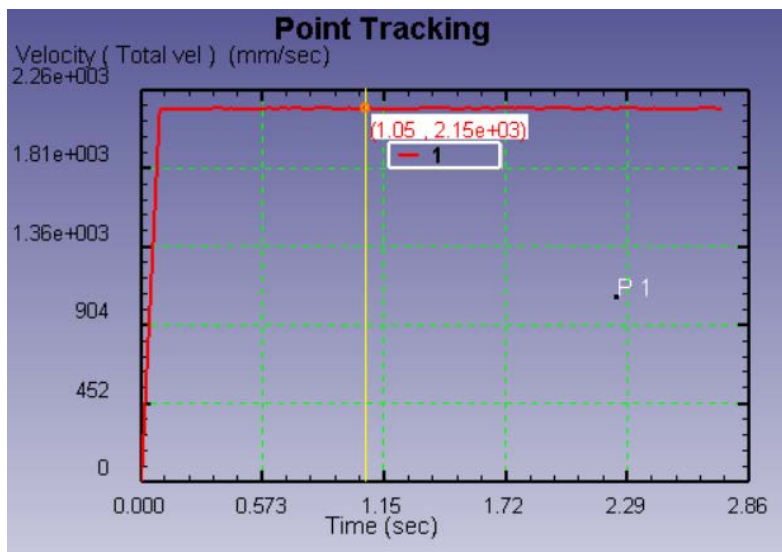


Figure 34: Total velocity vs time at 0.3 shear 250 RPM

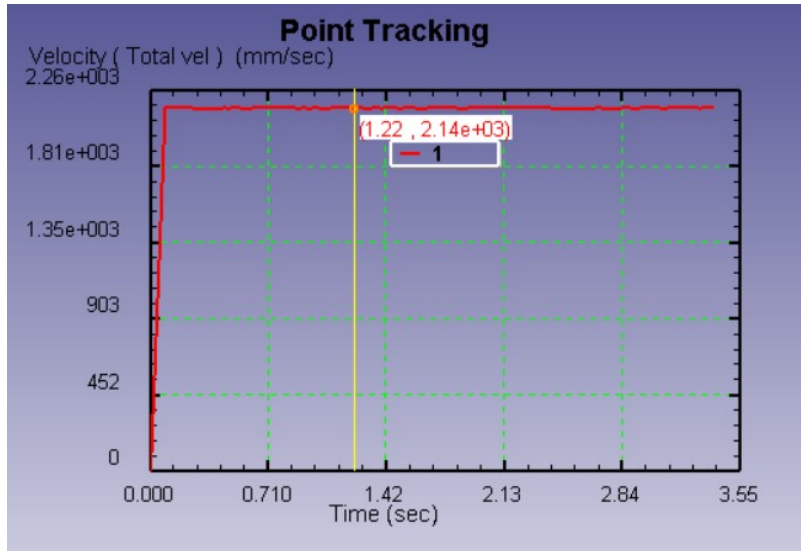


Figure 35: Total velocity vs time at 0.4 shear 250 RPM

Effect to Max Load:

Table 12: Max Load for different shear friction coefficient values at 250 RPM

	0.2 shear (τ)	0.3 shear (τ)	0.4 shear (τ)
Max Load	75345077.02	73949187.84	73949187.84
(F)			
(N)			

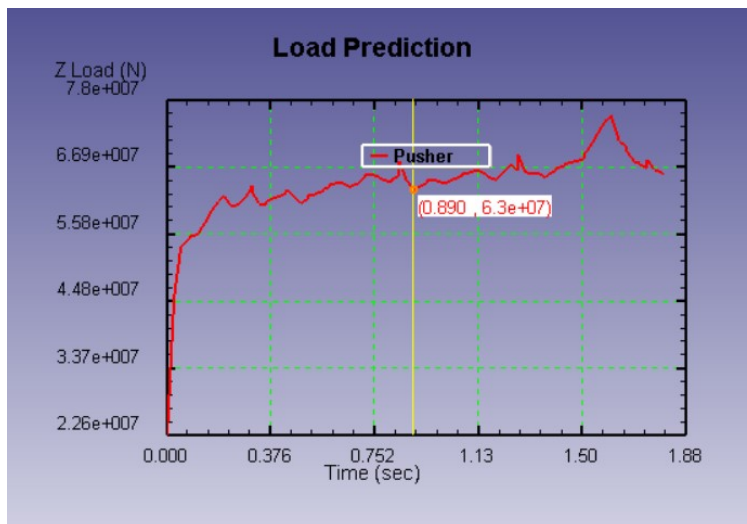


Figure 36: Pusher load vs time at 0.2 shear 250 RPM

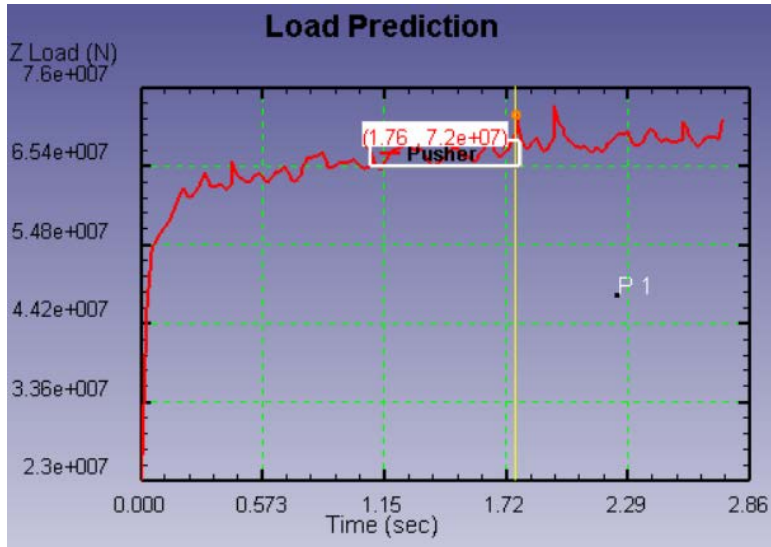


Figure 37: Pusher load vs time at 0.3 shear 250 RPM

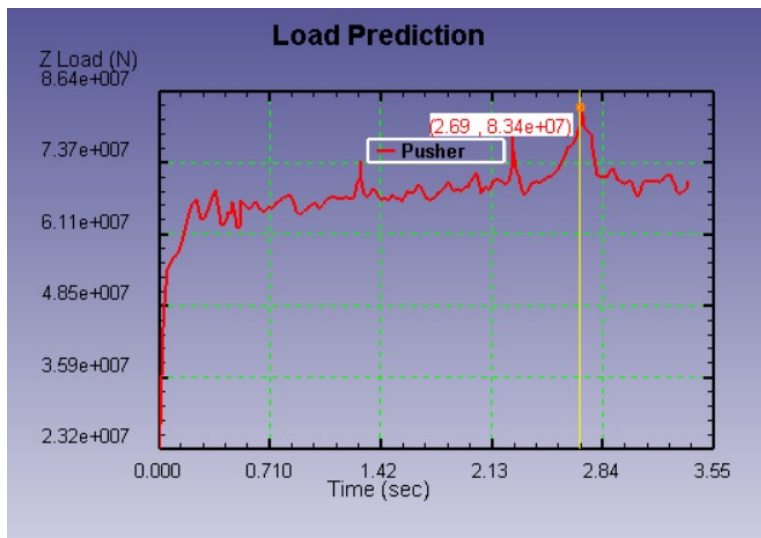


Figure 38: Pusher load vs time at 0.4 shear 250 RPM

Table 13: General data table that Analysis for effective parameters

	Shear friction (τ)	Strain rate ($\dot{\epsilon}$) (mm/mm)/s	Max principal stress (σ_1) (MPa)	Velocity (V_{avg}) (mm/s)	Max Load (F) (N)
150 RPM	0.2	2.60944	1016.22	1286.855	80901767.97
	0.3	2.46347	1494.54	1286.482	78278188.35
	0.4	2.26482	1325.76	1285.908	82031854.99
200 RPM	0.2	2.56942	1073.57	1716.293	73016960.30
	0.3	2.24739	1339.32	1715.750	74189744.04
	0.4	2.12966	1015.89	1714.799	73168539.79
250 RPM	0.2	3.08779	1054.07	2145.605	75345077.02
	0.3	2.88011	850.65	2144.908	72035038.07
	0.4	2.83363	1189.60	2144.216	73949187.84

3.2. Effects of Parameters

At 150, 200 and 250 RPM, the shear friction coefficient value increases, while the strain rate value has a decreasing trend. High strain rate is beneficial for our process. As a result, it is more beneficial for us to choose a low shear friction coefficient value, regardless of the RPM value.

When we examine the maximum principal stress values for 150 and 200 RPM values, it is more useful for us to be close to 0.2 and 0.4 shear friction coefficient values. Because the low maximum principal stress value is ideal for our process and this value is provided in the specified region. at the point where the shear friction coefficient value is 0.3, Maximum principal stress increases. However, at 250 RPM, this is not the case. A shear friction coefficient value of 0.3 is the ideal region for our maximum principal stress value.

When both the rotation speed values and shear friction coefficient values change, the maximum load value does not change at stable rate. At this point, it is more beneficial for our process to have a low max load, so the most optimum situation occurs when the rotation speed is 250 RPM and the shear friction coefficient value is 0.3.

The shear friction coefficient value is 0.2, 0.3 and 0.4, while the Strain Rate value at 250 RPM is relatively higher in all cases. It is more advantageous for us to choose 250 RPM when the shear friction coefficient value is constant.

While the shear friction coefficient value is 0.2, 0.3 and 0.4, there is no direct relationship between rotation die speed to the max principle stress value. However, since the smaller the max principle stress value, the more advantageous it will be for us and the other effect strain rate is high at this point, it is more beneficial for us to choose the shear friction coefficient as 0.3 and the rotation speed value as 250 RPM.

At 0.2, 0.3 and 0.4 shear friction coefficient values, it is observed that the total velocity value increases when the rotation speed increases. A high total velocity value is more beneficial for our process. Therefore, it will be more advantageous to choose a high rotation speed value.

At 150, 200 and 250 RPM, when the shear friction coefficient value increases, the total velocity value decreases. Since a high total velocity value will be more beneficial for our process, it is more beneficial to keep the shear friction coefficient value low.

4. ENERGY COST ANALYSIS

Firstly, in order to perform this extrusion process, we must use a press with a compression force of 82 MN, which is the largest load (at 150 RPM 0.4 shear). We chose a suitable press for this, the 90 MN extrusion press. [21]

Then, we calculated the power required to operate this press by multiplying the compression force (82 MN) by the upper translation velocity (4 mm/s).

$$P = F \times V_T = (82 \text{ MN}) \times \left(4 \frac{\text{mm}}{\text{s}}\right) = 328 \text{ kN} \cdot \frac{\text{m}}{\text{s}} = 328 \text{ kW}$$

We have calculated the required Energy and Price for each case in Table 13. While doing this calculation, we thought that we were running the press for 4 hours a day and we received the kWh price of industrial electricity at 3.7839 ₺. [22]

$$E = P \times t = (328 \text{ kW}) \times (4 \text{ h}) = 1312 \text{ kWh}$$

$$\text{Price} = E \times (\text{electricity kWh price}) = (1312 \text{ kWh}) \times \left(3.7839 \frac{\text{₺}}{\text{kWh}}\right) = 4964.48 \text{ ₺}$$

Table 14: Case, Energy, Price Table

Case	Energy (kWh)	Price (₺)
1	1294.4	4897.88
2	1252.8	4740.47
3	1312	4964.48
4	1168	4419.60
5	1187.2	4492.25
6	1171.2	4431.70
7	1204.8	4558.84
8	1152	4359.05
9	1182.4	4474.08

The energy cost is the lowest in the case 8 (250 RPM and 0.3 shear). This 4359.05 ₺ price is more economical than the other cases.

5. CONCLUSION

In conclusion, the design and analysis of an extrusion die with a rotating die component were the main topics of this research project. The goal was to look into how a rotating die affected the extrusion process and evaluate any potential benefits. Using the DEFORM3D program, finite element analysis was used to simulate the extrusion process and assess die performance while taking into account variables like die rotation speed and friction coefficient.

The project's findings gave important new information about how rotation speed and shear friction coefficient affect various parameters. It was found that the shear friction coefficient increased while the strain rate decreased at all rotation die speeds. While a low shear friction coefficient value should be preferred regardless of the RPM value, a high strain rate was found to be advantageous for the process.

The maximum principal stress values at rotational speeds of 150 and 200 RPM were examined, and it was found that being close to shear friction coefficient values of 0.2 and 0.4 is more beneficial. The reason for this is that a lower maximum principal stress value is thought to be ideal for our process, and such values are obtained within the specified range. However, If the maximum principal stress rises to a shear friction coefficient of 0.3 , It should be mentioned that for 250 RPM, this trend is not valid. In fact, for our maximum principal stress value at this rotation speed, a shear friction coefficient value of 0.3 becomes the preferred range.

Variations in rotational speed and shear friction coefficient had no discernible impact on the maximum pusher load value. A low maximum load was thought to be better for the process, though. Therefore, the rotation speed of 200 RPM and the shear friction coefficient value of 0.2 were found to be the most advantageous conditions.

Furthermore, the strain rate at 250 RPM was noticeably higher in all cases when the shear friction coefficient value was constant at 0.2, 0.3 and 0.4. Therefore, in such circumstances, selecting a rotation speed of 250 RPM was advantageous.

The maximum principle stress value does not directly relate to die rotation speed value when the shear friction coefficient values are 0.2, 0.3 and 0.4. Having a lower maximum principle stress value is beneficial though. Therefore, a shear friction coefficient of 0.3 and a rotation speed value of 250 RPM are more beneficial. These decisions can improve the system's performance and reduce the maximum principle stress.

It is obvious from the observations made at shear friction coefficient values of 0.2, 0.3, and 0.4 that increasing rotation speed causes the total velocity value to rise. Selecting a high rotation die speed value is more advantageous for the process.

At three different RPM values (150, 200, and 250), the relationship between shear friction coefficient and total velocity has been studied. The results show that the total velocity value decreases as the shear friction coefficient value increases. Selecting a low shear friction coefficient value is more advantageous because a high total velocity value is better for our process.

In addition, in terms of cost, 250 RPM and 0.3 shear friction coefficient value are the ideal option and more economical than other cases.

Finally, with this project, we have seen whether the extrusion process is applied to steel or not. Also, a shear friction coefficient value of 0.4 has brought high load results for our process, and it should not be excluded that the friction values may actually be lower.

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