MARMARA UNIVERSITY
FACULTY OF ENGINEERING

DESIGN AND ANALYSIS OF AN EXTRUSION DIE HAVING ROTATING DIE

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GRADUATION PROJECT REPORT

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by

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First, I would like to thank my supervisor Prof.Dr. Aykut Kentli, for the valuable guidance and advice on preparing this thesis and giving me moral and material support.

July, 2023 Ömer Burak Say

CONTENT TABLE

Abstract

This thesis examines the optimization of exit diameters and rotational speeds of the mold in the extrusion process of aluminum materials using the friction extrusion method. Friction extrusion is an advanced technique used for continuous shaping of aluminum materials, offering advantages in terms of energy efficiency and production efficiency.

This study investigates the impact of exit diameters and rotational speeds of the mold on aluminum profile production in the friction extrusion process. Optimal exit diameters and rotational speeds are important parameters that need to be determined to achieve higher-quality profiles, improve energy efficiency, and optimize the production process.

In this study, different combinations of exit diameters and rotational speeds of the mold are tested using experimental studies and data analysis methods. The experiments conducted on aluminum materials evaluate the effects of exit diameter and rotational speed on profile quality, tolerances, and energy consumption.

The obtained results will contribute to determining the optimal exit diameters and rotational speeds for aluminum profile production using the friction extrusion method. This study can be considered as a step towards developing more efficient and sustainable production methods in the aluminum extrusion industry.

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1. Introduction

1.1. General Information

Finite element analysis uses complex mathematical equations, models, and simulations to understand how objects interact with physical forces. This aids engineers in understanding object durability and how to optimize it. Finite element analysis is a method of structural analysis that uses mathematical processes. The material definitions required for the composite structure were determined by experimental methods and entered into the FEA program.[1] FEA requires you to break down a larger, more complicated object into more manageable sections. As you keep splitting the structure, you get a better idea of how the object will respond to stressors. This method of breaking down a structure for FEA is known as the finite element method (FEM). For finite element analysis to perform its necessary simulations, a mesh -- containing millions of small elements that together form the shape of a structure -- must be created. Calculations must be performed on every single element; the combination of each of these individual answers provides the final result for the full structure.

FEM is an efficient mathematical tool that used for investigating issues of contact surface like chip formation and method variables i.e., physical quantizes [2]. A three-dimensional machining model is created with Deform-3D FEM software. The input parameters temperature, effective stress, effective strain, and effective strain rate were used to analyze the output parameters. DEFORM 3D software results of the FEM model results are compared with experimental results, which is done by response surface methodology. The projected FEM model provide less than 15 % and 14 % relative error of thrust force are found [3]. The modelling has been done by using 3D modelling software SOLIDWORKS and simulation through the Finite element based package DEFORM 3D software. The forming load can be estimated by the results obtained from the Finite element analysis through DEFORM 3D software.

Extrusion is a metalworking process that uses compressive forces to deform a billet of material through a die opening to create a desired cross-sectional shape. The process is typically used to produce long, cylindrical products such as rods, tubes, and profiles. Friction extrusion is a variation of the extrusion process that uses friction to generate heat and plasticize the material. This allows for the processing of materials that would be difficult or impossible to extrude using conventional methods. Friction extrusion is a versatile process that can be used to produce a wide range of materials with a variety of properties.[4] Friction extrusion is often used to produce powders, composites, and other materials that are difficult to consolidate using other methods.

To understand and predict the behavior of materials during friction extrusion, the finite element method (FEM) is often employed. FEM is a numerical technique that divides a domain into smaller finite elements and approximates the physical behavior of these elements by solving a set of equations. By applying FEM principles, the behavior of the material, such as deformation, temperature distribution, and other relevant parameters, can be simulated and analyzed.

DEFORM 3D is a specific software package that utilizes the finite element method to simulate and analyze various manufacturing processes, including friction extrusion. By using DEFORM 3D, engineers and researchers can input parameters such as material properties, boundary conditions, and tool geometry to model the behavior of materials during friction extrusion. The software then uses FEM principles to predict the deformation, temperature distribution, and other important aspects of the process.

In summary, friction extrusion is a metal forming process that relies on frictional forces, while the finite element method is a numerical technique used to simulate and analyze complex engineering problems. DEFORM 3D is a powerful tool that can be used to simulate friction extrusion processes. It allows us to predict the material flow and stress distribution during the process, which can help us to optimize the process parameters and improve the quality of the final product [5]. DEFORM 3D combines these concepts by utilizing FEM to model and predict the behavior of materials during friction extrusion, enabling engineers and researchers to optimize the process and understand its underlying mechanisms.

1.2.Experiment Information

Extrusion process is a common manufacturing method where polymers or metal alloys are melted in a thermoplastic state and forced into a mold to shape materials in a controlled manner. Extrusion is a widely-used manufacturing process to produce complex profiled products over the entire extrudate length [6]. In this method, as the material moves within a mold, friction occurs between the material and the mold surface, enabling the shaping of the material. Extrusion has been well established as a reliable and economical process in the automobile and aerospace industries to manufacture components of superior mechanical strength [7].

This study focuses on the friction extrusion method and examines the effects of variables such as exit diameters and rotational speeds of the mold using the Deform 3D software. The friction extrusion process was patented in 1993 by The Welding Institute [8].Friction extrusion offers certain advantages over other extrusion methods. For example, materials can be shaped with higher quality and less deformation. Too-low and too-high processing temperatures resulted in cold tearing and hot cracking effects, respectively [9]. Therefore, optimizing the use of the friction extrusion method can provide significant added value in industrial applications.

The aim of this thesis is to understand the fundamental principles of the friction extrusion process, analyze friction forces and material behavior, and investigate the impact of process variables such as exit diameters and rotational speeds of the mold on the results. The Deform 3D software is used as the main research tool for this study. This program enables us to analyze the friction extrusion process in more detail by simulating the flow and deformation of the material.

The purpose of this study is to understand the fundamental principles of the friction extrusion method and the impact of process variables on the results, thus contributing to the optimization of the friction extrusion process in industrial applications. This research aims to provide information that will contribute significantly to the field of materials science and the manufacturing industry.

This thesis work brings a new perspective to the studies on the friction extrusion method and serves as a fundamental step towards enhancing the efficiency of friction extrusion in industrial applications. The obtained results will guide future studies aimed at optimizing the friction extrusion process and improving quality in material shaping processes.

2. Problem Statement:

Considering that exit diameters and rotational speeds of the mold are important parameters in aluminum profile production using the friction extrusion process, this study aims to examine how specific combinations of exit diameter and rotational speed affect parameters such as stress, Y-loads, maximum stress principle, effective strain, and velocity.

The exit diameters used in the experiments are set as 30 mm, 40 mm, and 50 mm, while the rotational speeds are set as 100 rpm, 200 rpm, and 300 rpm, respectively. During the experiments, parameters such as stress, Y-loads, maximum stress principle, effective strain, and velocity are measured and recorded.

The main objective of this study is to analyze how these parameters change with specific combinations of exit diameter and rotational speed and develop an understanding to optimize the friction extrusion process in terms of quality, performance, and energy efficiency.

This analysis will enable the understanding of important parameters associated with exit diameters and rotational speeds in the aluminum profile production process and contribute to the future use of the friction extrusion process in a more efficient and optimized manner.

The results of this study will provide practical insights for reducing energy consumption and optimizing the production process in the aluminum extrusion industry.

3. Design

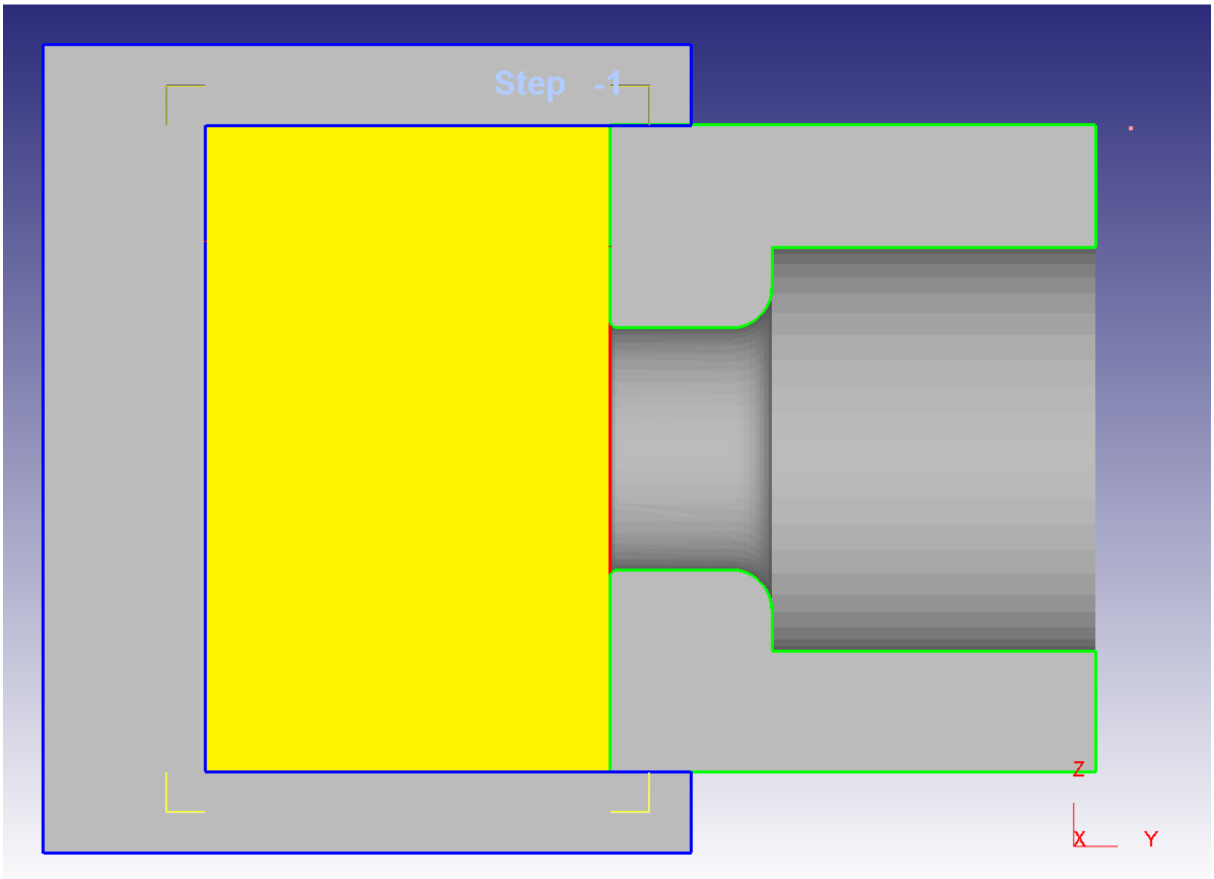

Figure 1 Ø30mm outlet diameter design

I am performing rotational and pushing movements in this heart-shaped mold in my heart. In the design of the mold, the diameter is given to the areas where the top die presses on the material to reduce the loads on the top and bottom dies and to provide an easy and comfortable workflow for the workpiece. Additionally, the exit diameter inside the mold is wider to facilitate rapid cooling of the material.

Workpiece: Designed with a diameter of Ø80mm and a width of 50mm.

Top Die: The mold is designed with three different exit diameters, namely Ø30, Ø40, and Ø50mm.

4. Setup

In this thesis, the drawings that we created in Solidworks and saved as .stl files for the analyses conducted using DEFORM 3D are shown as an example setup in Figure 2. The setup section will be provided in detail for the workpiece, top die, bottom die, and inter-object parts.

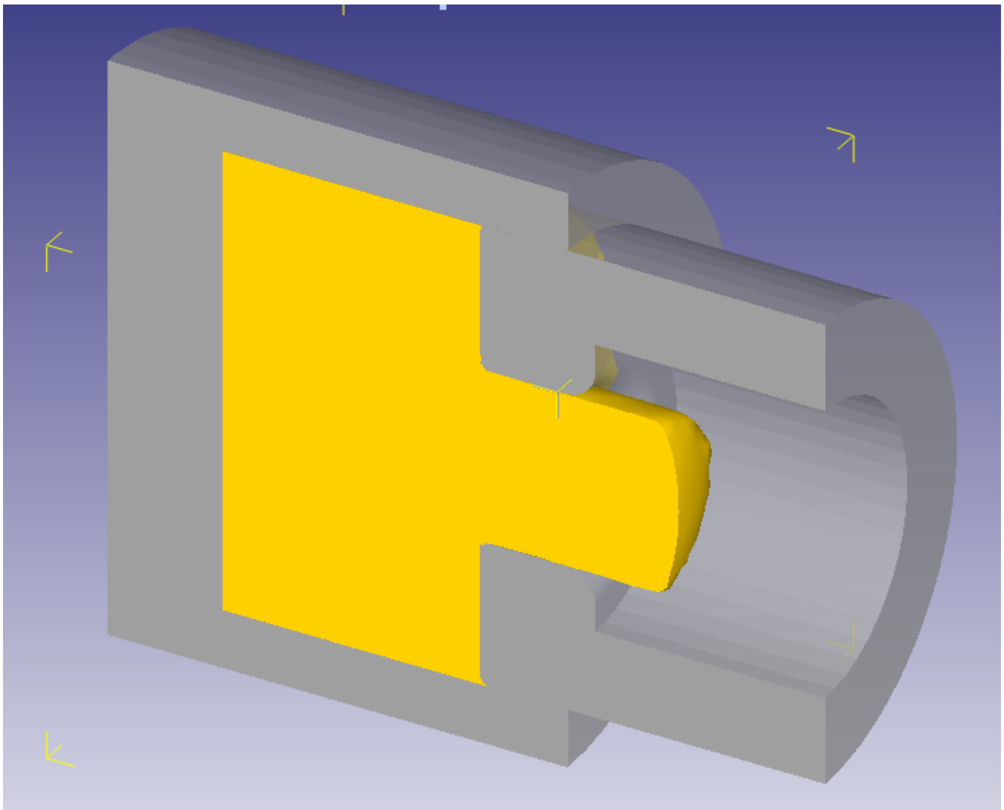

Figure 2 General Setup Figure

4.1 Workpiece

Type:

- Object type: Plastic
- Tempreture: 300°c
- Type Name: ALUMINUM-7075[480-930F(250-500C)]
- Flow stress:
- Strain: 0 - 0.6
- Strain Rate: 0.001 – 100
- Temperature: 250 – 500°c

Mesh:

- Mesh number Number: 52542
- Number of nodes : 11445
- Surface polygones: 9804
- Elements : 52542

4.2 Top Die

- Object type : Rigid
- Tempreture:20°c

Movement:

Translation:

- Type: Speed
- Direction: -Y
- Constant Value: 1 mm/sec

Rotation:

- Type: Constant Angular Velocity (100, 200, 300 RPM)

4.3 Buttom Die

- Object type : Rigid
- Tempreture:20°c

4.4 Inter-Object

- Relation(Master-Slave) Friction
- Top Die – Workpiece Shear 0,3
- Buttom Die – Workpiece Shear 0,3

Friction:

- Type: Shear
- Value: 0,3 (Hot forging (Lubricated))

Contact BBC:

- Tolerance: 0,0605 mm

5. Results and Discussions

This section presents the results and comparisons of the analyses we conducted. The results are examined under four main headings: effective stress, effective strain, velocity, and Y load. These obtained results are analyzed based on changes in RPM and output diameter, and Table 1 is created accordingly.

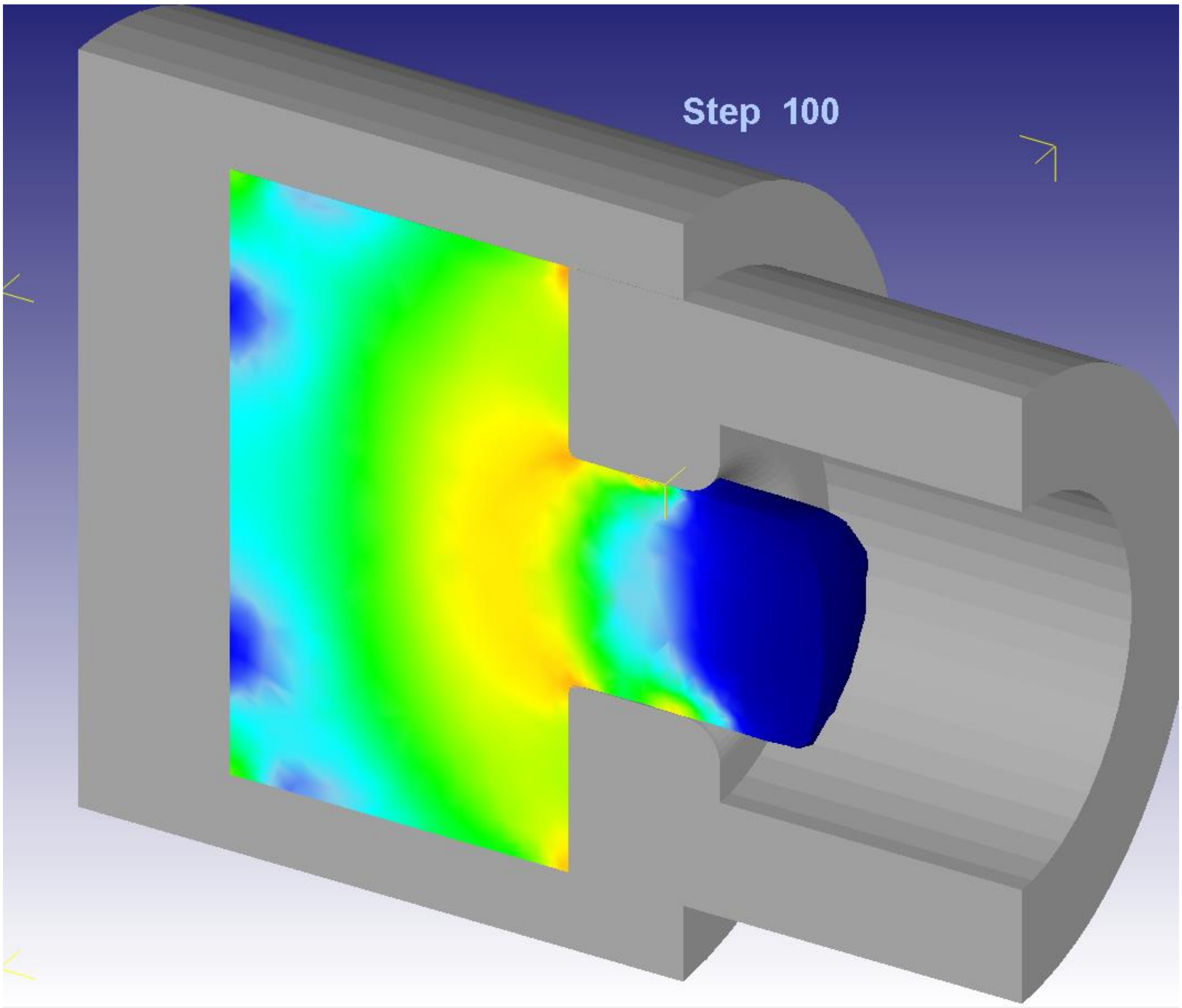

Figure 3 Stress Effective Figure

Table 1 Exit Diameter-Rpm Analyzed data

Ømm-RPM	Stress Effective (MPa)	Strain Effective (mm/mm)	Velocity (mm/sec)	Y Load (kN)	
				Top Die	Buttom Die
30-100	165	2,78	7,78	1906	1893
30-200	173	2,67	9,43	1860	1857
30-300	175	2,39	12	1845	1840
40-100	164	3,47	6,13	1490	1485
40-200	167,5	2,78	9,25	1466	1460
40-300	174	2,47	11,3	1450	1443
50-100	162	3,97	5,04	1139	1131
50-200	165,2	3,54	8,4	1128	1120
50-300	172	2,77	9,8	1117	1107

5.1 Stress Effective

- Effect of RPM: When examining the data, it can be observed that an increase in RPM generally leads to an increase in effective stress levels. This trend can be observed for different diameters as well. For example, for a 30 mm diameter, increasing the RPM from 100 to 300 results in an increase in the effective stress level from 165 MPa to 175 MPa. Similarly, for 40 mm and 50 mm diameters, an increase in RPM also leads to an increase in effective stress levels.

- Effect of Diameter: Analyzing the data for various diameters reveals that effective stress levels change with diameter. For a given RPM, the effective stress levels vary as the diameter increases. For instance, at 100 RPM, the effective stress is 165 MPa for a 30 mm diameter, whereas it decreases to 164 MPa for a 40 mm diameter and 162 MPa for a 50 mm diameter. This indicates that for a given RPM, effective stress levels decrease with an increase in diameter.

5.2 Strain Effective

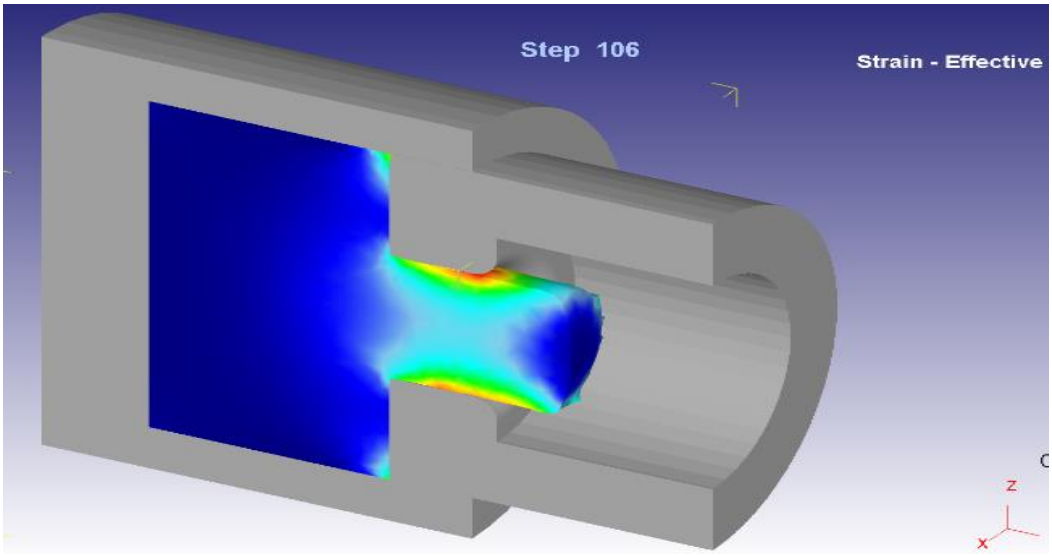

Figure 4 Strain Effective Figure

- Effect of RPM: When examining the data, it is observed that an increase in RPM generally leads to a decrease in effective strain levels. This trend can be observed for different diameters as well. For example, in the case of a 30 mm diameter, increasing the RPM from 100 to 300 causes the effective strain level to decrease from 2.78 to 2.39. Similarly, for the 40 mm and 50 mm diameters, an increase in RPM results in a decrease in effective strain levels.

- Effect of Diameter: Analyzing the data for various diameters reveals that diameter has a significant impact on effective strain levels. For different diameters at a specific RPM, an increase in diameter leads to changes in effective strain levels. For instance, at 100 RPM, the effective strain is 2.78 for a 30 mm diameter, but it increases to 3.47 for a 40 mm diameter and 3.97 for a 50 mm diameter. This indicates that with an increase in diameter, the effective strain levels generally increase at a given RPM.

5.3 Velocity

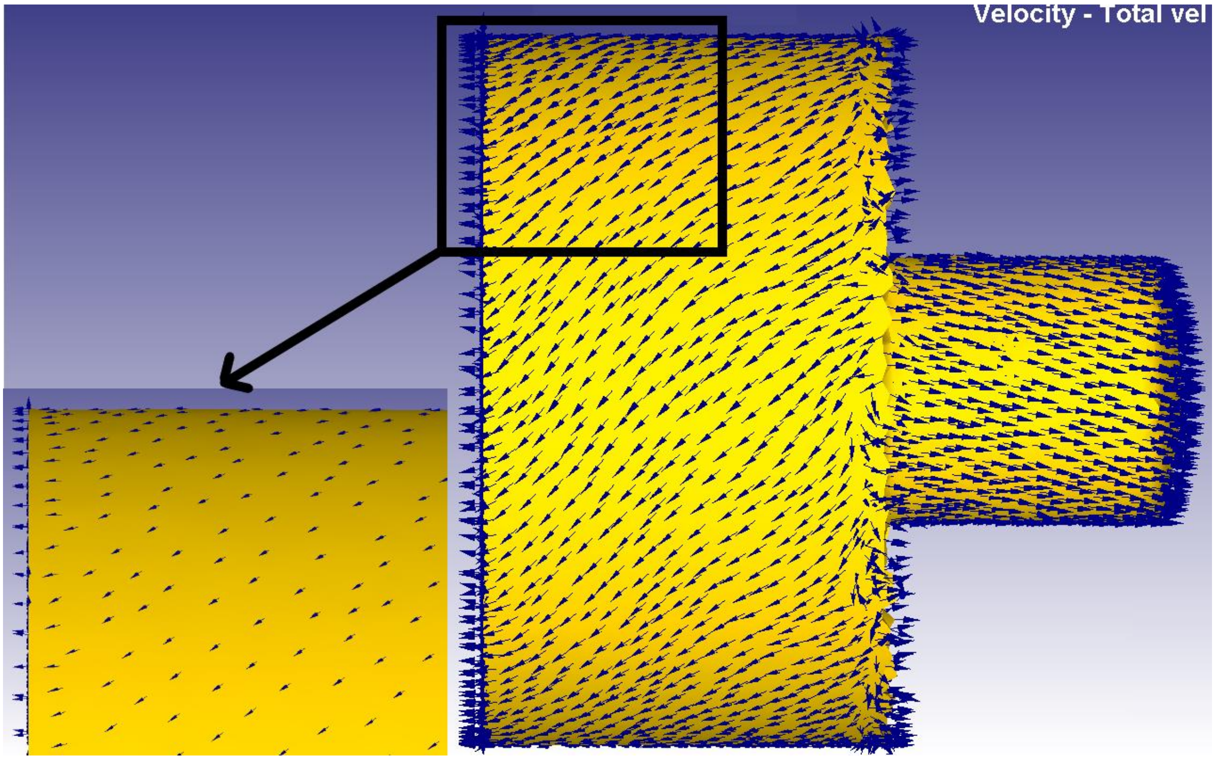

Figure 5 Velocity Figure

- Effect of RPM: When analyzing the data, it can be observed that an increase in RPM generally leads to an increase in speed. This trend can be observed for different diameters as well. For example, for a 30 mm diameter, increasing the RPM from 100 to 300 results in an increase in speed from 7.78 to 12. Similarly, for 40 mm and 50 mm diameters, an increase in RPM also leads to an increase in speed.

- Effect of Diameter: Analyzing the data for various diameters reveals that diameter has a significant impact on speed. For different diameters at a given RPM, an increase in diameter leads to an increase in speed. For instance, at 100 RPM, the speed is 7.78 for a 30 mm diameter, whereas it decreases to 6.13 for a 40 mm diameter and 5.04 for a 50 mm diameter. This indicates that for a given RPM, speed decreases with an increase in diameter.

5.4 Y Load (Top Die and Buttom Die)

- Effect of Diameter: When examining the data, we observe a significant impact of diameter on the Y load. Generally, an increase in diameter leads to a decrease in the Y load. For example, in the top die, the Y load decreases from 1.906 MPa for a 30mm diameter to 1.139 MPa for a 50mm diameter. A similar trend is applicable to the bottom die as well.

- Effect of RPM: Analyzing the data, we observe that the effect of RPM on the Y load is limited. In different diameters and RPM values, the change in RPM generally results in a small variation in the Y load. For instance, in the top die with a 30mm diameter, increasing the RPM from 100 to 300 only slightly affects the Y load.

- Comparison between Top and Bottom Dies: When comparing the data, we observe that higher Y load values are generally obtained in the top die. For example, in the top die with a 30mm diameter, the Y load is 1.906 MPa, whereas in the bottom die, it is 1.893 MPa. A similar trend is observed for other diameters and RPM values as well. When the analysis results were compared with the analysis results of H. Zhang et al. on a similar project, it was observed that close results were obtained.[10]

6. Cost Energy Analysis

6.1 Angular Velocity Cost

- First, it takes time for the upper molds to reach speeds of 100, 200, and 300 RPM. All molds with different diameters (Ø30, Ø40, Ø50) reach these speeds at different times. These times can be obtained from the Deform 3D program. The average of the values before the time when the angular velocity is constant is taken for torque. The torque values should be converted to N-m. These processes are repeated for each output diameter and rotation speed.

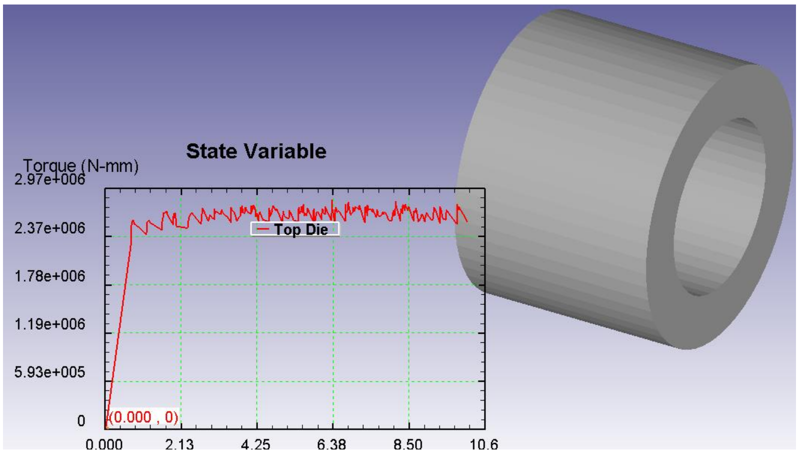

Figure 6 Torque (N-mm)

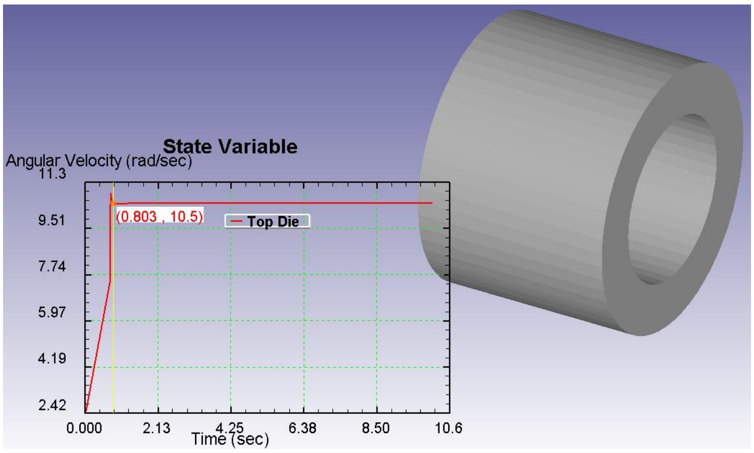

Figure 7 Angular velocity (rad/sec)

$$w_{avg} = \frac{(w_0 + w_1)}{2}$$

$$T_{avg} = \frac{(T_0 + T_1)}{2}$$

$$P_1(watt) = T_{avg}(Nm) * w_{avg}(rad/sec)$$

- Secondly, the average torque should be taken for the period after the angular velocity graph reaches a constant value. Then, the following operations should be continued.

$$P_2(watt) = T_{avg}(Nm) * w(rad/sec)$$

$$P = P_1 + P_2$$

- The obtained P value is converted to kWh to determine the amount of energy consumed in one hour. Since this rotational operation will be performed by an electric motor, it is multiplied by the electricity prices applicable in Turkey to calculate the cost.

$$kWh = (watts \times hrs) \div 1000$$

Monthly Consumption Amount: 240 kWh and lower = **1,48 tl**

Monthly Consumption Amount 240 kWh upper = **2,22 tl**

• In this analysis, 2,22 TL was taken as a reference.

6.2 Velocity Cost

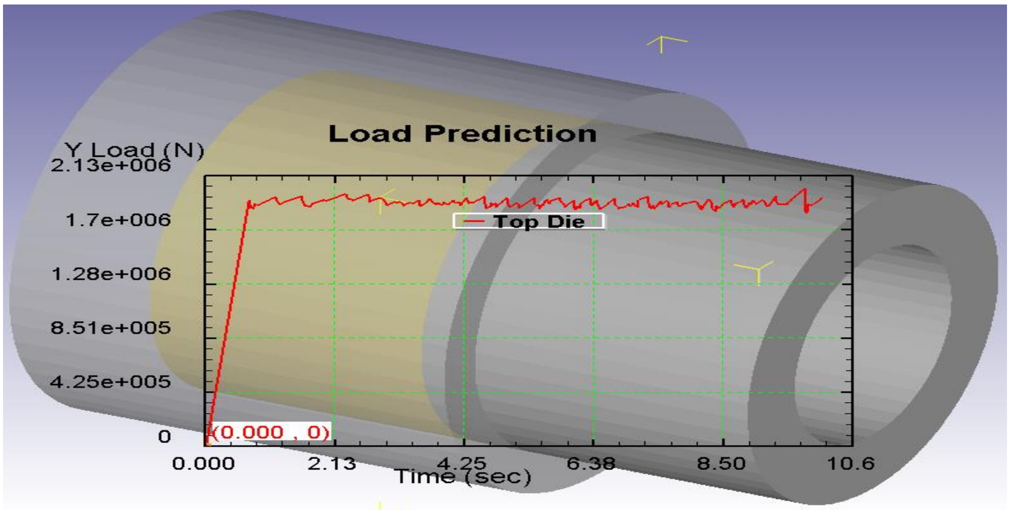

Figure 8 Y load (N)

- First, the average of the loads was taken from the graph with Y loads for the top die from the Deform 3d program. Then, the work was found by multiplying the force by 0.05 m, which is the displacement of the top die. As a result of the following operations, the cost was found by converting watts to kWh and multiplying with the prices given above.

$$Work = F(N) * \Delta x(m)$$

$$P(watt) = \frac{Work(Nm)}{60(sec)}$$

- After the calculations, assuming that the company operates for 10 hours per day and produces one product every 1.5 minutes using the friction extrusion process, the daily production is estimated to be 400 units. The energy costs for this company are provided in Table 1.

Table 2 Cost Analysis

Ømm-RPM	30-100	30-200	30-300	40-100	40-200	40-300	50-100	50-200	50-300
ANGULAR COST	₺ 275.0667	₺ 545.7333	₺ 818.0667	₺ 249.0667	₺ 323.7333	₺ 743.9333	₺ 217.8667	₺ 430.4667	₺ 643.0000
VELOCITY COST	₺ 15.6000	₺ 15.2667	₺ 15.0667	₺ 12.2667	₺ 11.9333	₺ 12.2667	₺ 9.4000	₺ 9.2000	₺ 9.2000
TOTAL	**₺ 290.6667**	**₺ 561.0000**	**₺ 833.1333**	**₺ 261.3333**	**₺ 335.6667**	**₺ 756.2000**	**₺ 227.2667**	**₺ 439.6667**	**₺ 652.2000**

- Angular Cost: The observed angular cost values in the data were obtained based on the combinations of diameter and RPM. Our analysis demonstrates a significant influence of diameter and RPM on the angular cost. Generally, an increase in diameter leads to a decrease in the angular cost. For example, in the 30-100 combination, the angular cost is 0.6877₺, while it decreases to 0.5447 ₺ in the 50-100 combination. When we observe the rpm increase, we see that the costs increase with the rpm in all cases.

- Velocity Cost: The data in the table includes the speed cost values obtained according to the diameter and RPM combinations. Our analysis reveals that diameter and RPM are decisive factors for speed cost. Generally, an increase in diameter leads to a decrease in speed cost. For example, while the speed cost is 0.0390₺ in the 30-100 combination, it decreases to 0.0235₺ in the 50-100 combination. It can be said that the increases in Rpm cause a decrease even though they create minor changes in costs.

- In the case of recycling of aluminum waste, it has been estimated by Gronostajski and Matuszak (1999) that direct recycling can save about 40% of material, 26–31% of energy consumption, and 16–60% of labor costs [11].

7. CONCLUSION

Based on the experimental results, it has been observed that changes in parameters such as exit diameter and rotational speed have significant effects on effective stress, effective strain, material flow rate, and upper-lower die loads in friction extrusion process.

Firstly, it has been found that increasing the mold exit diameter leads to a decrease in effective stress. This can be explained by the fact that the material flow becomes more dispersed as the exit diameter increases. In the friction extrusion experiment, the die moved down while it was in rotation to push the billet material out through the extrusion hole to produce a wire[12]. These results demonstrate that the mold exit diameter during friction extrusion process causes a decrease in effective stress values. Additionally, an increase in rotational speed has been determined to result in an increase in effective stress.

Secondly, it has been observed that increasing the rotational speed leads to a decrease in effective strain. The increase in rotational speed reduces the friction force on the material, resulting in lower strain formation. This indicates that rotational speed is an important parameter affecting stress formation in friction extrusion. The mold exit diameter slows down the material flow, causing an increase in effective strains due to increased friction.

Thirdly, the material flow rate decreases with an increase in the mold exit diameter, while it increases with an increase in rotational speed. These findings indicate that as the exit diameter grows, the material flow spreads over a larger area, resulting in a decrease in flow rate. Furthermore, an increase in rotational speed has a positive impact on the material flow rate. These findings highlight the importance of material flow rate as a control parameter for quality and efficiency in friction extrusion.

Lastly, both upper and lower die loads decrease with an increase in the mold exit diameter, as well as with an increase in rotational speed. This is a result of the material spreading over a larger area and the loads being distributed more evenly. These findings emphasize the consideration of the mold exit diameter in mold design, as it can impact the efficiency of the production process.

When examining the cost-related experimental results, we can see that to keep the reference RPM parameter of the upper die constant, different loads were applied by the Deform3D program every second. These torque variations resulted in different values for different mold combinations. The increase in RPM increases the power required for the rotational action, leading to increased costs. On the other hand, an increase in the mold exit diameter reduces the power requirement for the rotational action, resulting in lower torque and observed cost reductions. Additionally, for the upper die, different pushing loads were applied to achieve the pushing action at a rate of 1mm/sec. The average of these loads for each mold was used to calculate the power requirements in watts. When looking at these power requirements, although RPM has a minimal effect, it was observed that an increase in the mold exit diameter leads to cost reductions.

All these findings highlight the need to consider factors such as mold exit diameter and rotational speed to optimize the friction extrusion process, improve quality, and increase efficiency.

8. Referance

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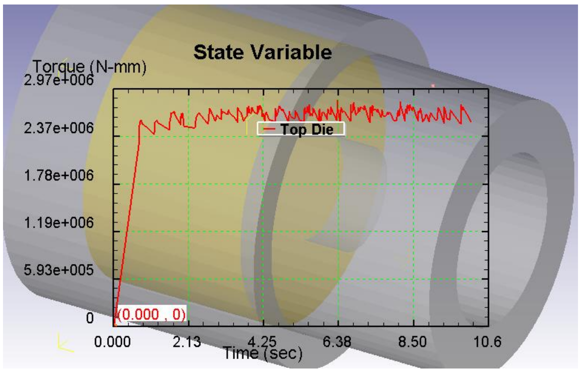
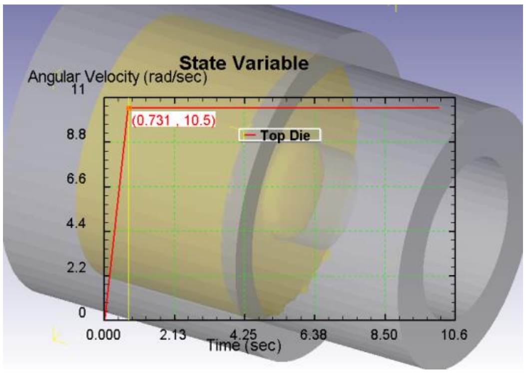
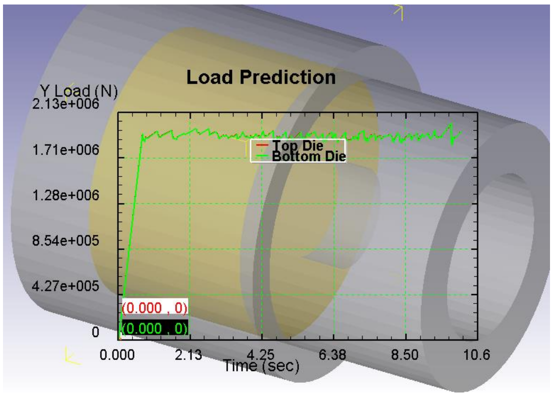
10. Appendices

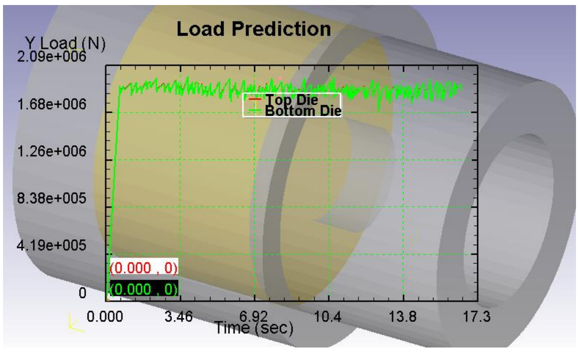
1) Ø30-100RPM

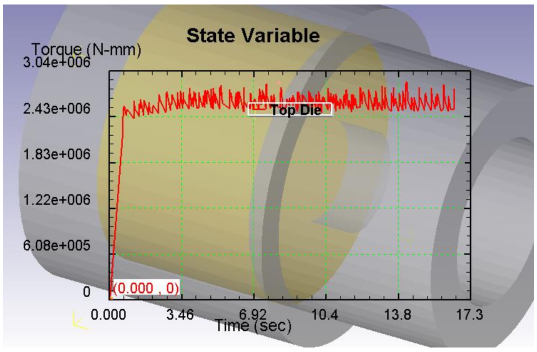


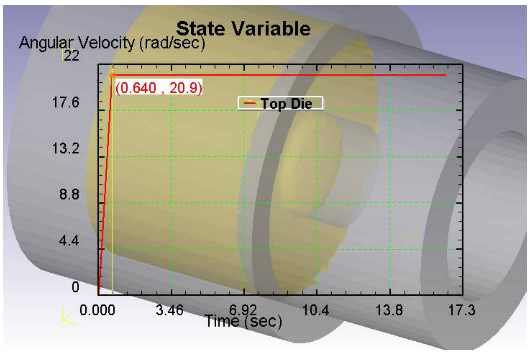




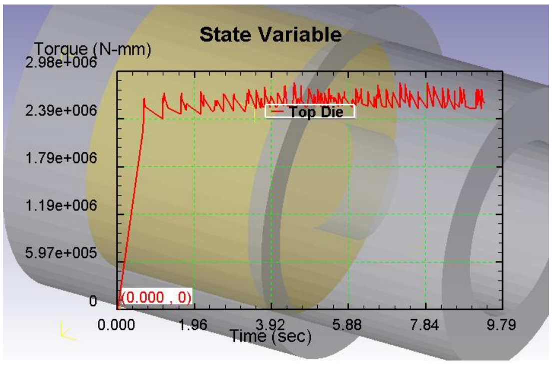
2) Ø30-200RPM

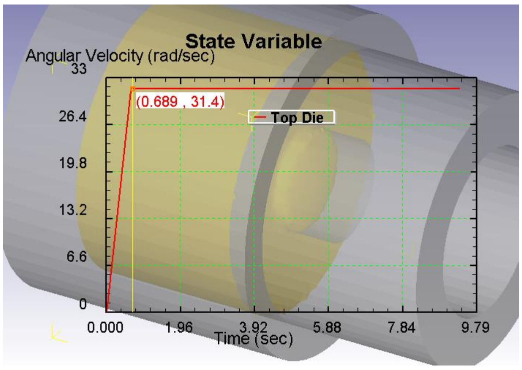


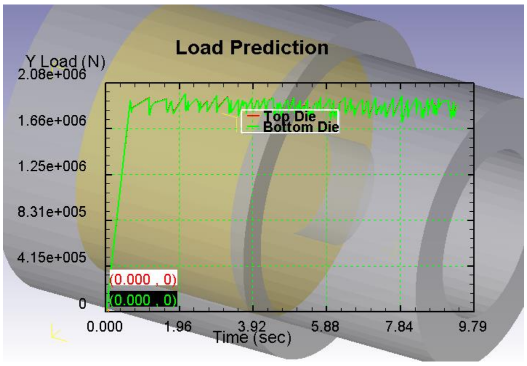




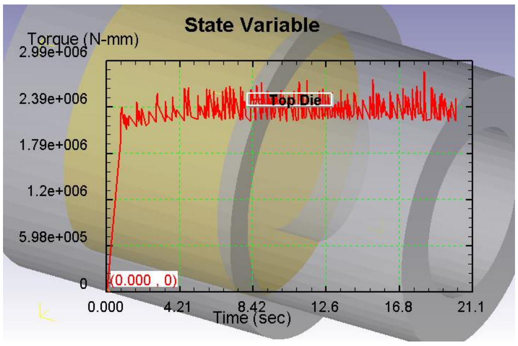
3) Ø30-300RPM

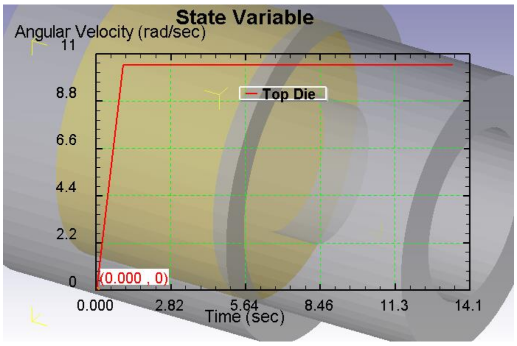


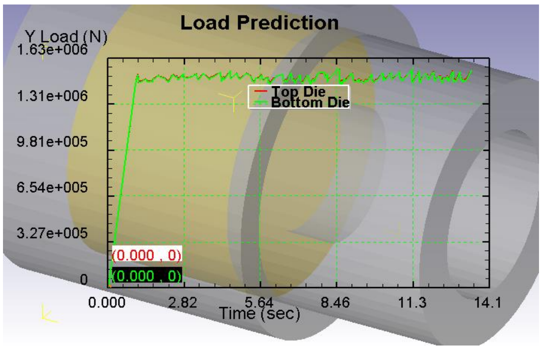




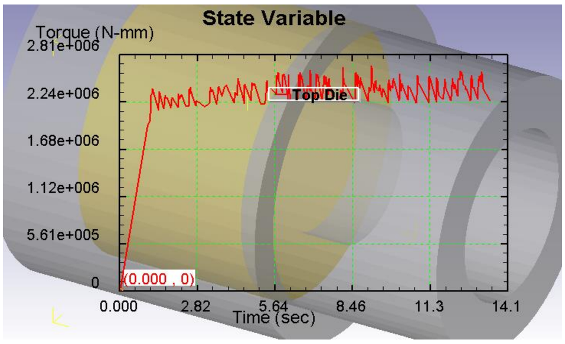
4) Ø40-100RPM

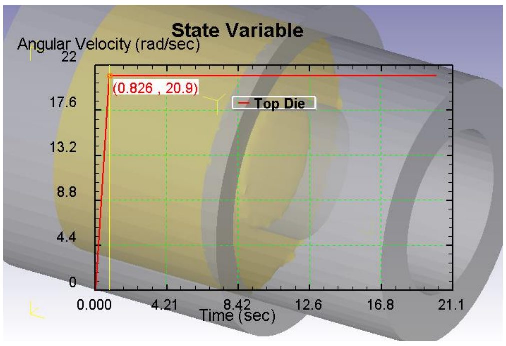


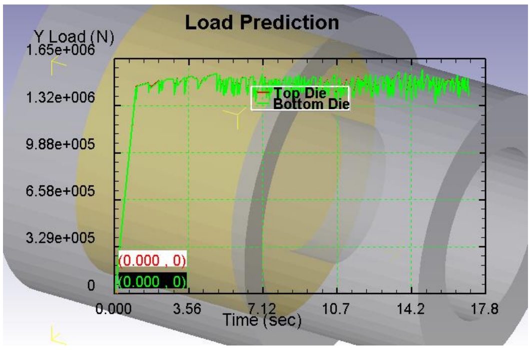




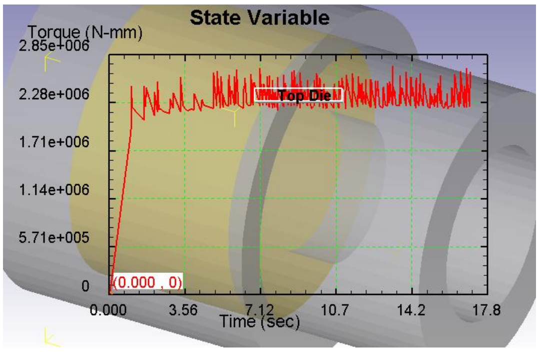
5) Ø40-200RPM

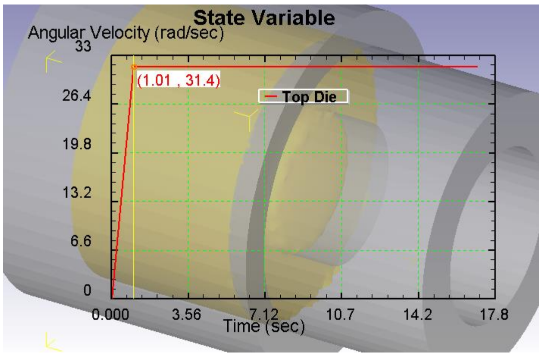


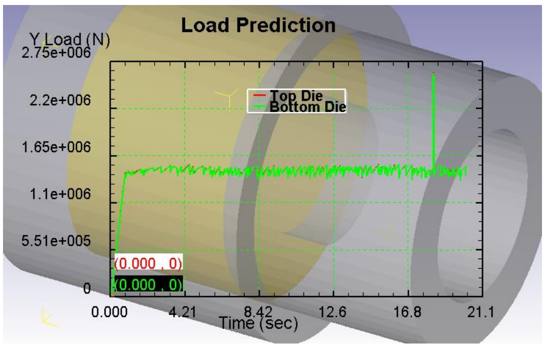




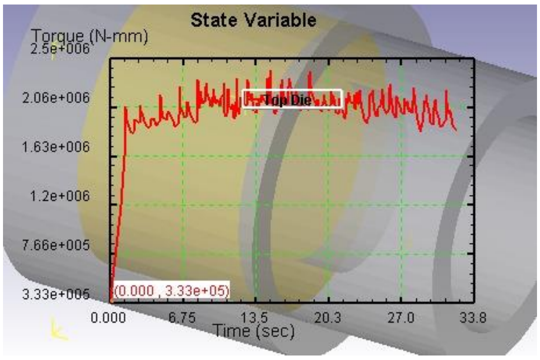
6) Ø40-300RPM

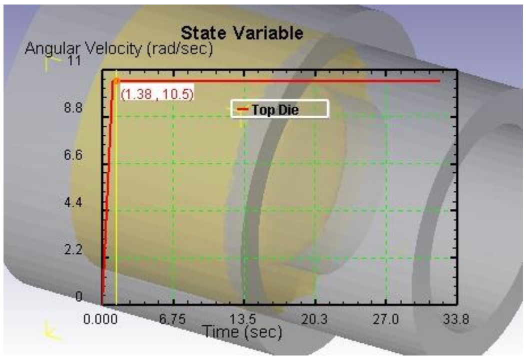


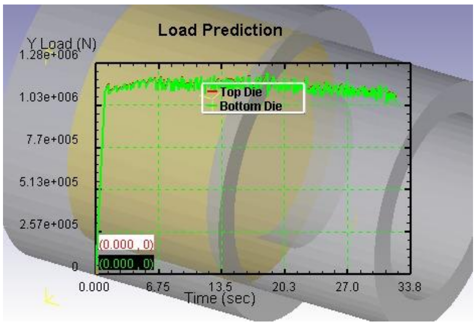




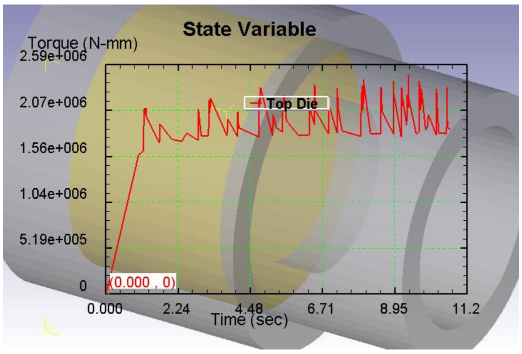
7) Ø50-100RPM

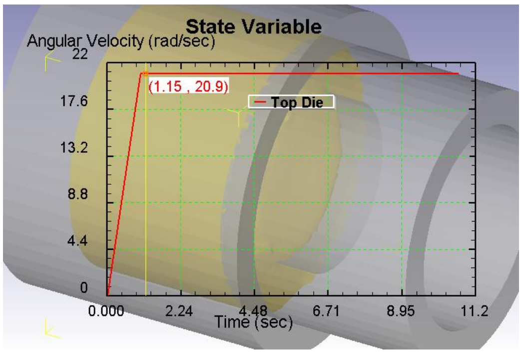


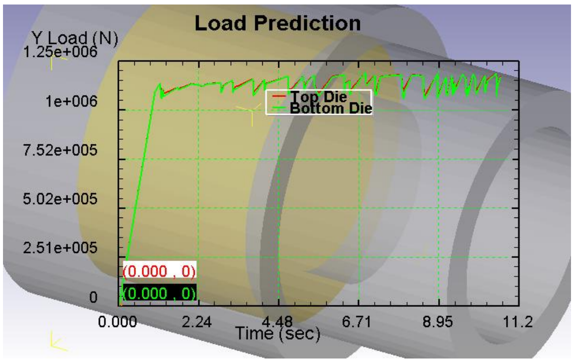




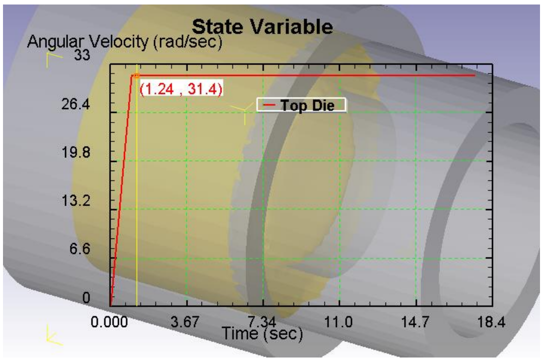
8) Ø50-200RPM

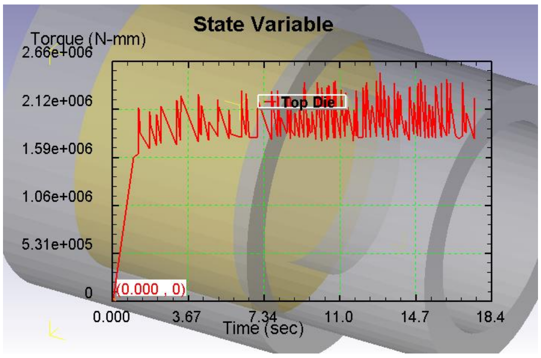


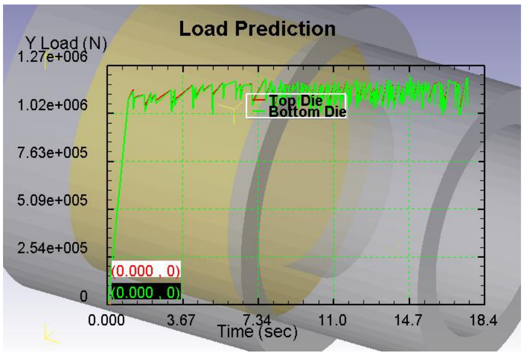




9) Ø50-300RPM


State Variable
Angular Velocity (rad/sec)
33
26.4
19.8
13.2
6.6
0
(1.24 , 31.4)
Top Die
0.000
3.67
7.34
11.0
14.7
18.4
Time (sec)


State Variable
Torque (N-mm)
2.66e+006
2.12e+006
1.59e+006
1.06e+006
5.31e+005
0
(0.000 , 0)
Top Die
0.000
3.67
7.34
11.0
14.7
18.4
Time (sec)


Load Prediction
Y Load (N)
1.27e+006
1.02e+006
7.63e+005
5.09e+005
2.54e+005
0
Top Die
Bottom Die
(0.000 , 0)
(0.000 , 0)
0.000
3.67
7.34
11.0
14.7
18.4
Time (sec)