Analysis of Die
BASE_v1
Using Altair Inspire Extrude

Friday 19th March, 2021

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Contents

1.0 Introduction 1
2.0 Problem Description 2
2.1 Process Data 2
2.2 Model Setup 3
2.3 Material Properties 4
2.4 Flow Network Diagram 5
3.0 Results 6
3.1 System Information 6
3.2 Convergence Data 6
3.3 Profile Nose Cone 7
3.4 Extrusion Force and Pressure 9
3.5 Temperature Solution 15
3.6 Velocity Solution 22
4.0 Productivity Calculations 26
4.1 Input Data 26
4.2 Profile Length 26
4.3 Scrap Calculations 27

Appendix A Boundary Conditions **28**

Appendix B Boundary Faces Along Different Flow Paths **30**

1.0 Introduction

Altair Inspire Extrude is used to study the material flow and heat transfer during extrusion of profile BASE_v1. The objective of this study is to calculate the shape of profile as it exits the die, compute the required extrusion force and exit temperature.

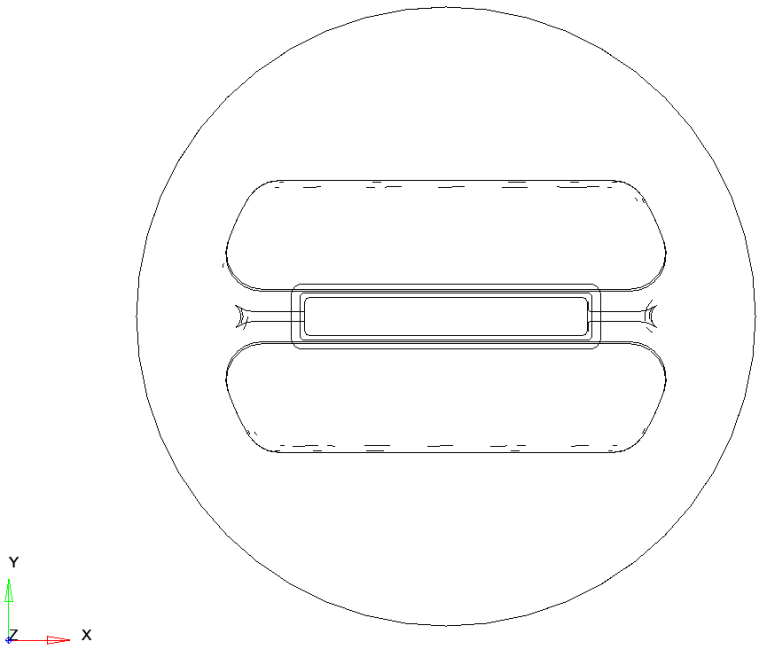

Figure 1: Die Layout

Figure 2: Workpiece Components

2.0 Problem Description

This section lists the problem data used for this analysis.

2.1 Process Data

Input Files

Model Name	BASE_v1
Run Control Data	BASE_v1.hx
Mesh Data	BASE_v1.grf

System Units

Length	Millimeters [mm]
Velocity	Millimeters/sec [mm/s]
Temperature	Celsius [$^{\circ}C$]
Stress	MegaPascals [MPa]

Profile Data

Profile Type	Hollow	Shape Factor	4.96
Perimeter [mm]	309.10	Profile Area [mm^2]	309.57
Min. Wall Gap [mm]	1.95	Max. Wall Gap [mm]	2.16

Billet/Die Data

Container Diameter [mm]	136.53	Number of Holes	1
Billet Length [mm]	432.67	Butt Length [mm]	25.40
Extrusion Ratio	47.15		

Process Conditions

Ram Speed [mm/s]	3.000	Ram Accln. Time [s]	5.00
Billet Preheat [$^{\circ}C$]	460.00	Axial Taper [$^{\circ}C$]	0.00
Radial Taper [$^{\circ}C$]	0.00	Lateral Taper [$^{\circ}C$]	0.00
Container Temperature [$^{\circ}C$]	425.00	Die Temperature [$^{\circ}C$]	460.00

2.2 Model Setup

Activated Solver Features

Extrusion Type	Direct Extrusion	Analysis Type	Steady State
Profile Shape Prediction	✓	Die Stress Analysis	×
Charge Weld Length	×	Skin Tracking	×
Seam Weld Location	✓	Weld Strength	✓
Bearing Optimization	×	Grain Size Calc.	✓

Mesh Data

Total Elements	396,324	Total Nodes	115,192
Workpiece Elements	396,324	Tool Elements	0
Tetrahedral Elements	299,680	Pyramid Elements	0
Triangular Prism Elements	96,644	Hexahedral elements	0

Workpiece/Tool Data

Component	**Alloy**	**Volume** $[mm^3]$	**Elements**	**Nodes**
Billet3D	AA6063	6315000.000	74,657	14,553
Porthole-WC3D	AA6063	118500.000	57,987	11,728
Mandrel3D	H-13	1026000.000	362,519	68,079
WeldChamber3D	AA6063	160800.000	167,036	33,107
Die3D	H-13	1118000.000	310,277	57,440
Bearing3D	AA6063	3096.000	39,180	25,024
Profile3D	AA6063	9287.000	57,464	35,972

2.3 Material Properties

Material properties for AA6063

Thermo-mechanical Properties

Density $[kg/m^3]$	2700.00	Specific Heat $[J/kg\text{-}K]$	900.00
Conductivity $[W/m\text{-}k]$	198.00	Reference Temperature $[K]$	700.00
Solidus Temperature $[K]$	889.00	Liquidus Temperature $[K]$	927.00
Young's Modulus [Pa]	4.00e+010	Poisson Ratio [-]	0.35

Flow Stress Model - SineHypInv

Stress Exponent [-]	5.385	Activation Energy $[J/mol]$	1.416e+005
Reciprocal Strain Factor [-]	5.911e+009	Alpha $[1/Pa]$	4.000e-008
Gas Constant $[J/mol\text{-}K]$	8.314	Strain Rate Offset $[1/s]$	1.000e-004

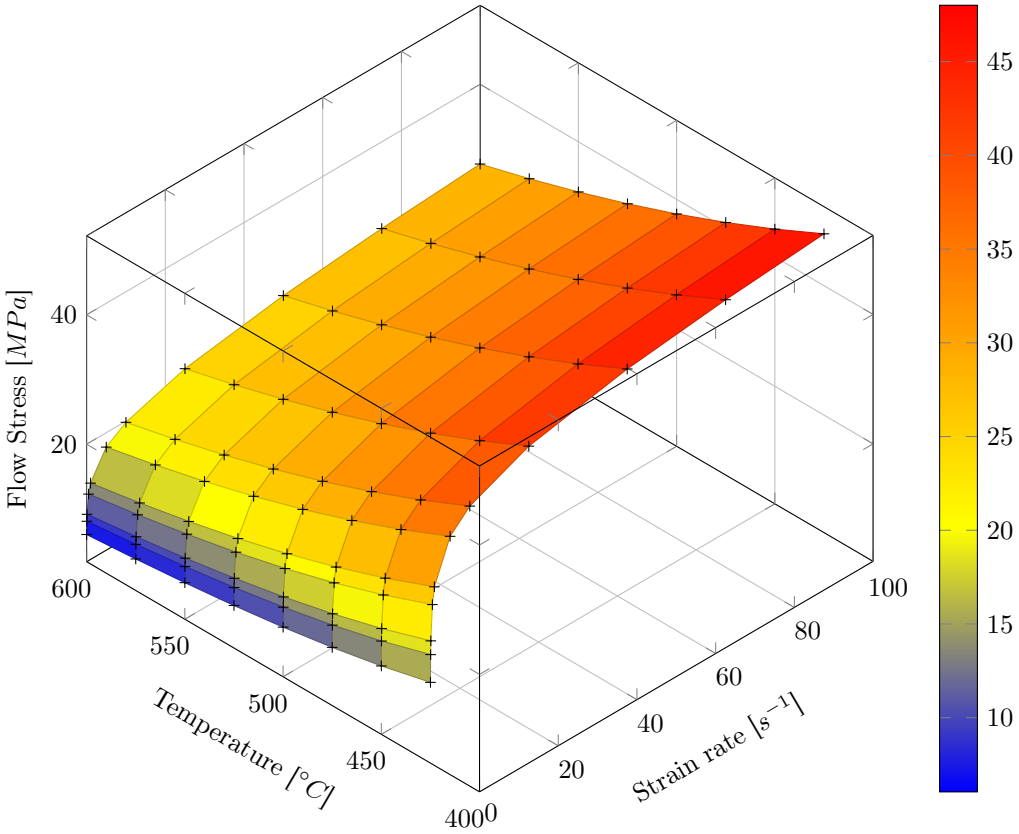

Figure 3: Flow stress $[\sigma = f(\dot{\varepsilon}, T)]$ data for AA6063

2.4 Flow Network Diagram

The flow network diagram shows how the billet material flows through the die.

Section	Flow Section ID	Boundary Name	Area $[mm^2]$	Area [%]	Section Extrusion Ratio
1	A1	Billet_DummyBlock	14597.30	100.00	1.00
Flow Section B			4386.97		3.33
2	B1	Billet_Porthole_WC1	2193.48	50.00	
2	B2	Billet_Porthole_WC2	2193.49	50.00	
3	C1	Porthole_WC_Bearing	309.57	100.00	47.15
4	D1	Bearing_Profile	309.57	100.00	47.15
5	E1	ExitHole1	309.57	100.00	47.15

Table 1: FlowNetwork

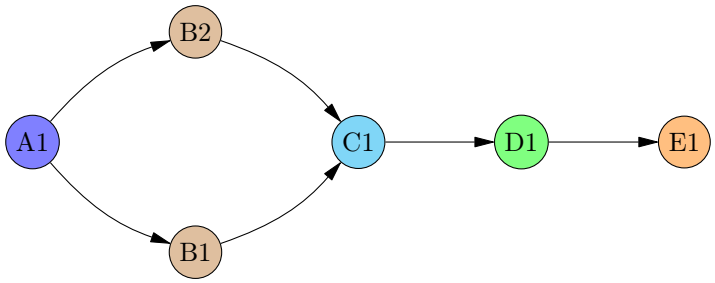

Figure 4: Flownetwork diagram

3.0 Results

3.1 System Information

Configuration and CPU Time

Solver Version	2021	Build Tag	1044376_8855200_Ce64BW42R21B2:74710
Computer Name	MSI	System CPU [MHz]	2600
Operating System	Windows 10	Version	(Build 9200)
Number of Processors	12	Processors Used	—
Available RAM [GB]	21.00	Available Swap [GB]	36.00
CPU Time [hrs]	5.16	Wall Clock	2.17

3.2 Convergence Data

Run Control Data

Nonlinear Iterations	25	Nonlin Conv. Tol.	0.010
Number of Cycles	1	Time Steps/Cycle	1

The solution converged in 7 nonlinear iterations. The following plot shows convergence of velocity, pressure, and temperature solution.

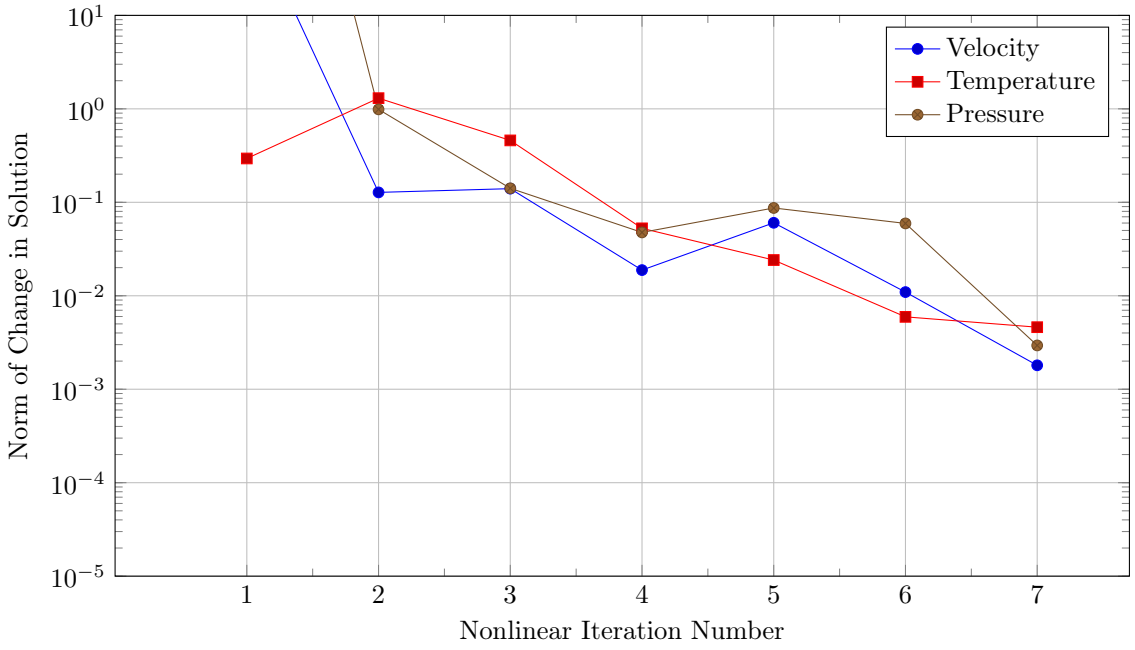

Figure 5: Solution convergence plot

3.3 Profile Nose Cone

Images in this section show how the profile nose cone is formed from multiple viewpoints. Please use the GUI to further inspect it in greater detail.

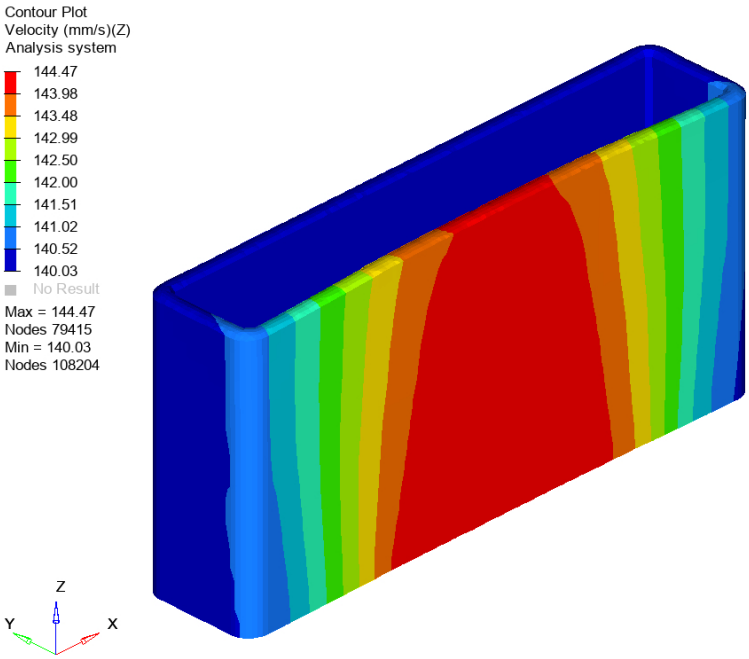

Figure 6: Profile Iso View

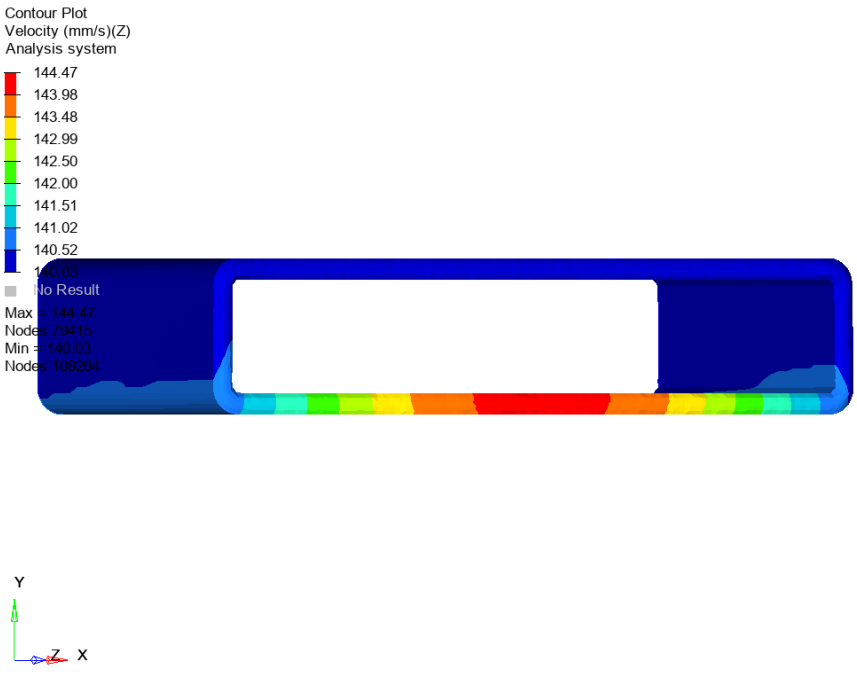

Figure 7: Profile Right View

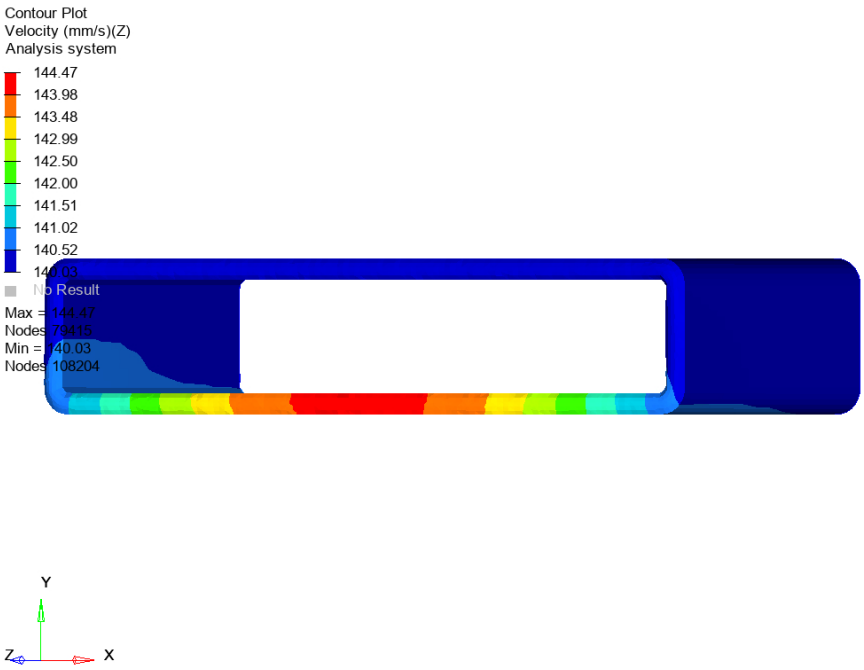

Figure 8: Profile Left View

3.4 Extrusion Force and Pressure

Calculated ram force and extrusion pressure at different sections inside the container and die are presented here.

Ram Force:

Computed value of ram force is : **778.61** $Tons$ = **6.93** MN

Pressure Contours:

Pressure distribution in the workpiece is shown below.

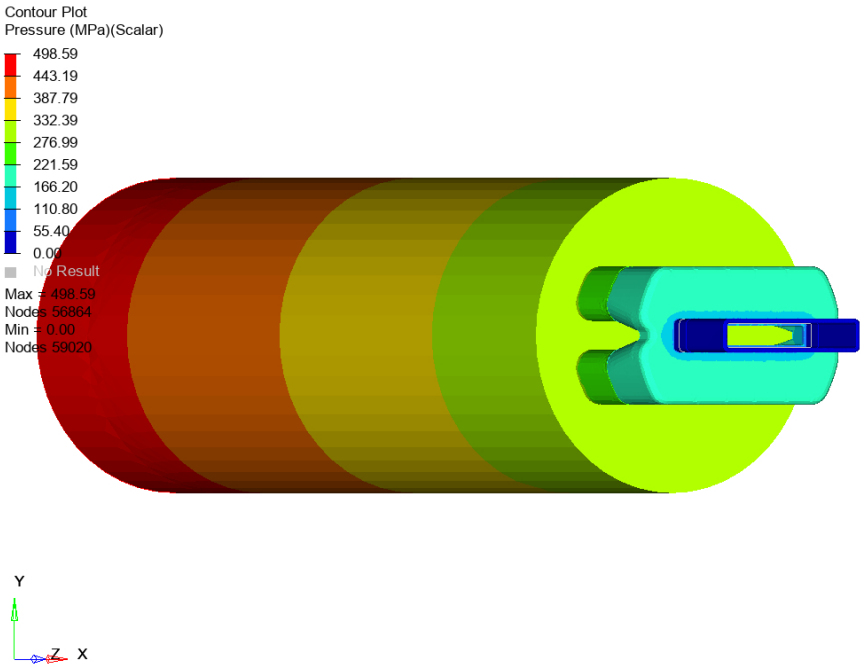

Figure 9: Pressure distribution inside the workpiece

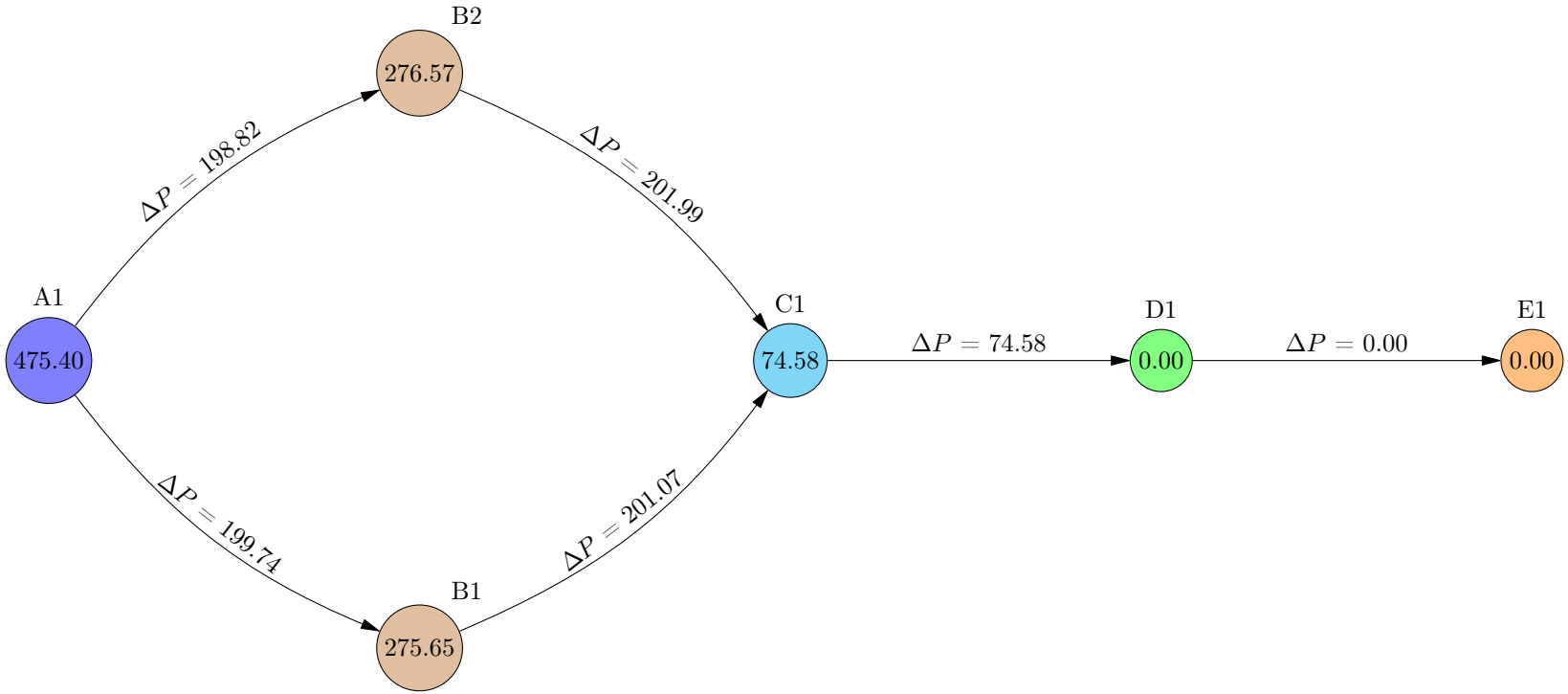

Figure 10: Pressure $[MPa]$ and change in pressure at different sections

Pressure Distribution at Different Sections Along Extrusion Direction:

Pressure contours and pressure drop at different locations is presented here.

Section 1:
The first section represents the contact surface where the dummyblock touches the billet.

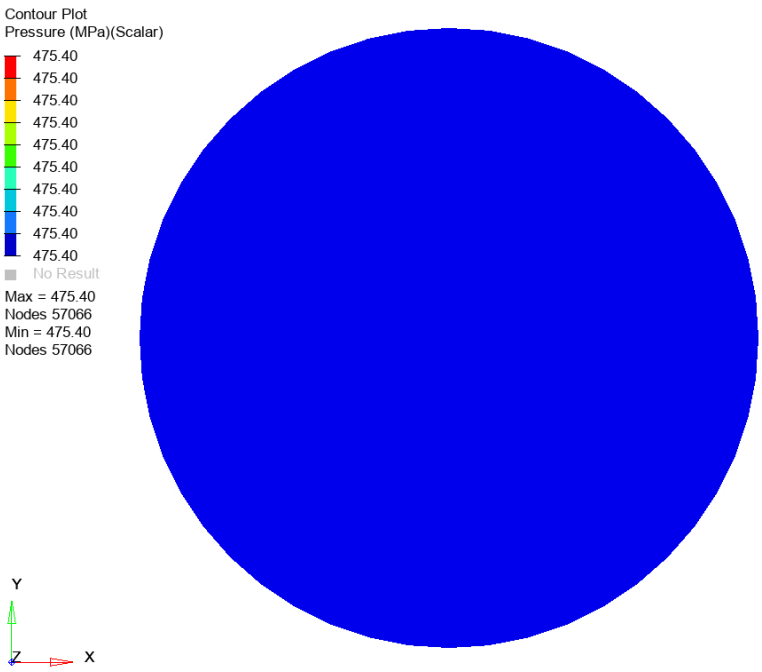

Figure 11: Pressure distribution at Section 1 of Table 1

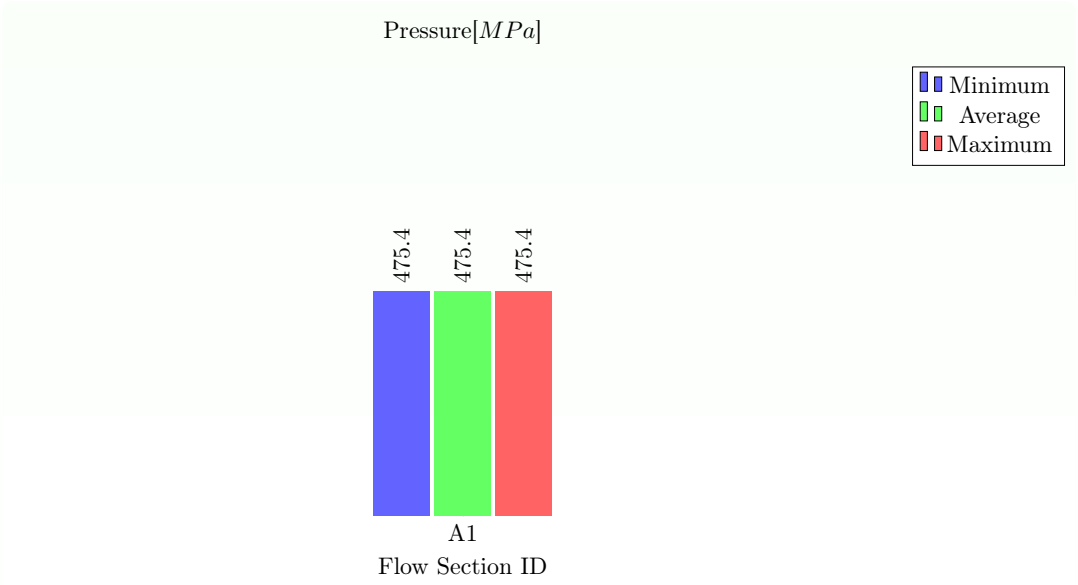

Figure 12: Minimum, average, and maximum Pressure at Section 1

Section 2:

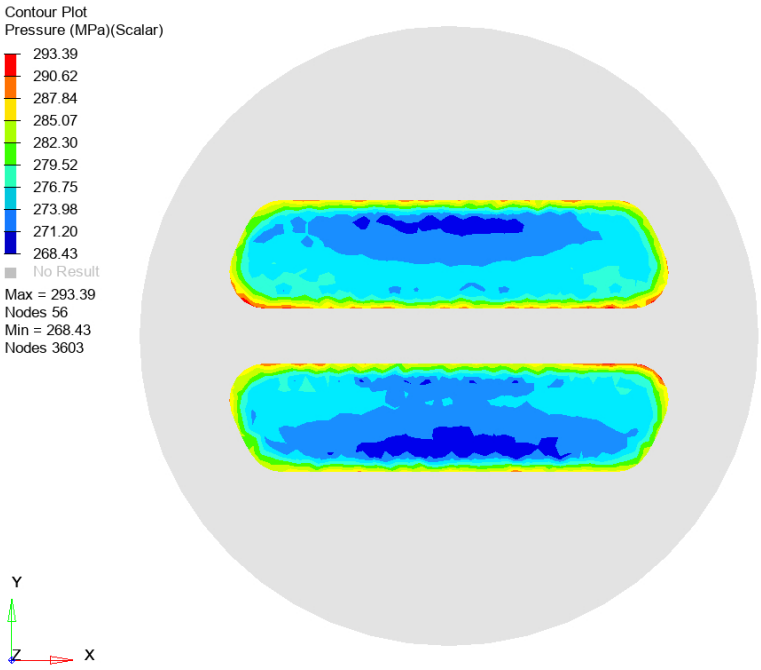

Figure 13: Pressure distribution at Section 2 of Table 1

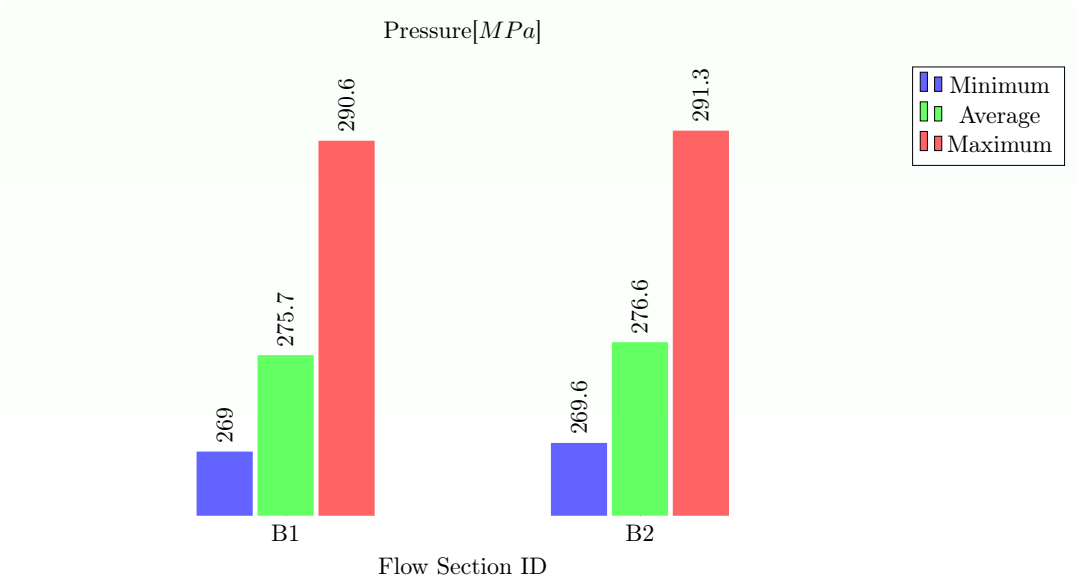

Figure 14: Minimum, average, and maximum Pressure at Section 2

Section 3:

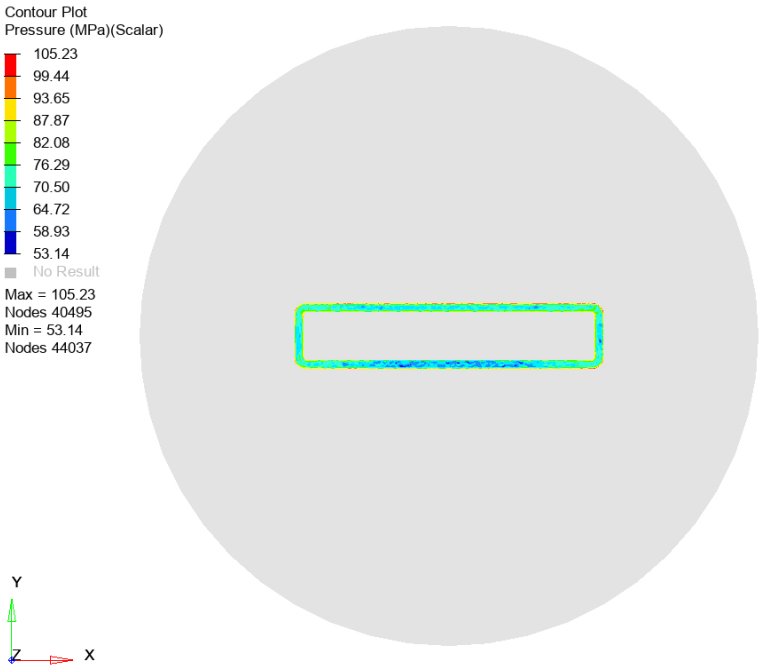

Figure 15: Pressure distribution at Section 3 of Table 1

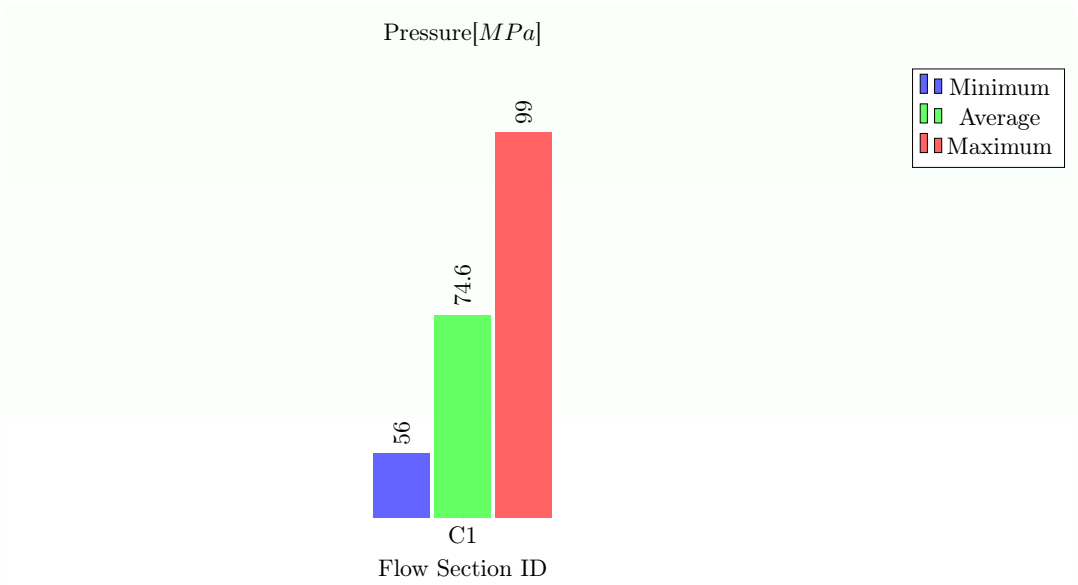

Figure 16: Minimum, average, and maximum Pressure at Section 3

Section 4:

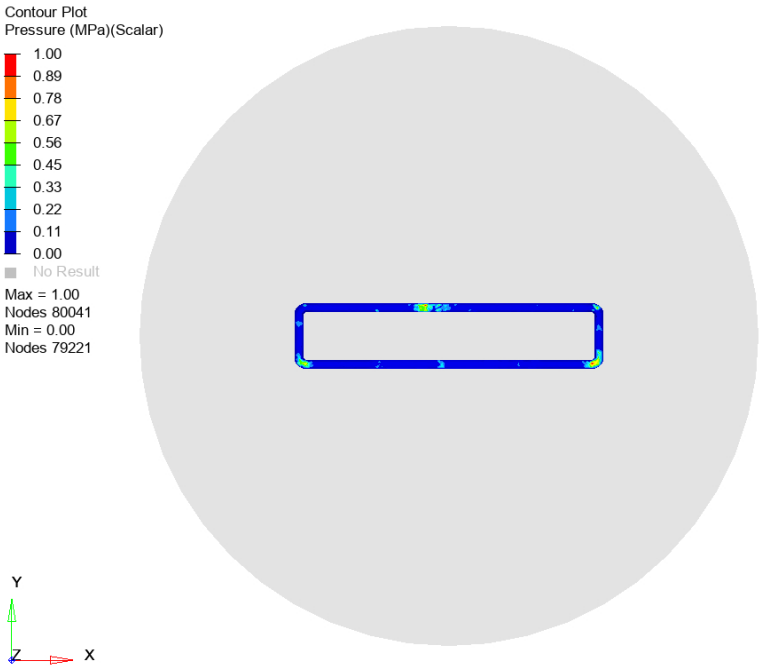

Figure 17: Pressure distribution at Section 4 of Table 1

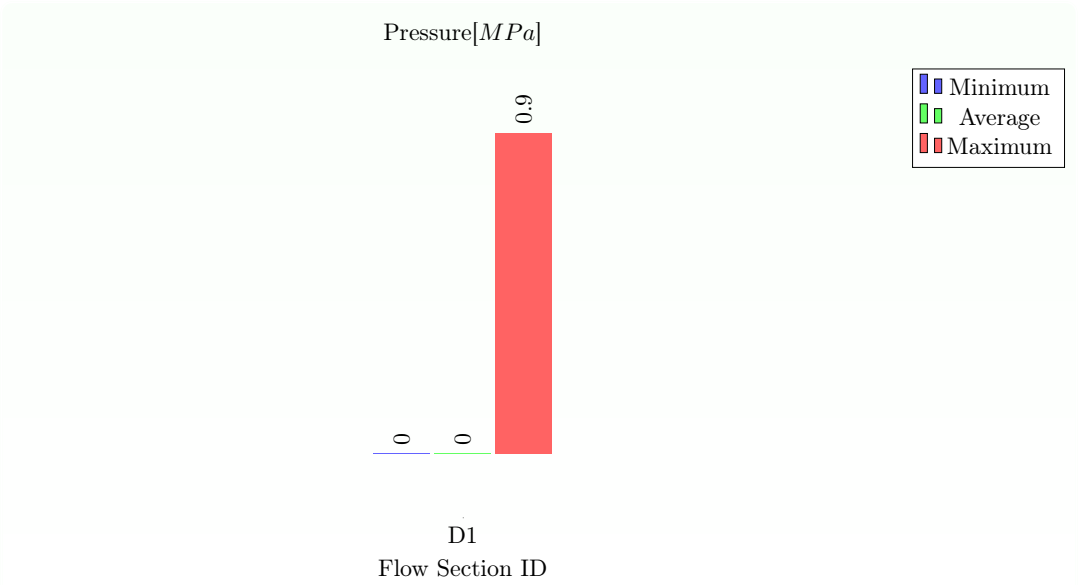

Figure 18: Minimum, average, and maximum Pressure at Section 4

3.5 Temperature Solution

Exit temperature and temperature distribution inside the workpiece is presented here.

Temperature Contours:

Temperature distribution in the workpiece is shown below.

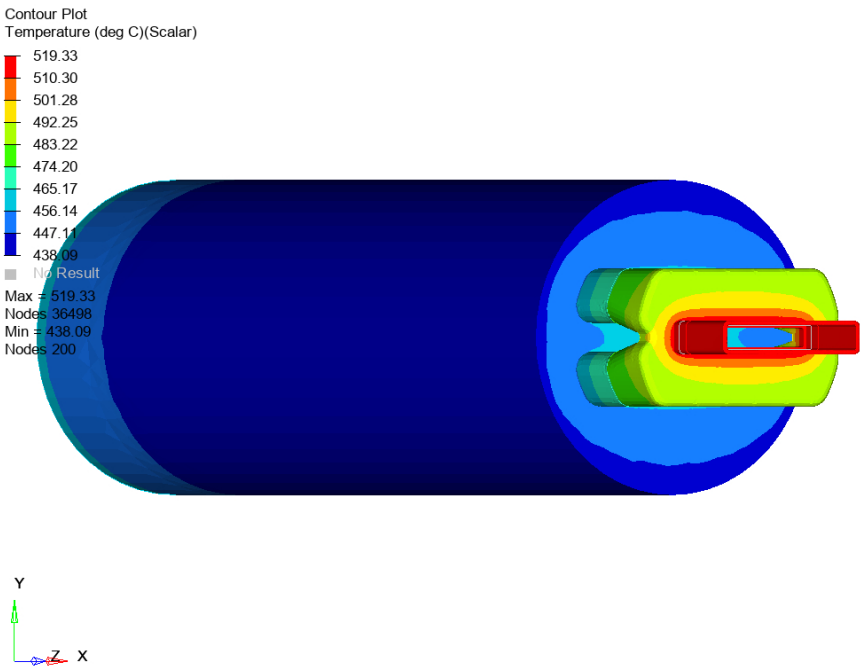

Figure 19: Temperature distribution inside the workpiece

Profile Surface Temperature

Difference in maximum and minimum temperature on profile surface is used to determine the quality of extruded profile. Large variations in surface temperature indicate the profile may have wavy surface.

Boundary Name : FreesurfaceHole1Outer
Temperature Difference on Profile Surface = 0.49 % - Within acceptable range.

Boundary Name : FreesurfaceHole1Inner1
Temperature Difference on Profile Surface = 0.47 % - Within acceptable range.

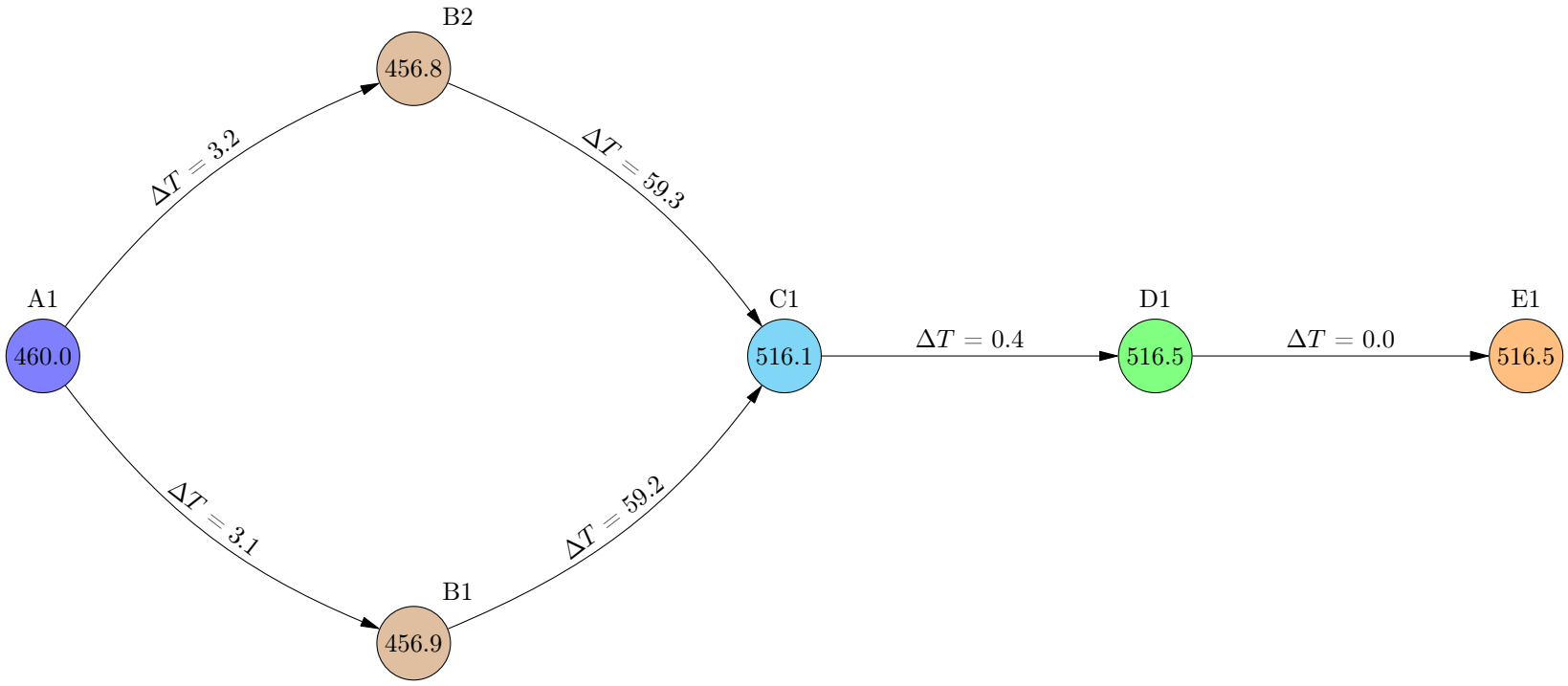

Figure 20: Temperature [$^{\circ}C$] at different sections

Exit Temperature:

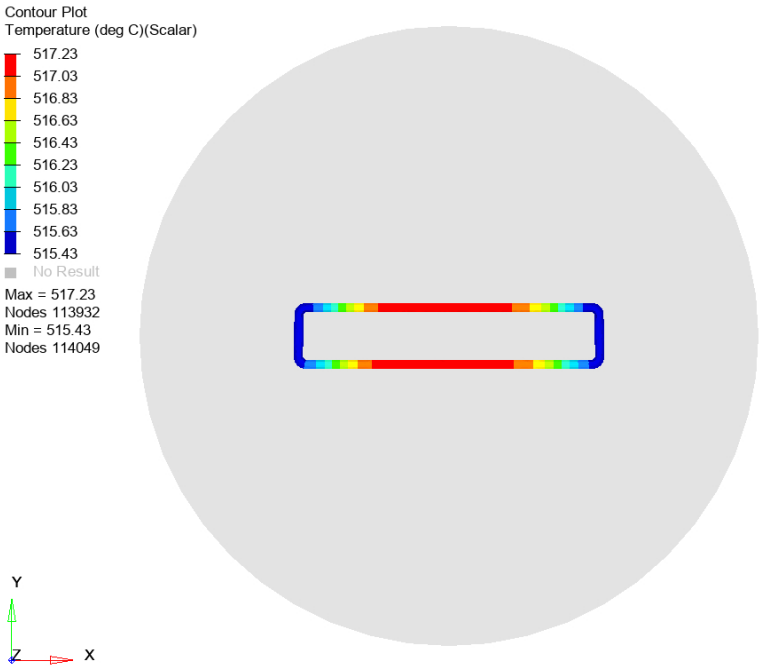

Figure 21: Temperature at the exit surface

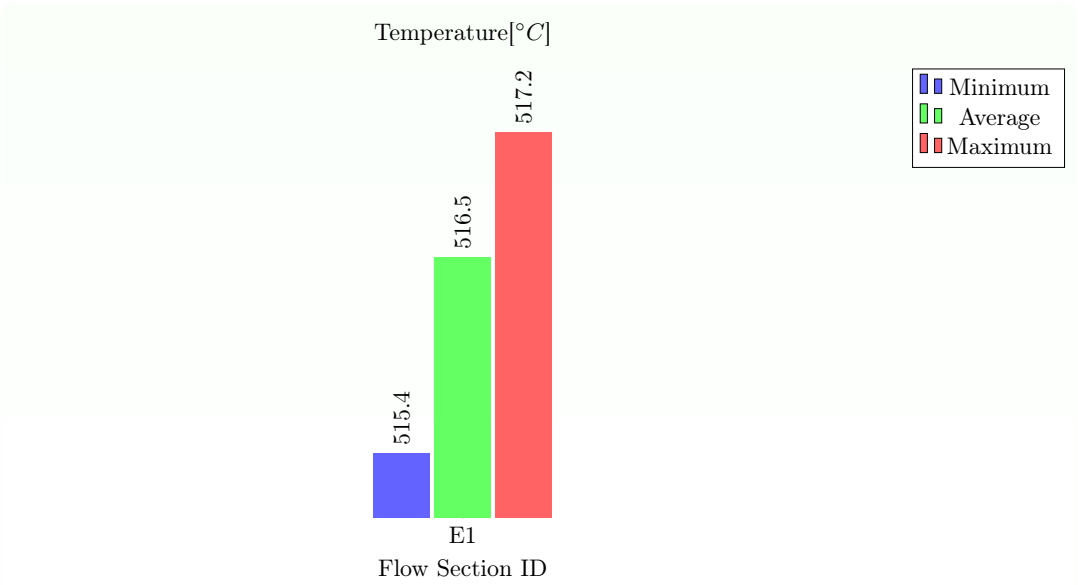

Figure 22: Minimum, average, and maximum Temperature at Section 5.

Section 1:
The first section represents the contact surface where the dummyblock touches the billet.

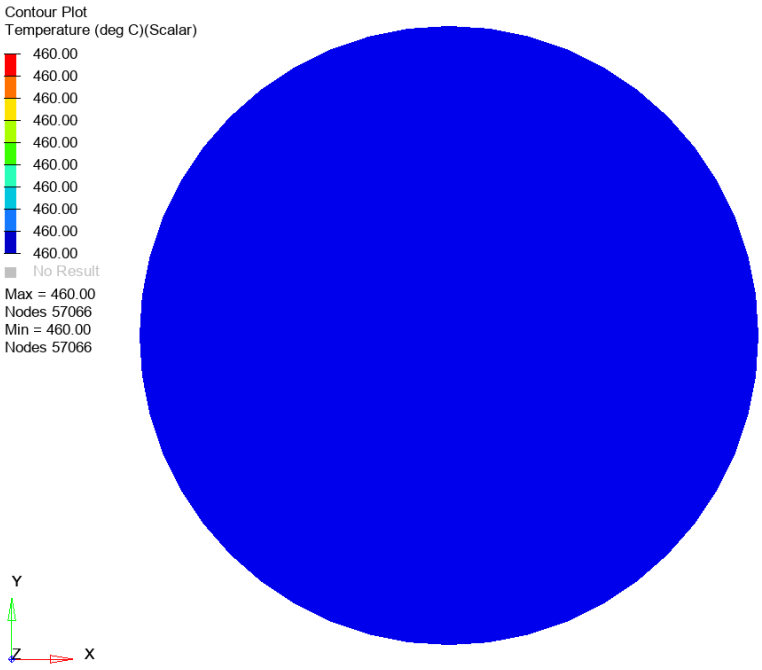

Figure 23: Temperature distribution at Section 1 of Table 1

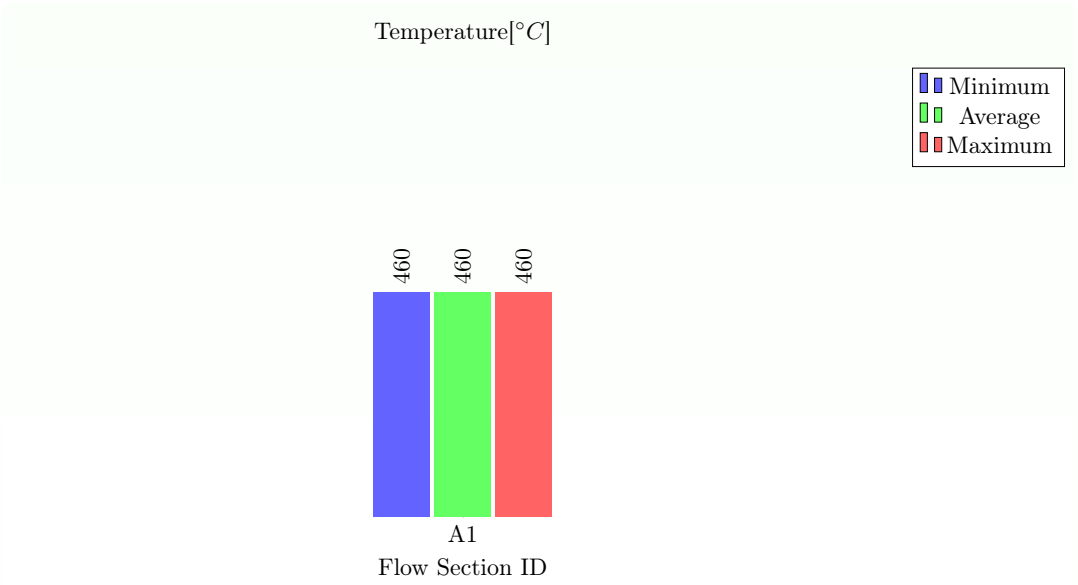

Figure 24: Minimum, average, and maximum Temperature at Section 1.

Section 2:

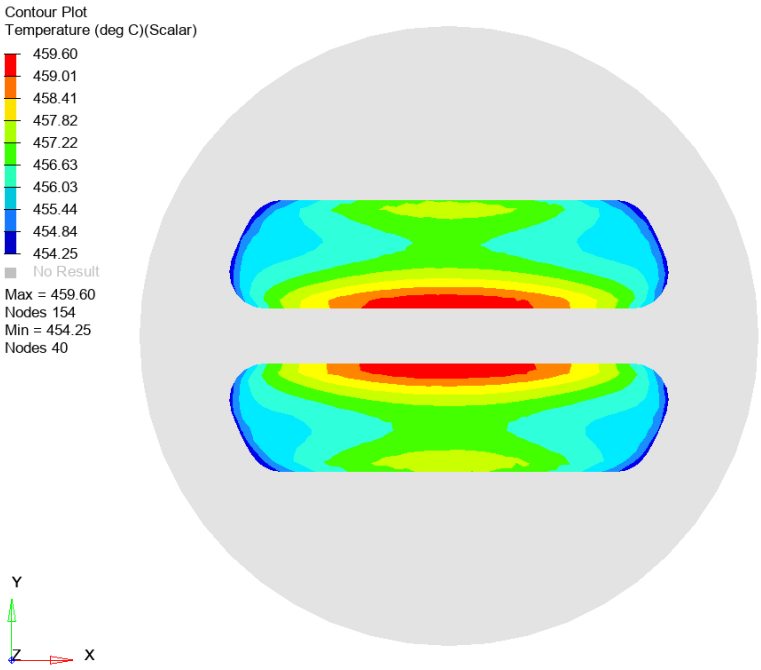

Figure 25: Temperature distribution at Section 2 of Table 1

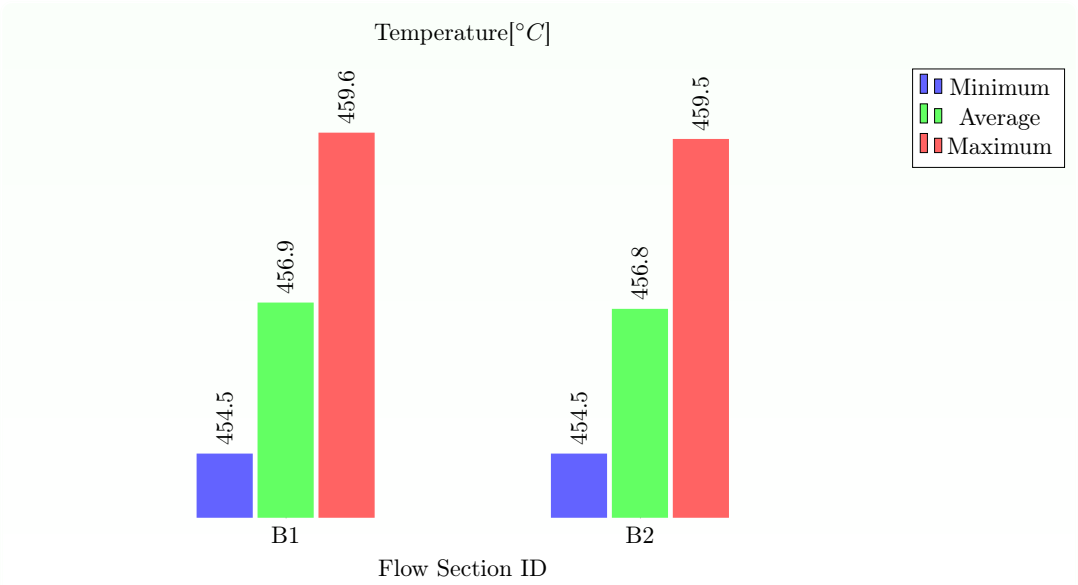

Figure 26: Minimum, average, and maximum Temperature at Section 2.

Section 3:

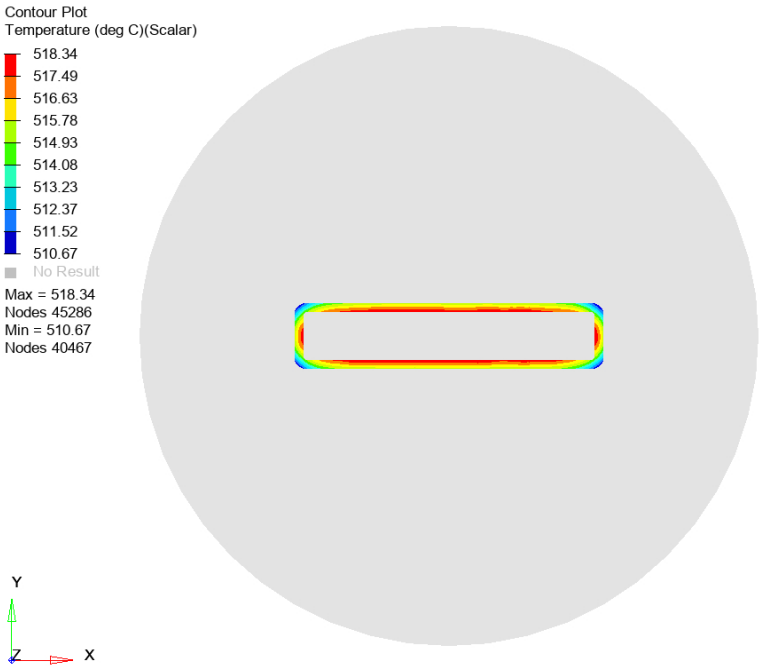

Figure 27: Temperature distribution at Section 3 of Table 1

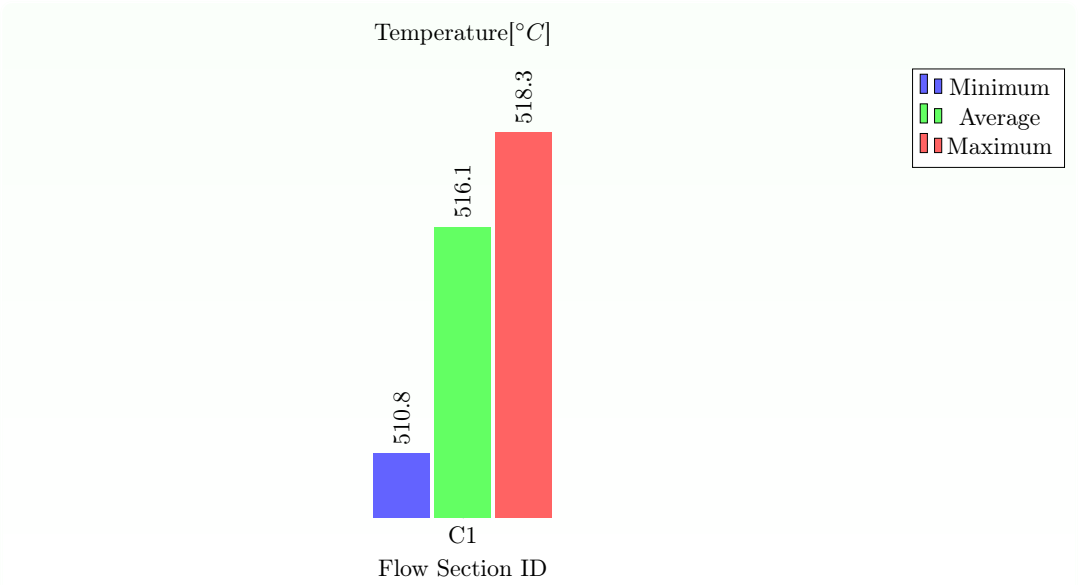

Figure 28: Minimum, average, and maximum Temperature at Section 3.

Section 4:

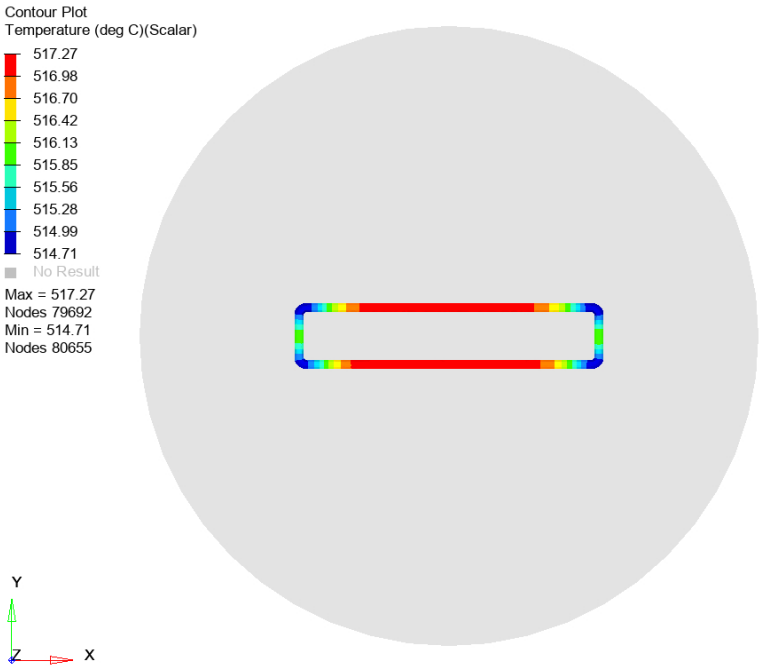

Figure 29: Temperature distribution at Section 4 of Table 1

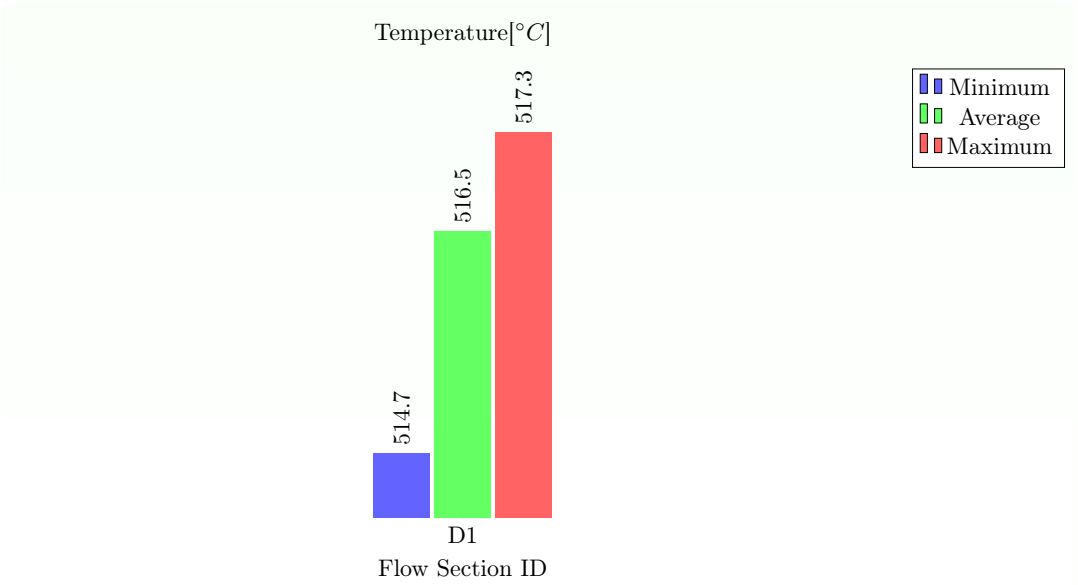

Figure 30: Minimum, average, and maximum Temperature at Section 4.

3.6 Velocity Solution

Material flow inside the workpiece is presented here.

Velocity Contours:

Velocity distribution in the workpiece is shown below.

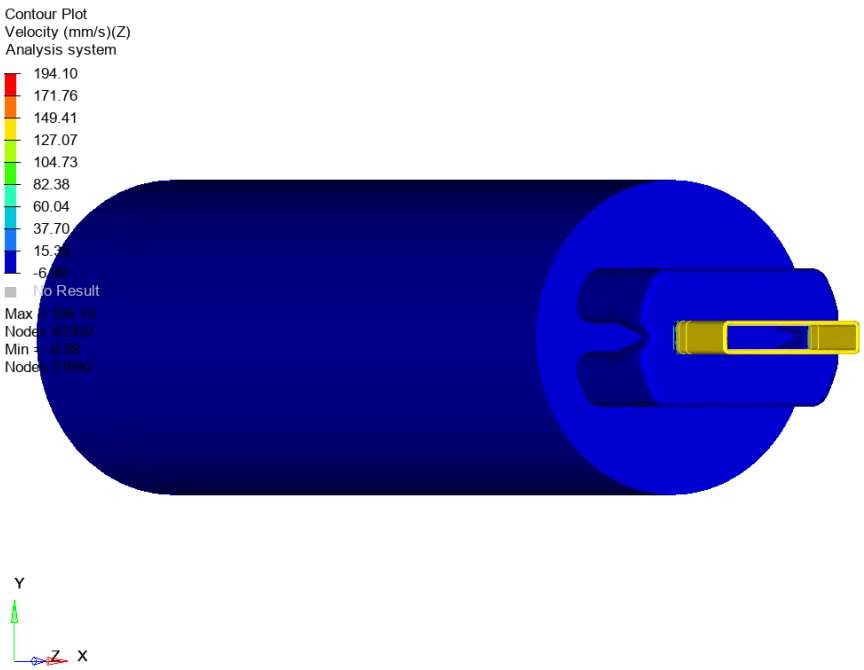

Figure 31: Velocity distribution inside the workpiece

Profile Shape Predictions

The velocity distribution at the exit surface is used for determining if the mass flow is balanced. In addition, this data is used to predict profile shape and compute extrusion profile length.

Boundary Name : ExitHole1
Flow is Balanced in the Extrusion Direction.
Velocity in X-Direction is large - Will cause the profile to deflect.
Velocity in Y-Direction is small - Within acceptable limits.

Velocity distribution at the Exit Surface (Section 5):

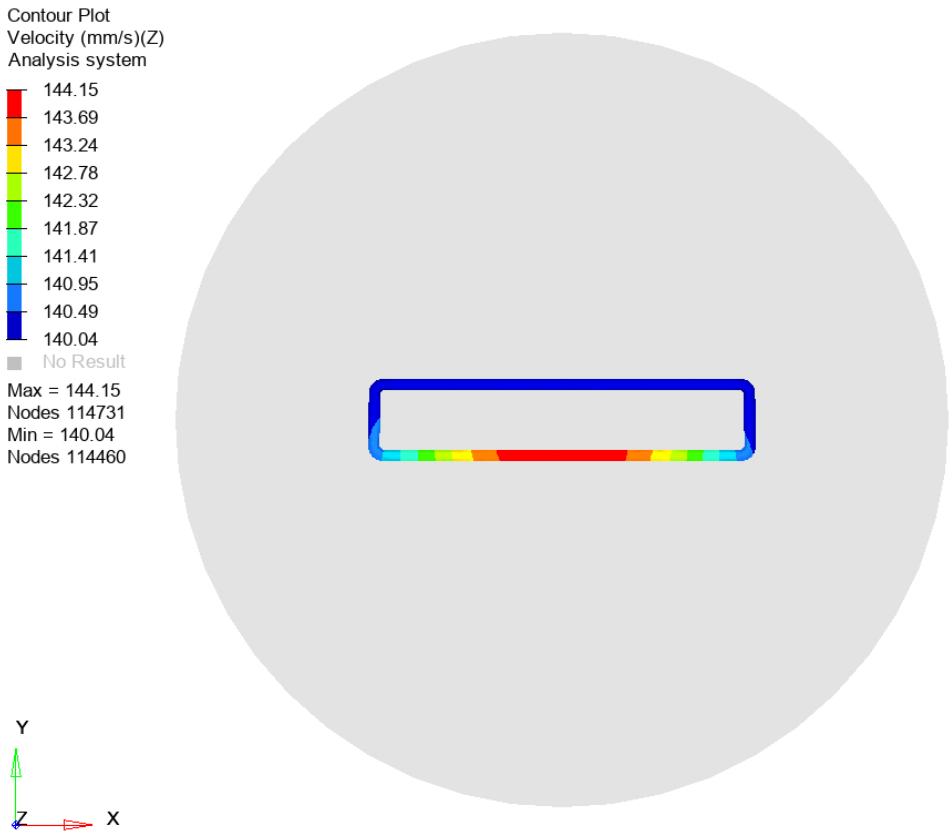

Figure 32: Profile shape as it exits the die

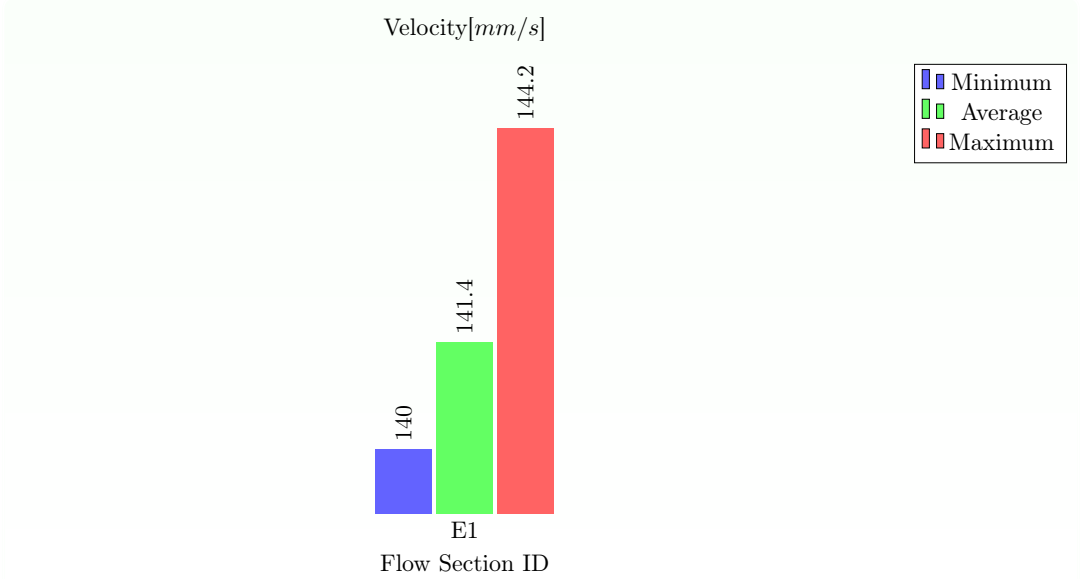

Figure 33: Minimum, average, and maximum Exit Velocity at Section 5.

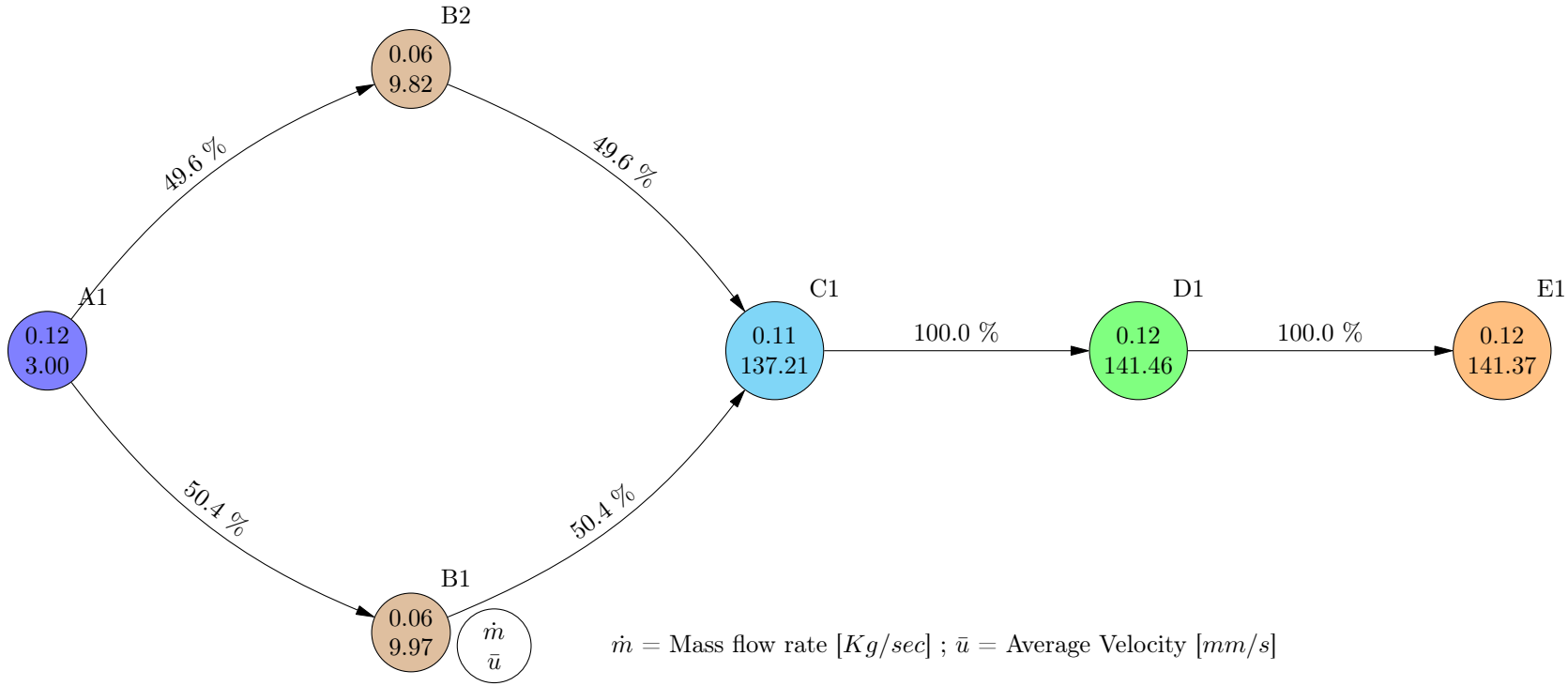

Figure 34: Mass flow rate and average velocity at different sections

4.0 Productivity Calculations

4.1 Input Data

Profile Data			
Profile Type	Hollow	Shape Factor	4.96
Perimeter [mm]	309.10	Profile Area [mm^2]	309.57
Min. Wall Gap [mm]	1.95	Max. Wall Gap [mm]	2.16
Billet/Die Data			
Container Diameter [mm]	136.53	Number of Holes	1
Billet Length [mm]	432.67	Butt Length [mm]	25.40
Extrusion Ratio	47.15		
Process Conditions			
Ram Speed [mm/s]	3.000	Ram Accln. Time [s]	5.00
Billet Preheat [$°C$]	460.00	Axial Taper [$°C$]	0.00
Radial Taper [$°C$]	0.00	Lateral Taper [$°C$]	0.00

4.2 Profile Length

Extrusion cycle time = 138.26 s
Extruded profile length = 19.19 [m]

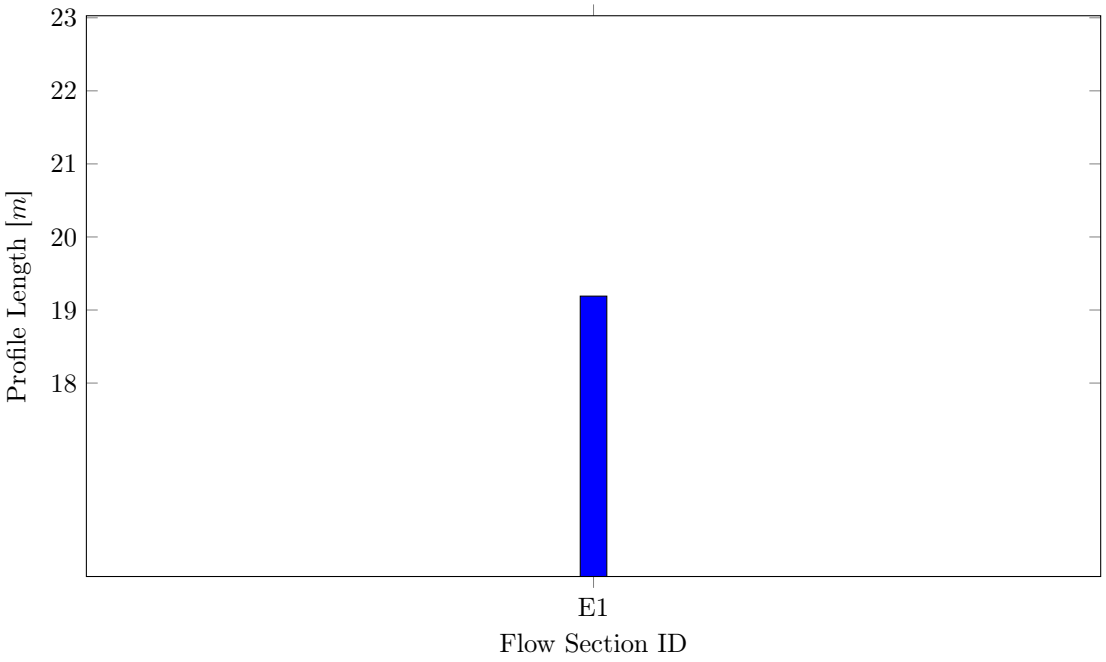

Figure 35: Extruded profile length.

4.3 Scrap Calculations

Billet weight [Kg]	=	17.05
Scrap in container [Kg]	=	1.00
Scrap in die [Kg]	=	6.55
Total scrap* [Kg]	=	7.55
Total scrap* [%]	=	44.29

*Total scrap does not include back-end scrap and charge weld (transverse weld) scrap. Charge weld scrap will be considered in the transient analysis of the metal extrusion process.

Appendix A

Boundary Conditions

Surface Name: Billet_DummyBlock
Surface Definition: - Billet-Dummy block contact surface

X-Velocity $[mm/s]$	= 0.000	Y-Velocity $[mm/s]$	= 0.000	Z-Velocity $[mm/s]$	= 3.000
Temperature $[°C]$	= 460.00				
Strain [-]	= 0.001				

Surface Name: Billet_Mandrel
Surface Definition: - SolidWall - Workpiece-Tool Contact Surface

X-Velocity $[mm/s]$	= 0.000	Y-Velocity $[mm/s]$	= 0.000	Z-Velocity $[mm/s]$	= 0.000
Temperature $[°C]$	= 460.00				

Surface Name: Billet_Container
Surface Definition: - SolidWall - Workpiece-Tool Contact Surface

X-Velocity $[mm/s]$	= 0.000	Y-Velocity $[mm/s]$	= 0.000	Z-Velocity $[mm/s]$	= 0.000
Temperature $[°C]$	= 460.00				

Surface Name: Porthole_Die
Surface Definition: - SolidWall - Workpiece-Tool Contact Surface

X-Velocity $[mm/s]$	= 0.000	Y-Velocity $[mm/s]$	= 0.000	Z-Velocity $[mm/s]$	= 0.000
Temperature $[°C]$	= 460.00				

Surface Name: BearingHole1Outer
Surface Definition: Bearing - Bearing region of the die

Bearing Profile	= prof_BearingHole1Outer
Min. Length $[mm]$	= 5.00
Max. Length $[mm]$	= 5.00
Friction Model	= Viscoplastic
Friction Coefficient	= 0.30
Heat Flux $[W/m^2]$	= 0.000

Surface Name: BearingHole1Inner1
Surface Definition: Bearing - Bearing region of the die

Bearing Profile	= prof_BearingHole1Inner1
Min. Length $[mm]$	= 5.00
Max. Length $[mm]$	= 5.00
Friction Model	= Viscoplastic
Friction Coefficient	= 0.30
Heat Flux $[W/m^2]$	= 0.000

Surface Name: FreesurfaceHole1Outer
Surface Definition: Free Surface - Profile surface after it exits the die

Heat Flux $[W/m^2]$	= 0.00

Surface Name: FreesurfaceHole1Inner1
Surface Definition: Free Surface - Profile surface after it exits the die

Heat Flux $[W/m^2]$	= 0.00

Surface Name: ExitHole1
Surface Definition: Outflow - End of the profile

X-Traction $[MPa]$	= 0.000	Y-Traction $[MPa]$	= 0.000	Z-Traction $[MPa]$	= 0.000
Pressure $[MPa]$	= 0.000				
Heat Flux $[W/m^2]$	= 0.000				

Appendix B

Boundary Faces Along Different Flow Paths

Please refer to the figure depicting flow network and the legend table for details. Billet_DummyBlock face is not shown in the figure.

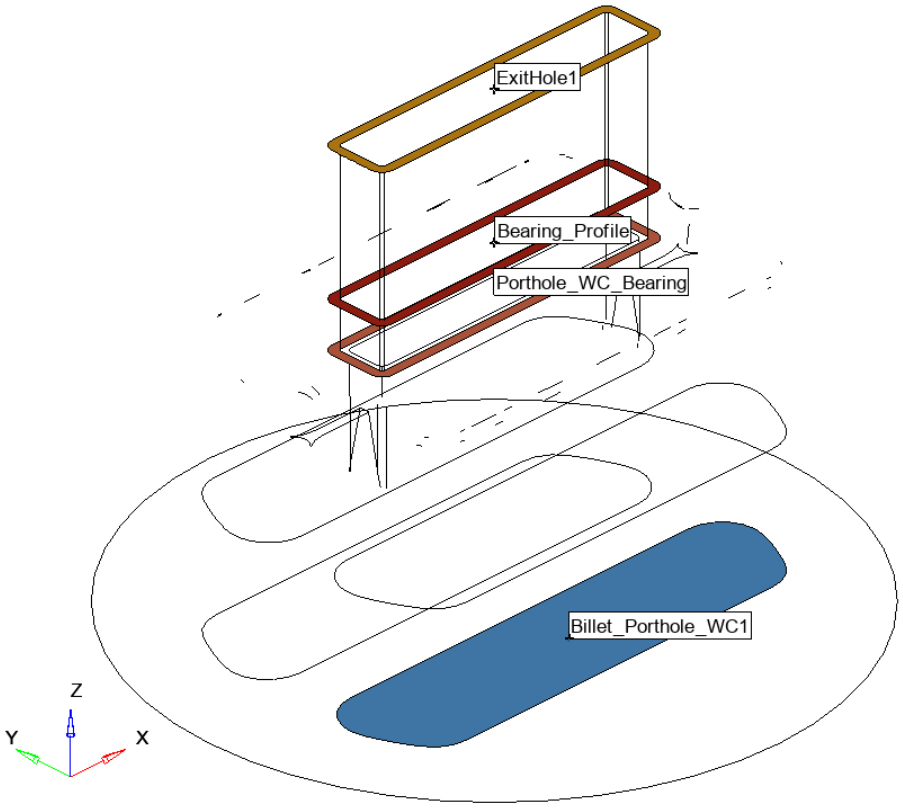

Figure B.1: Boundary faces along the flow path A1–B1–C1–E1.

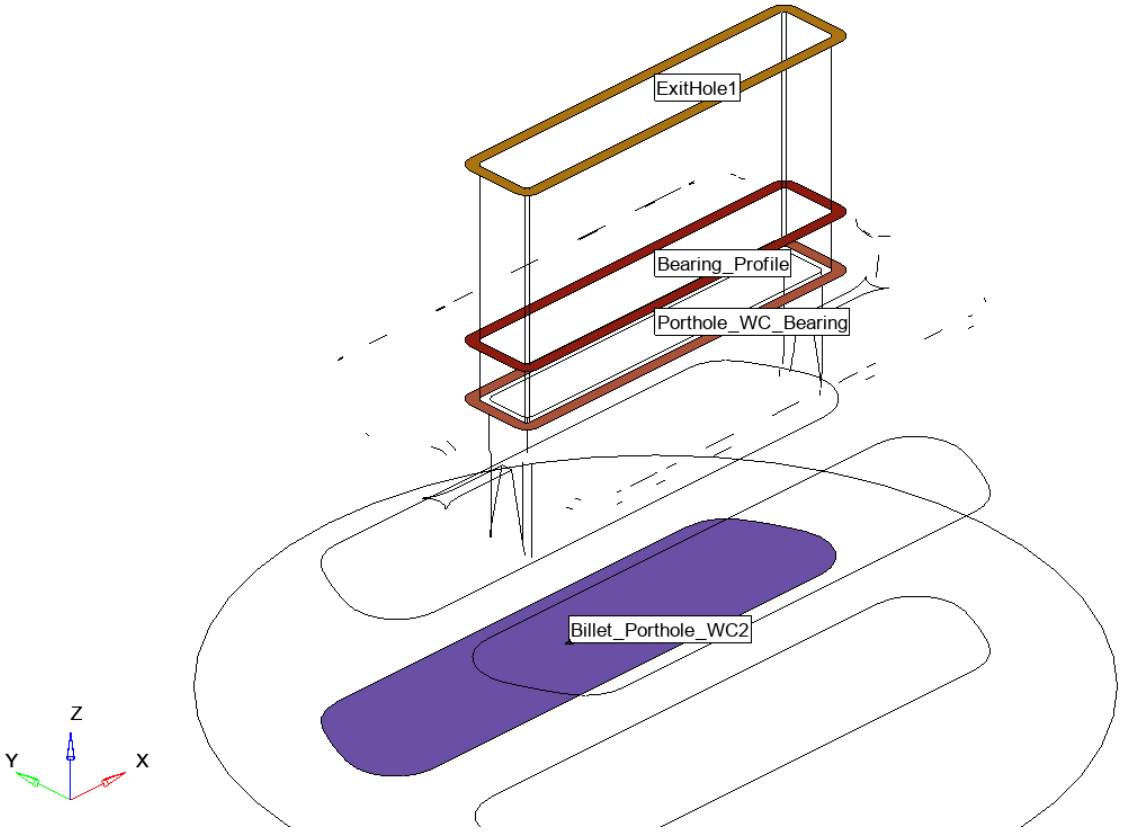

Figure B.2: Boundary faces along the flow path A1–B2–C1–E1.