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A study on the effects of the extrusion process parameters using FEM

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ABSTRACT

In this study finite element analyses of rod extrusion process are carried out considering various processing parameters. The objective is to study the effect of these parameters on mechanical performance. Seventy seven cases are simulated and corresponding stress; plastic strain and load distribution are critically examined. Based on these results, salient conclusions are drawn which will help select parameters for quality and economical extrusions.

KEYWORDS

Extrusion;
Finite element analysis;
Die angle;
Stress;
Strain hardening exponent.

INTRODUCTION

Extrusion is an important metal forming operation. It is a manufacturing process used to create long objects of a fixed cross sectional profile. The extrusion process is based on the plastic deformation of a material due to compressive and shears forces only. Basically, this procedure is based on the reducing and shaping the cross section of piece of metal squeezing the material through an orifice or a die (Figure 1). Typically the blocks of metal used for this procedure are long straight parts with circular cross sections. Extruded parts usually have a constant cross-section along its span. This type of process works inexpensively when it is used to produce parts that come in large quantities. Another reason that makes this process efficient is its flexibility. That is, if a part with a different cross section is needed it is not necessary to get another machine to produce it; it would only require to change the type of die. Therefore, extrusion is recommended for the production of a vast selection of sections. Some of the prominent researches on extrusion are given below :

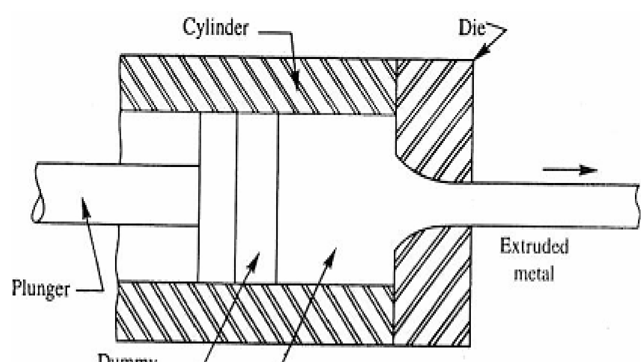

Figure 1 : Schematic of extrusion.

Kang et al.[7] analyzed three dimensional hot extrusion processes through landless square die considering as a non steady state problem. To overcome severe mesh distortion problem, an automatic remeshing technique was proposed by employing a modular conceptual mesh structure. Reddy et al.[14] carried out a comprehensive investigation of an axisymetric steady state tube extrusion through a streamlined die using FEM and studied the influence of process variable on tool design and final product quality for a strain hardening material. Joun and Hwang[6] attempted shape optimal design of tube extrusion using sensitivity and rigid visco-plastic finite element approach. Hur et al.[5] carried out an analysis for the dimensional accuracy of the cold forged products that was strongly dependent on the elastic characteristics of the die. Therefore a design method that made the elastic deformation of the prestressed die as small as possible was proposed for precision cold forging. Gouveia et al.[4] carried out the finite element modeling of cold formed extrusion using an updated Lagrangian finite element formulation. Kim, Kang and King[8] optimized die profile of axisymmetric extrusion of MMCs using FEM in order to obtain uniform strain rate profile. Cosenza et al.[2] carried out the damage and fracture study of cold extrusion dies considering a few different die reduction zone geometries. Peng et al.[12] carried out the finite element analysis of springback and secondary yielding effect during forward extrusion. The response of work material during forward extrusion and the subsequent unloading process was analyzed with a view of examining difficulties in prediction of component form errors, when different consecutive models were used. Ponalagusamy et. al.[10] attempted to design streamlined dies using Bezier curve and upperbound theorem. Lee, Ko and Kim[9] optimized the die profile using Bezier curve to get uniform microstructure in hot extrusion. Bhavin Mehta[1] and Narayanasamy et al.[10] used neural networks and genetic algorithms respectively for die profile design.

In this study effect of material, geometry and frictional parameters on extrusion process are studied using simulation techniques. Results are critically examined in terms of stress, strain and extrusion load.

GEOMETRICAL, MATERIAL & FRICTIONAL PARAMETERS

In Figure 1 a schematic rod extrusion process is shown. Following geometrical, material and frictional parameters are considered in the study -

Geometrical parameters

(i). Billet diameter = 80 mm
(ii). Billet length = 60 mm
(iii). Extruded rod diameter = 40 mm
(iv). Half die angle = 30^0, 45^0 and 60^0

In this way, extrusion ratio comes out to be 4.

Material properties

Billet is modeled as rigid plastic material. Power law equation has been used for the modeling the stress strain behavior[3]:

$$\sigma = K\varepsilon^n$$

Where n is strain hardening exponent and K is strength coefficient.

Following values of material parameters are accounted-

(i). Young's Modulus = 78000 MPa
(ii). Poison's ratio = 0.33
(iii). Strength coefficient (K) = 500, 600 and 700 MPa
(iv). Strain hardening exponent n = 0.1, 0.15 and 0.2

Friction

Coulomb friction criteria has been taken into the account for contact modeling between different bodies. Three values of Coulomb friction coefficient viz 0.1, 0.15 and 0.2 are taken into consideration.

FE MODELING AND BOUNDARY CONDITIONS

Finite Element Modeling of the rod extrusion process is carried out using MSC. Superform software (Ref.15). Die and punch are modeled as rigid and billet is modeled as deformable bodies. Axisymmetric finite element modeling is carried out using 4 nodes quadrilateral elements[16]. A typical FE model is shown in Figure 2. There are 600 element and 651 nodes in the model. Displacement boundary condition is applied on the ram. Ram is given a displacement of 20 mm. Interaction of billet and die is accounted through contact algorithms of the software. Finite element simulation is carried out in incremental manner in 50 steps. Mesh distortion is automatically taken care of by the in built mesh adaptivity algorithm in the software Simulation results for the three dies, considering different material parameter are given in TABLE 1, 2 and 3.

TABLE 1 : Stress, strain & load for 30° die.

S. NO	K	n	Friction coulomb	Effective stress (N/mm^2)	Plastic strain	Load (N)
1	500	0.1	0.1	558.6	2.438	7.27E+06
2	500	0.15	0.1	627.1	2.389	7.30E+06
3	500	0.2	0.1	657.1	2.452	7.37E+06
4	500	0.1	0.15	615	3.088	9.93E+06
5	500	0.15	0.15	648.1	3.098	9.85E+06
6	500	0.2	0.15	677.8	3.182	1.01E+07
7	500	0.1	0.2	644	6.172	1.22E+07
8	500	0.15	0.2	688.2	5.648	1.25E+07
9	500	0.2	0.2	733	5.567	1.28E+07
10	600	0.1	0.1	672.26	2.433	8.72E+06
11	600	0.15	0.1	835.2	2.434	8.86E+06
12	600	0.2	0.1	749.8	2.393	8.90E+06
13	600	0.1	0.15	749.9	3.119	1.19E+07
14	600	0.15	0.15	789.7	2.979	1.19E+07
15	600	0.2	0.15	841.5	3.168	1.23E+07
16	600	0.1	0.2	754.8	6.037	1.51E+07
17	600	0.15	0.2	863.8	5.886	1.70E+07
18	600	0.2	0.2	875.2	5.615	1.57E+07
19	700	0.1	0.1	812.6	2.447	1.03E+07
20	700	0.15	0.1	883.3	2.38	1.04E+07
21	700	0.2	0.1	886.5	2.43	1.06E+07
22	700	0.1	0.15	872.4	3.054	1.38E+07
23	700	0.15	0.15	946.2	3.072	1.43E+07
24	700	0.2	0.15	969	3.056	1.43E+07
25	700	0.1	0.2	890.9	5.9	1.78E+07
26	700	0.15	0.2	956.6	5.726	1.96E+07
27	700	0.2	0.2	1025	5.144	1.93E+07

TABLE 2 : Stress, strain & load for 45° die.

S. NO	K	n	Friction coulomb	Effective stress (N/mm^2)	Plastic strain	Load (N)
1	500	0.1	0.1	688.7	4.292	7.55E+06
2	500	0.15	0.1	688.1	4.386	7.58E+06
3	500	0.2	0.1	735.6	4.032	8.00E+06
4	500	0.1	0.15	671.5	5.371	9.55E+06
5	500	0.15	0.15	726.1	4.997	9.74E+06
6	500	0.2	0.15	718.6	4.653	1.04E+07
7	500	0.1	0.2	689.1	6.747	1.17E+07
8	500	0.15	0.2	769.1	7.14	1.27E+07
9	500	0.2	0.2	835.2	6.586	1.23E+07
10	600	0.1	0.1	707.9	4.264	9.19E+06
11	600	0.15	0.1	761.2	4.221	9.48E+06
12	600	0.2	0.1	824.5	3.915	9.92E+06
13	600	0.1	0.15	837	5.329	1.19E+07
14	600	0.15	0.15	781.8	4.949	1.21E+07
15	600	0.2	0.15	861.6	4.553	1.26E+07
16	600	0.1	0.2	810.1	6.724	1.50E+07
17	600	0.15	0.2	912.8	6.853	1.53E+07
18	600	0.2	0.2	955.9	6.869	1.67E+07
19	700	0.1	0.1	874	4.368	1.09E+07
20	700	0.15	0.1	923.1	3.889	1.12E+07
21	700	0.2	0.1	1125	3.858	1.15E+07
22	700	0.1	0.15	913.9	5.372	1.42E+07
23	700	0.15	0.15	965.8	4.956	1.49E+07
24	700	0.2	0.15	1058	4.659	1.57E+07
25	700	0.1	0.2	930.9	7.12	1.92E+07
26	700	0.15	0.2	995	7.096	2.19E+07

TABLE 3 : Stress, strain & load for 60° die.

S. NO	K	n	Friction coulomb	Effective stress (N/mm^2)	Plastic strain	Load (N)
1	500	0.1	0.1	735.8	5.953	7.88E+06
2	500	0.15	0.1	708.9	5.764	8.32E+06
3	500	0.2	0.1	775.7	4.507	8.81E+06
4	500	0.1	0.15	711.9	5.627	9.90E+06
5	500	0.15	0.15	718.1	5.376	9.67E+06
6	500	0.2	0.15	924.8	5.935	9.70E+06
7	500	0.1	0.2	672.2	8.06	9.51E+06
8	500	0.15	0.2	888.1	8.776	1.05E+07
9	600	0.1	0.1	759	5.27	9.90E+06
10	600	0.15	0.1	854.7	4.588	1.02E+07
11	600	0.2	0.1	828.1	5.835	1.04E+07
12	600	0.1	0.15	730.2	5.614	1.21E+07
13	600	0.15	0.15	842.7	5.743	1.20E+07
14	600	0.1	0.2	972.5	7.778	1.27E+07
15	600	0.15	0.2	844.1	6.784	1.51E+07
16	600	0.2	0.2	1032	7.602	1.48E+07
17	700	0.1	0.1	917.7	5.076	1.16E+07
18	700	0.15	0.1	1113	4.542	1.22E+07
19	700	0.2	0.1	1127	5.031	1.30E+07
20	700	0.1	0.15	1084	5.984	1.44E+07
21	700	0.2	0.15	1040	5.678	1.53E+07
22	700	0.1	0.2	911.6	7.274	1.85E+07
23	700	0.15	0.2	1224	7.639	1.91E+07
24	700	0.2	0.2	1145	7.723	2.03E+07

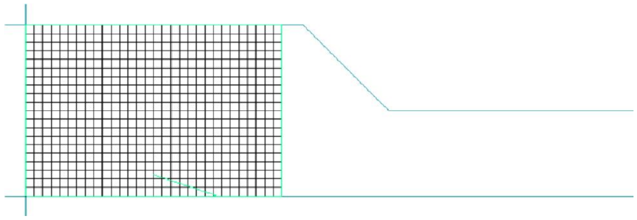

Figure 2 : FE mesh generation.

RESULT & DISCUSSION

Simulation results can be critically analysed under following heads:

Effective stress distribution

A typical stress contour is shown in Figure 3. Maximum stress is as high as 913 MPa. Stress vrs friction plot for different K and die angle are shown in Figure 4-6. It can be observed that stress increases with increase in n value. For constant K, n and friction, stress increases with increase in die angle. Stress also increases with increase in friction for all the cases. Rate of change of stress with respect to friction is highest for higher n value for all die angles. For constant n and friction, stress increases with increase in K value for all die angles.

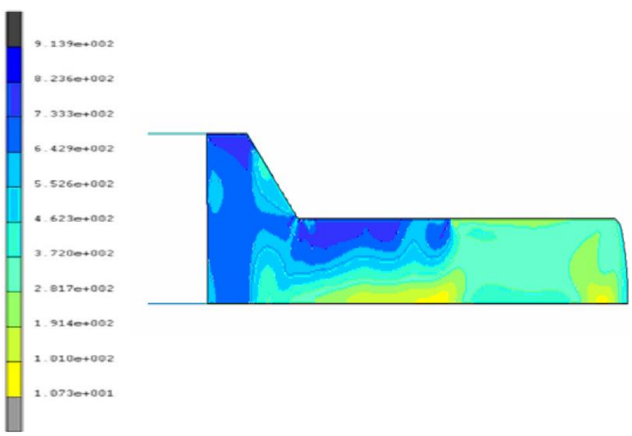

Figure 3 : Effective stress contour (MPa).

Plastic strain distribution

A typical plastic strain contour is shown in Figure 7. It can be observed that strain can be as high as 7. Strain vrs friction plot for different K and die angle are shown in Figure 8-10. Strain increases with increase in friction for all K, n and die angle. Strain increases with increase in K for all other parameters. Rate of change of plastic strain decreases with increase in die angle for all K, n and friction conditions. Plastic strain is not affected by n for all the friction and K values in lower angled dies.

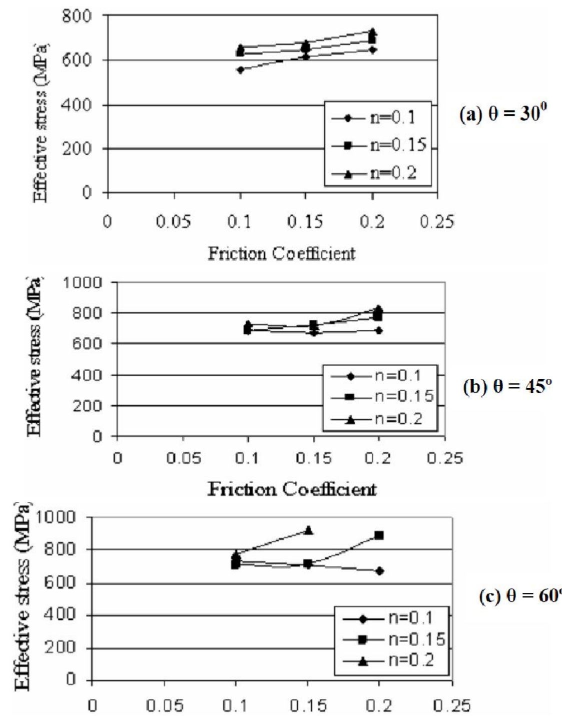

Figure 4 : Effective stress vrs friction (K = 500 MPa); (a) θ = 30° (b) θ = 45° (c) θ = 60°

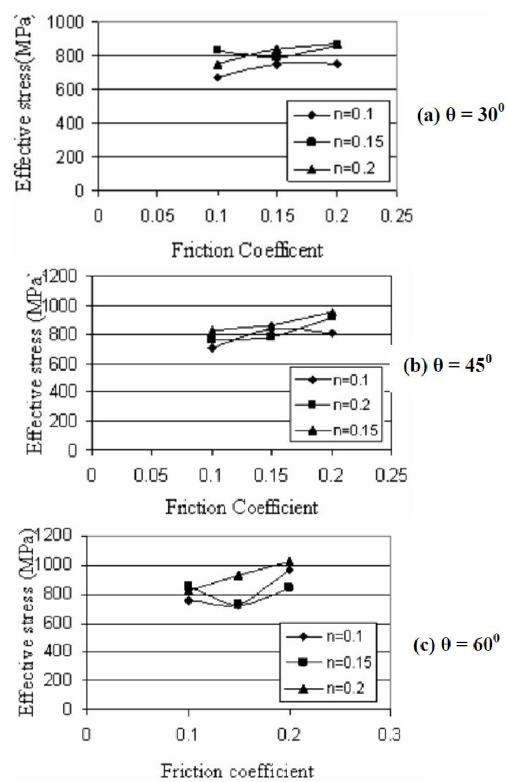

Figure 5 : Effective stress vrs friction (K = 600 MPa); (a) θ = 30° (b) θ = 45° (c) θ = 60°.

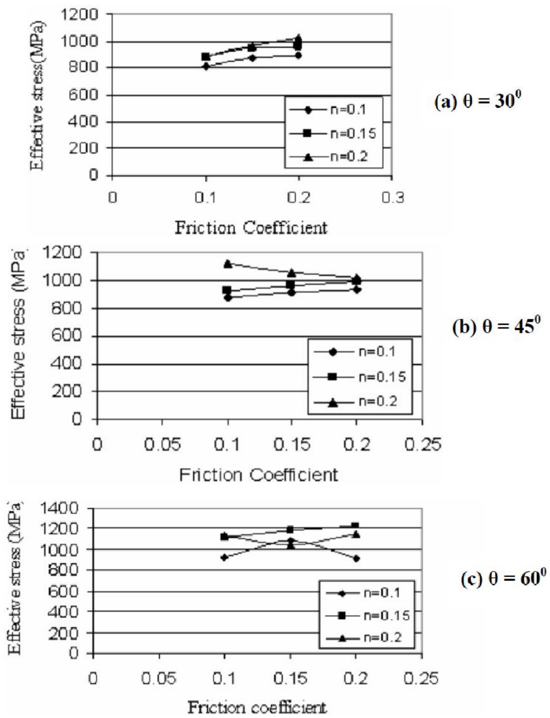

Figure 6 : Effective stress vrs friction (K = 700 MPa); (a) θ = 30° (b) θ = 45° (c) θ = 60°.

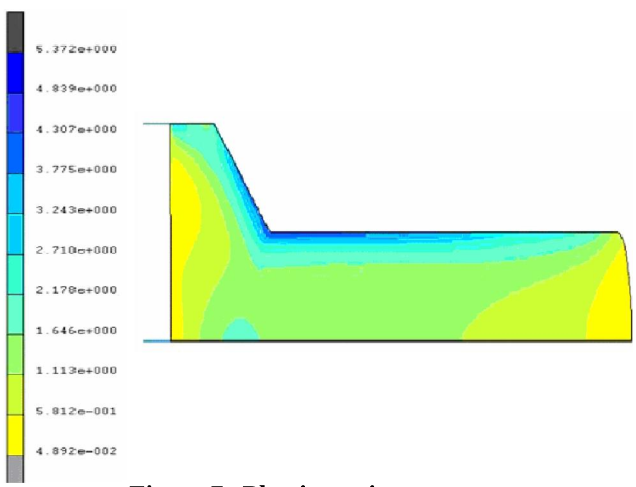

Figure 7 : Plastic strain contour.

Load distribution

A typical load curve of the extruded rod is shown in Figure 11. It can be observed that quite large load (14.2 MN) is required in the extrusion process. Load vrs friction plot for different K and die angle are shown in Figure 12-14. For different K, n and friction, extrusion load decreases with increase in die angle. For constant n, friction and die angle, extrusion load increases with increase in K value. Rate of change of load decreases with increase in die angle for all K values. Friction load increment, more or less, follows linear trend for all K, n and die angle. Difference in extrusion load with respect to n increases with increase in friction for all K and die angle.

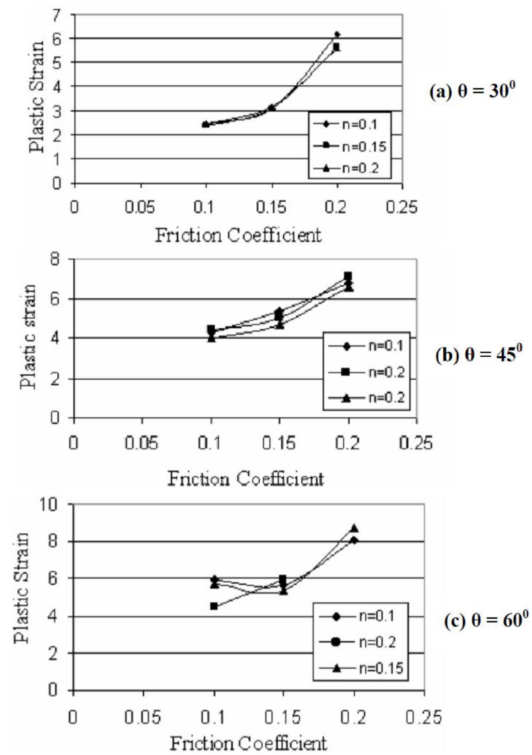

Figure 8 : Plastic strain vrs friction (K = 500 MPa); (a) θ = 30° (b) θ = 45° (c) θ = 60°.

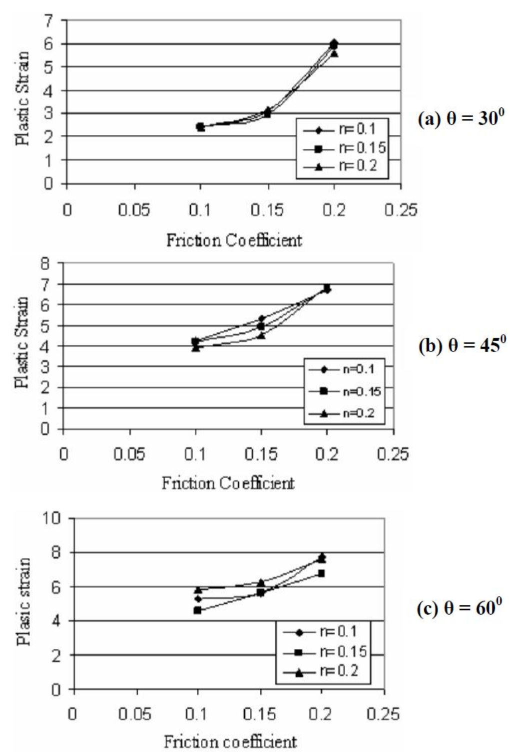

Figure 9 : Plastic strain vrs friction (K = 600 MPa); (a) θ = 30° (b) θ = 45° (c) θ = 60°.

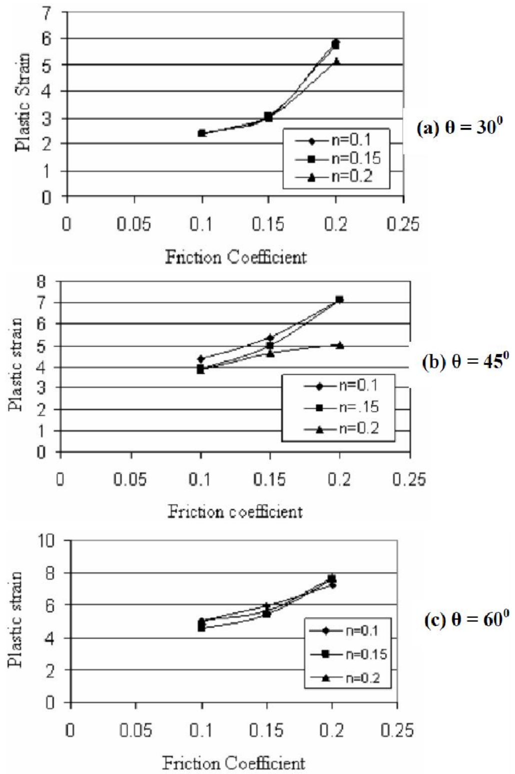

Figure 10 : Plastic strain vrs friction (K =700 MPa); (a) θ = 30º (b) θ = 45º (c) θ = 60º.

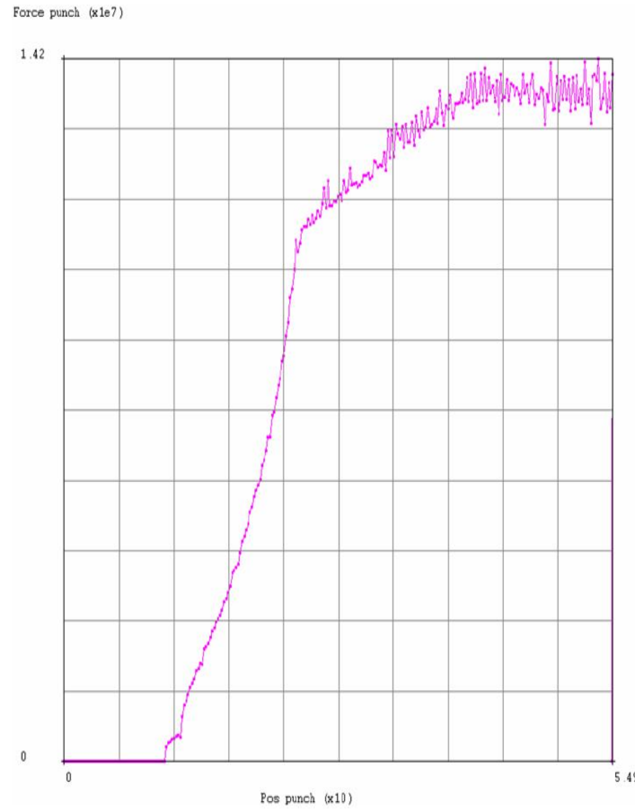

Figure 11 : Load distribution curve.

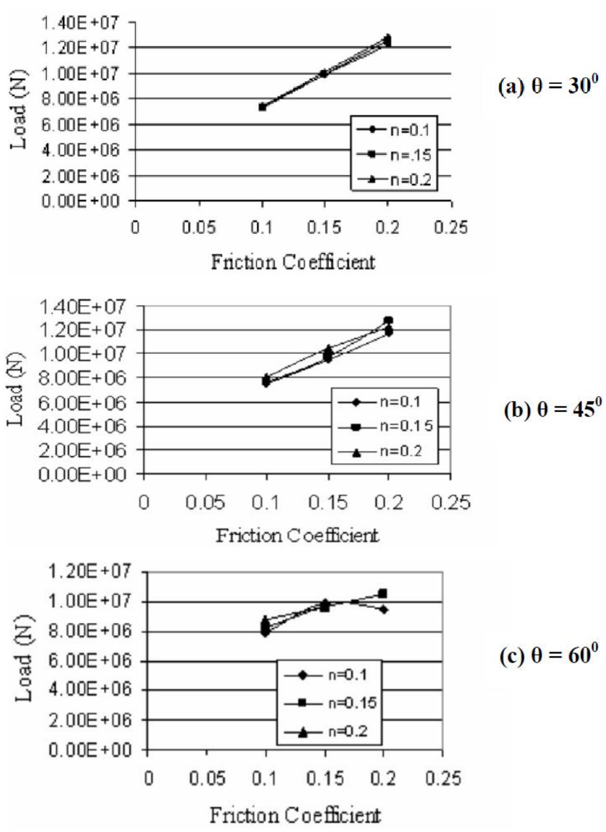

Figure 12 : Load vrs friction (K= 500 MPa); (a) θ = 30º (b) θ = 45º (c) θ = 60º.

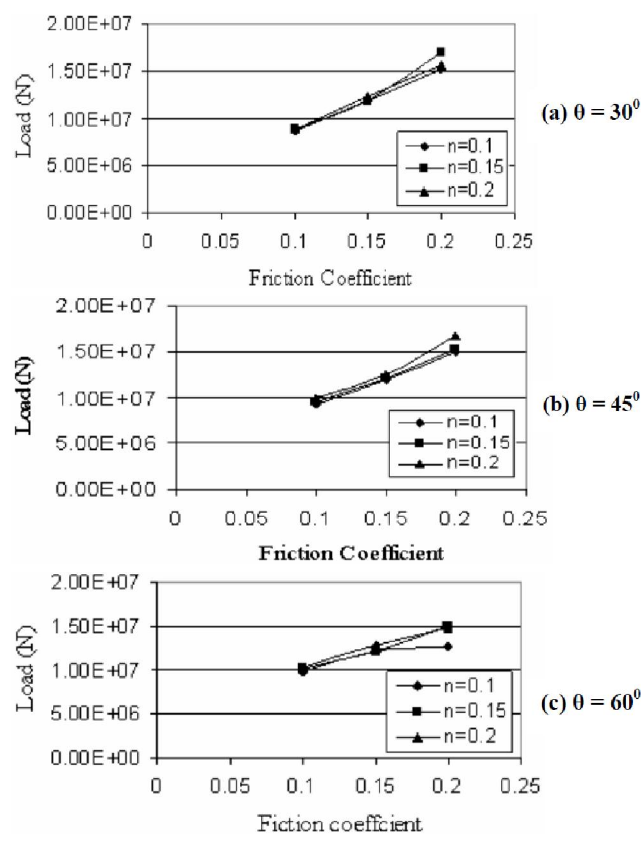

Figure 13 : Load vrs friction (K = 600 MPa); (a) θ = 30º (b) θ = 45º (c) θ = 60º.

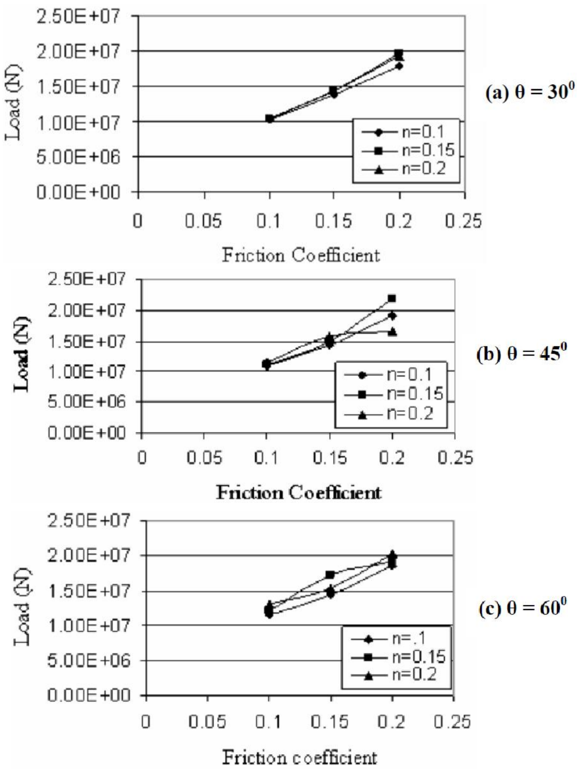

Figure 14 : Load vrs friction (K = 700 MPa); (a) θ = 30° (b) θ = 45° (c) θ = 60°.

CONCLUSIONS

In this study, effects of processing parameters on rod extrusion are studied using finite element simulation results. Seventy seven cases considering various geometrical, material and friction parameters are simulated. Effects of these parameters are critically analyzed in term of stress, strain and extrusion load. Stress and strain would help in quality control and load assessment would help in controlling energy requirement. These findings will assist the design engineers in efficient design of extrusion process.

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