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Research Article

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PERFORMANCE OF NYLON-6 ROD WITH RESPECT TO EXTRUSION PROCESS

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Keywords

Single screw extrusion, Nylon-6(M-28RC), Taguchi L9 orthogonal array, Computational fluid dynamics.

Abstract

Single screw extrusion is one of the key operations in polymer handling and is likewise a key segment in numerous other preparing operations. There are many process parameters for single screw extruder namely, dies temperature, barrel temperature, screw speed and composition. These parameters and their interaction have been investigated by different researcher for better quality outcomes. The present work studies the influence of three main process parameter namely, die temperature, barrel temperature and screw speed on the mechanical properties of Nylon6 (M-28RC grade) rods (as per ASTM standard) for the applications like Fishing rod, Carry bag handles, Holding Fan rods etc. The critical process parameters were optimized using Taguchi L9 OA and ANOVA variance for achieving high tensile strength and %elongation. Further, the optimized results have been investigated using ANSYS FLUENT 15.0 (CFD). The results of the study reveal that screw speed is the most contributing factor to control tensile strength and %elongation, the least contributing factor is barrel temperature. The effect of process parameters on the die of single screw extruder were investigated using CFD analysis.

1. Introduction

Polymeric materials are use to replace less strengthen metals due to their premium properties like [Singh et al., 2016]:-

- High strength to weight ratio
- Non- conductivity
- High temperature/chemical/corrosive resistance
- Re-process ability
- High clarity
- Low cost and so forth

Therefore, polymeric materials have become popular in the heavy load application such as automobiles, electrical and electronic, transport, medical, construction, household, ship-buildings. The most popular process to change the raw polymer material into final product is single screw extruder.

Polymeric extrusion is usually formed many complex and challenging shapes such as pipes, sheets, tubes, rods, plates, films, strapping etc (Chan Chung I.). The polymeric material is conveying along a screw and forcing the molten material through a die at a certain pressure, velocity and temperature. Single screw extrusion is used to create objects of fixed cross-sectional profiles. It consists of barrel, motor, Die, controllers, thermocouples. There are four process parameters in single screw-extruder: - Barrel temperature, Die Temperature, Speed, Material compositions (Tadamoto Sakai, 2013). The rising of initial barrel Temperature at compression zone will help better sticking of the pellet to the barrel wall there (khan et al., 2014).

Tensile testing is used to decide how the material will respond to powers being connected in strain. As the material is being pulled, the strength and material properties decided their elongation (Chul S Lee., 1972). The tensile testing of polymer is done according to ASTM-D638.

Genichi Taguchi has made valuable contribution to statistics and engineering. Taguchi has presented a few vital better approaches for conceptualizing a test that are extremely profitable, particularly in item advancement and mechanical designing (Gal- Ben I, 2005). Taguchi orthogonal depends on judgmental examining.

ANSYS gives a far reaching suite of computational fluid dynamics programming for demonstrating fluid stream and other related physical wonders. The ANSYS-FLUENT workbench15.0 is used to evaluate the behavior of fluid flowing inside the die and determine the significant parameters affecting the fluid flowing inside the die (Baalaganapathy Manohar., 2016).

2. Experimentation

The pilot experimentation and literature survey has been made to prepare an extruded rod. The first step was to check the possibility of preparation of Nylon-6 (M-28RC grade) rod with varying input parameters such as Barrel temperature, Die temperature and Screw speed. For the experimentation the selection of material for preparing the high load application rod is Nylon-6 due to their high strength to weight ratio. The process variables of single screw extruder is barrel temperature 180°C, die temperature 190°C and screw speed of 30rpm is randomly selected but obtained rod was irregular in shape, size and appearance, due to burnishing of material inside the die at high temperature and low speed. In this experimentation, Taguchi L9 orthogonal array was selected for design of experimentation. The process variables were chosen as availability on single-screw extruder, as barrel temperature, die temperature and rpm of the extruder screw. The barrel temperature was taken at 3 different levels of 150, 155 and 160ºC and the die temperature of 160, 165, 170ºC and rpm of extruder screw was taken as 55, 50, 45rpm and after that extruded rods was prepared according to the Taguchi L9 orthogonal array.

Table1. Parameter selection for experimentation

Levels	***Mean Barrel temperature (°C)***	***Mean Die temperature (°C)***	***Screw speed (rpm)***
1.	160	150	45
2.	165	155	50
3.	170	160	55

Table 1 shows the selected process parameters and their level for the final experimentation. Table 2 shows the design of experiment using L9 orthogonal array.

The investigations for tensile properties and % elongation were analyzed on universal tensile testing machine.

Table 2. Design of experiment using L9 OA

Experimental run	*Mean barrel temperature (°C)*	*Mean die temperature (°C)*	*Screw speed in rpm*
1.	160	150	45
2.	160	155	50
3.	160	160	55
4.	165	150	50
5.	165	155	55
6.	165	160	45
7.	170	150	55
8.	170	155	45
9.	170	160	50

3. Boundary conditions

Ansys Workbench15.0 was used for investigate the contribution of process parameters inside the die of single screw extruder. The design model of die was made in design modeler of Workbench. The fluid was flowing inside the die using fill cavity command. The investigation was made for the effect of parameters on the fluid flowing inside the die. The die was split into 2 portions for supply heat from the 2 heating coils individually and a heater was controlled by controllers.

A very fine mesh was generated in FLUENT meshing part. Large number of fine mesh gives very accurate results. The final mesh contained, for die no. of nodes is 53856 and elements are 44760, for part fluid flow no. of nodes is 34593 and elements are 168282 so, the overall domain mesh having 88449 nodes and 213042 elements. For investigation of parameters in single screw extruder using CFD, the level 9 was chosen because of optimal level (having high tensile strength and % Elongation).

For boundary condition, the parameter under level 9 was barrel temperature is 170°C, die temperature is 160°C and screw speed is 50rpm.

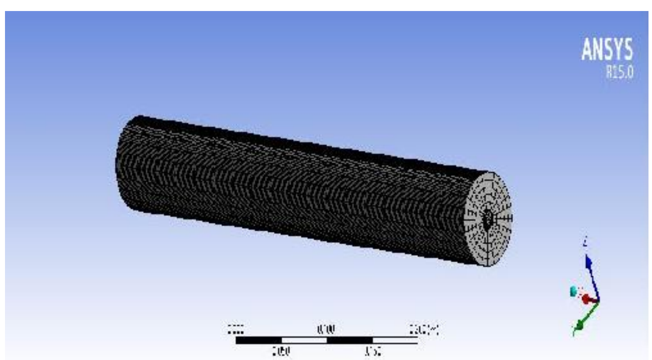


Figure1. Part die with mesh

The mass flow rate of Nylon-6 inside the die is 2.6456 g/10min. There are 4 band heaters was connected with two controllers.

4. Results and Discussion

After effective pilot experimentation at characterized level of process factors, Nylon-6(M-28RC grade) were set up according to Taguchi L9 orthogonal array, the outcomes for the distinctive yield parameters (to be specific: tensile strength and % elongation) discussed.

4.1 Tensile Strength at Peak

Table 3 shows the output of peak tensile strength for different parametric conditions based upon Taguchi L9 orthogonal array.

The maximum value of peak tensile strength was occurred for sample no. 9, in which the parametric conditions are barrel temperature 170ºC, Die temperature 160ºC and screw speed 50 rpm. The minimum value obtained for sample no. 7, which is the parametric conditions are barrel temperature 170ºC, die temperature 150ºC and screw speed 55 rpm. At this level high temperature and moderated screw speed gives good results.

Table 3. Outcome of peak tensile strength for different parametric conditions

Parameter condition	***A Mean Barrel temperature (°C)***	***B Mean Die temperature (°C)***	***C Screw speed (rpm)***	***Tensile strength (MPa)***	***SN ratio***
1.	160	150	45	49.883	33.9591
2.	160	155	50	50.124	33.0009
3.	160	160	55	49.742	33.9345
4.	165	150	50	50.394	34.0476
5.	165	155	55	49.742	33.9345
6.	165	160	45	50.210	34.0158
7.	170	150	55	49.642	33.9170
8.	170	155	45	50.274	34.0269
9.	170	160	50	50.510	34.0675

The Fig. 2, below shows that the SN ratio first decrease and then increase with barrel temperature without any sharpness resulted into less effect on SN ratio. The SN ratio for die temperature was first increase and then decrease with increase in die temperature. SN ratios for screw speed is first increases sharply and the again SN ratio is increase with screw speed sharply so, the effect of SN ratio at this parameter is high.

The main plot of SN ratio gives the proper justification that with increase in temperature and decrease in screw speed there will be increase in tensile strength.

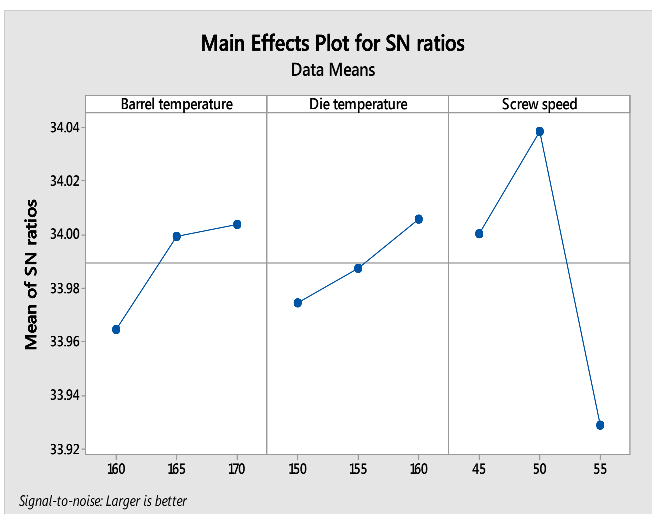


Figure 2. Main effect plot of S/N ratio for tensile strength

Table 4 shows that, screw speed has maximum impact for contributions in SN ratios whereas barrel temperature has minimum contributions.

Table 4. Response Table for Signal to Noise Ratios Larger is better

Level	*Barrel temperature (ºC)*	*Die temperature (ºC)*	*Screw speed (rpm)*
1.	33.96	33.97	34.00
2.	34.00	33.99	34.04
3.	34.00	34.01	33.93
Delta	0.04	0.03	0.11
Rank	2	3	1

The below Table 5 shown that, percentage error was found to be 4.037% for tensile strength. It shows that model has greater degree of precise. For optimization following formula based upon Taguchi design has been used:

$$\eta_{opt} = T + (T_{A3} - T) + (T_{B3} - T) + (T_{C2} - T)$$

Where 'T' is the overall mean of S/N ratio data, T_{A3} is the mean of S/N ratio data for barrel temperature at level 3 is maximum and T_{B3} is the mean of S/N ratio data for die temperature at level 3 and T_{C2} is the mean of S/N ratio data for screw speed at level 2.

Table 6 Modified ANOVA table for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Barrel temp.	2	0.002788	0.002788	0.001364	2.82	0.261	11.40
Die temp.	2	0.001494	0.00494	0.000747	1.55	0.393	6.244
Screw speed	2	0.0018736	0.0018736	0.009368	19.40	0.049	78.311
Residual error	2	0.000966	0.000966	0.000483			4.037
Total	8	0.023925	0.023625				

$y^2_{opt} = (10)^{\eta opt / 10}$ for properties, greater is better Calculation, overall mean of SN ratio (t) was taken from Minitab software17.0.

T = 33.8782

Therefore, ηopt = 34.2936

$y^2_{opt} = (10)^{\eta opt / 10}$ for properties, greater is better Therefore, yopt = 51.820

So, Optimum Tensile strength at Peak = 51.820%.

4.2 Percentage Elongation at Peak

As Table 7 shows the output of % Elongation at peak for different process parametric conditions based upon Taguchi L9 OA. The maximum value of peak %Elongation occurred for sample no. 9, which is the combination of parameters barrel temperature 170°C, die temperature 160°C and screw speed of 50rpm. . The minimum value obtained for sample no. 1, which having the process parametric conditions of barrel temperature of 160°C, die temperature of 150°C and screw speed of 45rpm.

The figure 2 shown, the SN ratios is first decrease as barrel temperature increased, but after that it increase with barrel temperature resulted into decreased SN ratios. The SN ratio for die temperature was first increase and furthers it increase with die temperature, but the increasing trend was not sharp.

Table 7. Outcome of peak Percentage elongation for different parametric conditions

Parametric Condition	*A. Barrel Temp. (in ºC)*	*B. Die Temp. (in ºC)*	*Screw Speed (rpm)*	*% Elongation*	*S/N Ratio*
1.	160	150	45	4.261	12.5902
2.	160	155	50	4.976	13.9376
3.	160	160	55	5.017	14.0089
4.	165	150	50	4.674	13.3938
5.	165	155	55	5.092	14.1378
6.	165	160	45	4.386	12.8414
7.	170	150	55	4.892	13.7897
8.	170	155	45	4.582	13.2211
9.	170	160	50	5.361	14.5849

A SN ratio for screw speed is increase sharply with decrease in screw speed results increase in SN ratio. The lower speed and higher temperature gives better % Elongation.

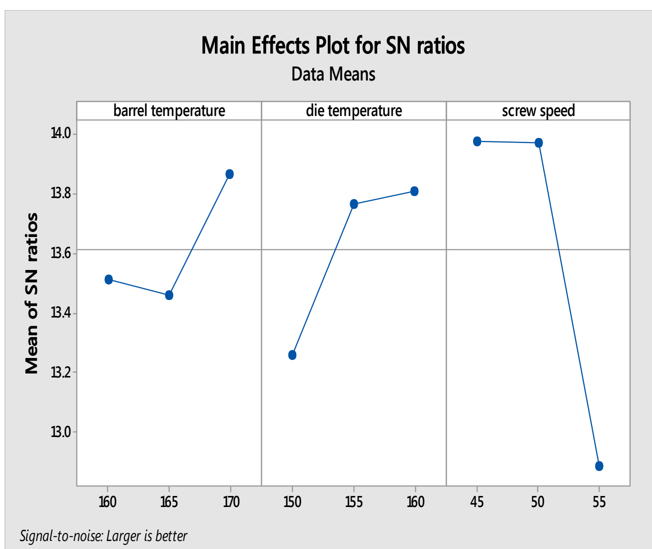


Figure 3. Main effect plot of S/N ratio for %Elongation

Table 8 shows that, screw speed has maximum contribution impact on SN ratios whereas barrel temperature has minimum contributions impact.

Table 8, error percentage found to be 3.414%. The maximum contribution of 70.95% was found for screw speed. And the total contribution of existing three parameters is 96.58%. The significant parameter are screw speed which having maximum contribution factor among another parameters.

Table 8. Response Table for Signal to Noise Ratios for % Elongation Larger is better

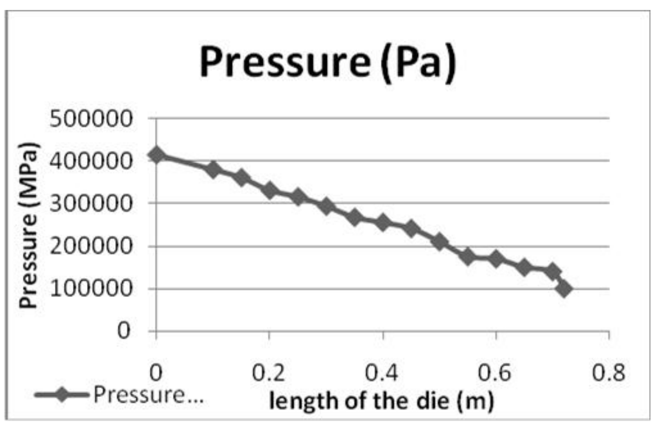
Level	*Barrel temperature(°C)*	*Die temperature(°C)*	*Screw speed (rpm)*
1.	13.51	13.26	13.98
2.	13.46	13.77	13.97
3.	13.87	13.81	12.88
Delta	0.41	0.55	1.09
Rank	3	2	1

The optimization performed for the peak %Elongation was similar to the tensile strength at peak of "greater is better" type, and calculated as; Optimum % Elongation at peak 5.34%.

Table 9 Modified ANOVA table for % Elongation

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution	Response
Barrel temperature	2	0.293	0.2937	0.14687	2.56	0.281	8.760	Not Significant
Die temperature	2	0.566	0.5665	0.28324	4.94	0.168	16.87	Not Significant
Screw speed	2	2.381	2.3816	1.19078	20.7	0.046	70.95	Significant
Residual Error	2	0.114	0.1146	0.05732				
Total	8	3.356						

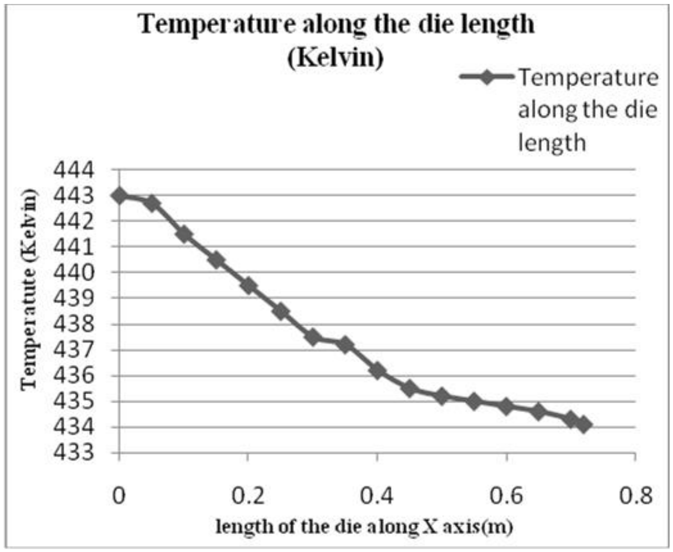
4.3 CFD Analysis



Graph1: Pressure along length of the die

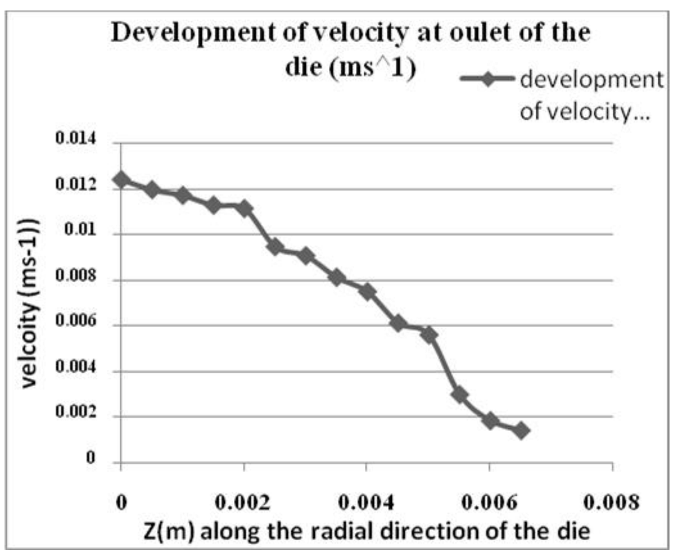
In the Graph1 effect of fluid pressure inside the die is keeps decreasing as the fluid keeps reaching the outlet of the die and finally is exposed to the atmospheric pressure. The pressure obtained inside the die is depends on the profile of screw and also the rpm of the screw.

The temperature profile is as expected and their results are validating with experimental results. The temperature of the die is 433°K, inlet temperature is 443°K, outlet temperature is 427°K and the final temperature is 443°K. The CFD value was closer to the practical value of temperature of molten polymer at 442°K



Graph 2. Temperature along length of the die

The velocity along the radial direction of the die is as high as 0.0125m/s. This high speed is attained at the centre part of the die along radial direction. The velocity depend on the screw geometry, when the screw have tighten grooves, better mixing is attained. The velocity at the centre of the die is getting approx. double then the experimental value, but at the wall of the die the velocity become constant. So, the effect of velocity inside the die is more as compared to temperature and pressure. The defects like blow holes inside the die was due to the improper velocity variation because the contribution of velocity is high at the centre of the die and the blow holes is increase with increase in velocity and decrease with decrease in velocity. The temperature inside the die is less contributing as compared to velocity.



Graph 3. Outlet velocity along the radial direction of the die

Conclusion

It can be seen from the result obtained from the experimental graph value is closer proximity with CFD graph values for temperature. The research successfully validates the use of CFD for investigate the process parameter inside the die of single screw extruder.

The maximum percentage elongation at peak was observed as **5.26%**. The maximum value of percentage at elongation for peak occurred for sample no. 9.

The maximum tensile strength at peak was **50.510 MPa**. The maximum value of strength for peak occurred for sample no. 9.

Furthermore the results reveal that presence of blow holes inside the final rod is due to the velocity contribution and their effect can be decreased by proper selection and control of screw speed.

The results shown that with increase in temperature and decrease in velocity better mechanical properties can be achieved.

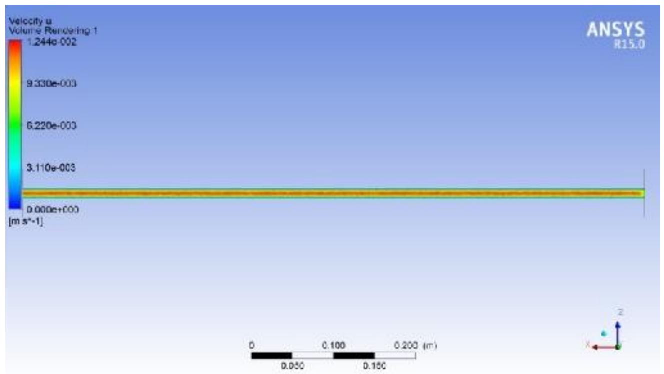
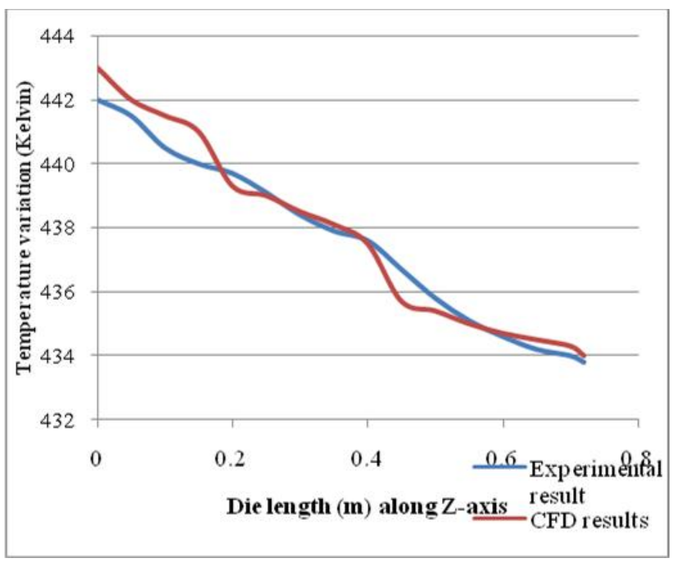


Figure 4. Velocity profile inside the die



Graph 4. Comparison results of experimental result and CFD result

References

[1] Boparai K Singh, Singh R, Singh H. (2016), “Experimental Investigations for Development of Nylon6-Al-Al2O3 Alternative FDM Filament”, *Journal of Rapid Prototyping Journal*, Vol. 22 Iss 4 pp.

[2] Lewis Jennifer, Adams James, Geil Phil. (1995) “Introduction to polymers”, *Material science and technology Journal.*

[3] Lee S Chul., Cad dell M Robert. , (1972) **“**Cold extrusion and cold drawing of polymeric rod: The influence on subsequent tensile and compressive mechanical properties”,*Journal of Material science and technology*, Vol. 10, pp 241-248.

[4] Jareka Bogusław, Kubika Aleksandra., (2015) "The examination of the Glass Fiber Reinforced Polymer composite rods in terms of the application for concrete reinforcement", *Journal of Procedia Engineering*, Vol. 108, pp 394 – 401.
[5] Sakai Tadamoto., (2013) "Screw extrusion technology — past, present and future" *Journal of Polimery*, Vol. 58, pp 11-12.
[6] Chung I Chan., "Extrusion of Polymers"., *Hanser publications*, 2nd editions.
[7] Manohar, B., Periasamy, C.(2016), "Computational fluid dynamics simulation of single screw extruders in cable industries". *IJRET: International Journal of Research in Engineering and Technology*, Vol. 5, pp. 2319-1163.
[8] I. Ben-Gal, (2005) "On the use of data compression measures to assess robust designs", *IEEE Trans. On Reliability*, Vol. 54, pp. 381-388.
[9] Jayaraman, M., Sivasubramanian, R., Balasubramanian, V. and Lakshinarayanan, A.K. (2009), "Optimization of process parameters for friction stir welding of cast aluminium alloy A319 by Taguchi method", *Journal of Scientific and Research*, Vol. 68, pp.36 – 43.
[10] Rao. N.P,"Manufacturing process book" edition II.
[11] Khan G.J., Dalu S.R., Gadekar S.S., (2014), "Defects in extrusion process and their impact on product quality" *International journal of mechanical engineering and robotics research*, Vol. 3, pp- 187-194.

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