***Problems of Tribology**, V. 29, No 4/114-2024, 47-53*

Problems of Tribology

Website: http://tribology.khnu.km.ua/index.php/ProbTrib

E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2024-114-4-47-53

Research on the wear resistance of the material cylinder of an automatic injection molding machine during plastics processing

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Received: 15 October 2024: Revised 10 Novemberl 2024: Accept 29 November 2024

Abstract

The article presents experimental studies of the pressure in the material cylinder of the D3328 automatic injection molding machine when processing various plastics, as well as experimental studies of wear along the length of the material cylinder of the DB3328 automatic injection molding machine after processing PS 68-30 fiberglass. Specially designed strain gauge pressure sensors were used. Signals from the sensors were output to an oscilloscope through the amplifying equipment and recorded on an oscillogram. The magnitude and distribution of pressure along the length of the material cylinder will significantly affect the amount of wear of both the screw and the cylinder. It was established that the pressure in the material cylinder of automatic injection molding machines is distributed unevenly along its length. The nature of the pressure distribution along the length of the material cylinder when processing various materials: during the injection period, the maximum pressure occurs in the melt zone with a subsequent sharp decrease in the middle zone and a slight increase in the loading zone. At the same time, the nature of the pressure change for all materials is similar at a diametrical gap between the screw and the cylinder δ=0.17 mm. With an increase in the gap δ to 0.74 mm, the nature of the pressure distribution in the injection zone changes only when processing fiberglass, which is due to the partial ingress of glass fibers into the gap between the screw and the cylinder. Its magnitude and nature of the distribution along the length for different materials are different and depend on the physical, mechanical and rheological characteristics of these materials, the design of the screw and the technological modes of processing. The maximum pressure occurs in the melt zone during the period of material injection into the mold for 0.4-0.5 s.

Key words: wear, fiberglass, cylinder, pressure, sensor.

Introduction

In modern conditions of the development of society, plastics are increasingly used in the national economy and technology. Products made of plastics in the household and household in many cases exceed 50% of the total number of used items. The reason for such widespread use of plastic products is a number of their advantages over other materials related to economy and practicality. In connection with this, the equipment for processing plastics - extruders and thermoplastic machines - has received a great development. Extruders are continuous-acting machines, while termo-plastic machines work cyclically, making products by casting into molds under a certain pressure [1-5]. Melting of plastics is achieved by heating them with special heaters and extrusion in the extrusion unit. The extrusion unit of thermoplastic machines includes a material cylinder and a screw with an injection system. The screw has a rotary and reciprocating movement, which it performs, respectively, during the period of collecting a portion of plastic and during the injection period.

Research Methodology

During the operation of the injection molding machine, a large pressure (up to 200MPa) occurs in the material cylinder, which affects both the strength of the material cylinder [5-7] and the wear resistance of the screw-cylinder pair [8]. The amount of pressure in the material cylinder of extruders and thermoplastic machines varies along its length and will be different when processing different materials. Therefore, the study of the magnitude and distribution of pressure in the material cylinder of thermoplastic machines and extruders and the nature of wear of the screw and cylinder of this unit during the processing of various materials are relevant.

We have carried out research on the amount of wear along the length of the material cylinder of the DB-3328 thermoplastic machine after its operation during PS 68-30 fiberglass processing. Research has established that the amount of wear along the length is different and was from 0.5 to 2 mm per diameter. The maximum wear of 2 mm was in the injection zone at a distance of 80 mm from the end of the cylinder and in the fiberglass loading zone (1.85 mm) at a distance of 400 mm from the injection zone. In the space between these zones, the amount of wear decreased to 0.5 mm. It is known from literary sources that the intensity of wear depends on many factors (properties of the material of the friction pairs, specific load on the friction surface, properties of the environment, temperature, sliding speed, etc.), among which the pressure on the friction surface is of great importance. In extruders and thermoplastic machines, friction and wear of parts occurs as a result of their contact with the processed material and when the surfaces of the screw and cylinder are in direct contact. The amount and distribution of pressure along the length of the material cylinder will significantly affect the amount of wear of both the screw and the cylinder. The maximum pressure in the material cylinder depends on the design parameters of the screw and cylinder, the temperature, the viscosity of the processed mass, and the rotation frequency of the screw and is theoretically found according to the formulas [9-10]:

- for variable height of screw turns and variable material viscosity:

$$P_{\max} = \frac{\Pi^2 D^2 n}{60}\left(\frac{\mu_1}{h_1^2} + \frac{\mu_2}{h_2^2} + \cdot + \frac{\mu_z}{h_z^2}\right), \tag{1}$$

- for screws with a constant height of the turn and a constant viscosity:

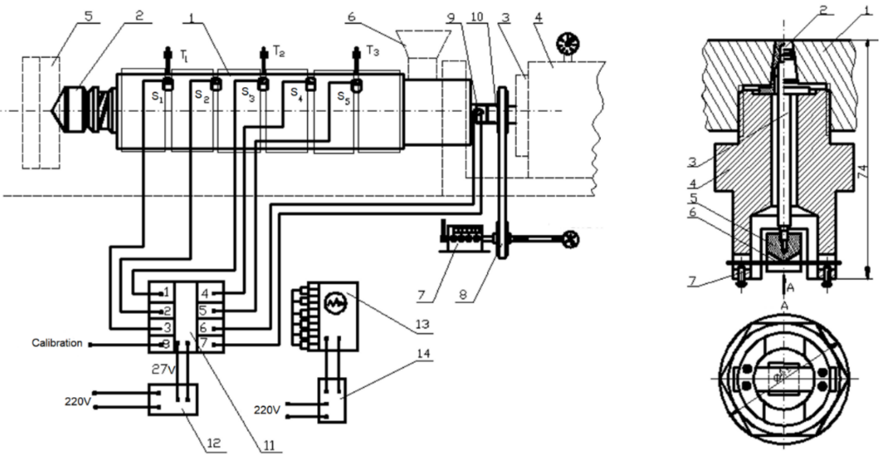
$$P_{\max} = \frac{\Pi^2 D^2 n \mu L}{60 h^2 \cdot H}, \tag{2}$$

where: D is the outer diameter of the screw;
n – rotation frequency of the screw;
H – screw pitch;
L– screw length;
h1, h2, hz– the height of the screw turn;
μ_1, μ_2, μ_z- the viscosity of the material melt at the boundaries of each turn of the screw.

The injection pressure for thermoplastic machines can be determined by the formula:

$$P_{ip} = \frac{\rho_2 D_2^2 \eta}{D^2} K_1 K_2, \tag{3}$$

where P_{ip}- pressure in the hydraulic system of the injection molding machine;
D_2- the diameter of the injection cylinder of the hydraulic system;
η- coefficient of useful action of the hydraulic cylinder;
K_1- the coefficient that takes into account friction costs in the melt;
K_2- the coefficient that takes into account the costs of hydraulic shocks.



a b

Fig. 1. a) Scheme of the experimental installation for determining the operational characteristics of thermoplastic machines and extruders: 1—material cylinder; 2—mouthpiece; 3—reducer; 4—hydraulic cylinder of the injection mechanism; 5—press form; 6—loading hopper; 7—screw rotation counter; 8—belt transmission; 9— strain gauges for torque measurement; 10—screw; 11—current amplifier; 12—amplifier power supply unit; 13—oscilloscope; 14—current rectifier; S_1, S_2, S_3, S_4, S_5—pressure sensors; T_1, T_2, T_3 — thermocouples. b) Pressure sensor: 1—material cylinder; 2—tail; 3—rod; 4—sensor body; 5—prism; 6—beam; 7—adjusting screw.

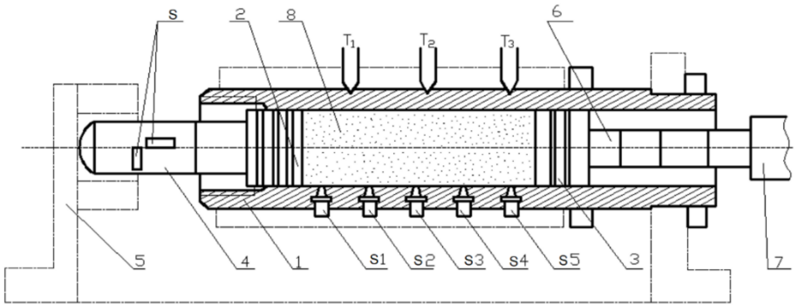


Fig. 2. Calibration scheme of pressure sensors: 1—material cylinder; 2—left plug; 3—right plug; 4—assembly rod; 5—mover; 6—rod of the right plug; 7—hydraulic cylinder rod; S1, S2, S3, S4, S5—pressure sensors; T1, T2, T3 — thermocouples; D is a strain gauge for measuring axial force.

Due to the fact that the pressure of the melt in the material cylinder of extruders and thermoplastic machines depends on many factors that are difficult to theoretically determine and take into account, there is a need to conduct experimental studies of the pressure in the material cylinder in different periods of the work cycle when processing different materials.

In order to study the pressure distribution along the length of the material cylinder from the injection molding machine during the processing of various plastics (high-pressure polyethylene, polystyrene, Kapron and fiberglass), an experimental installation (Fig. 1) was made on the basis of the injection molding machine D3328, in the material cylinder in which 5 pressure sensors were installed. The design of pressure sensors and the method of their installation in a material cylinder are shown in fig. 1. Signals from pressure sensors were output to the oscilloscope through the amplification equipment and recorded on the oscillogram. In the process of research, temperature in 3 zones, screw rotation frequency, torque and axial force on the screw were monitored.

The torque on the screw was measured by the tonometry method. The pressure in the hydraulic cylinder of the injection mechanism was measured by a standard pressure gauge and the tonometry method to record rapid pressure changes. The rotation frequency of the screw was fixed by a revolution counter.

Calibration of pressure sensors and strain gauges when measuring torque and axial force was carried out on a special device (Fig. 2) under conditions similar to the operating conditions of a thermoplastic molding machine with heating of plastic materials to 200-250°C. The auger was removed from the cylinder of the injection molding machine, the mouthpiece was unscrewed, and specially made plugs were inserted into it from both sides. The left plug 2 rested against the plate 5 through the collecting rod 4. The material cylinder was filled with plastic that melted as a result of heating by heaters. Through plug 3, with the help of rod 6 and the hydraulic injection cylinder of the hydraulic system, pressure was created when the "injection" button was turned on. The pressure in the material cylinder was recorded by sensors S1, S2, S3, S4 and S5, as well as a strain gauge glued on rod 4, which was previously tared and used as a dynamometer. Signals from sensors S1, S2, S3, S4 and S5 and the strain gauge on rod 4 were recorded through the amplifier on oscillograms, on the basis of which calibration graphs were built.

Experimental studies were carried out at the following constant values of the operational parameters of the installation: the inner diameter of the material cylinder is 40 mm, the injection pressure is 100 MPa, the pressure in the hydraulic cylinder is 50 MPa, and the pressure of the auger during loading is 0.4 MPa. Plastics with wide application in the national economy and a wide range of physical and mechanical characteristics were chosen as the tested materials, in particular: - high-pressure polyethylene, which is characterized by a wide range of material viscosity coefficient; polystyrene, which is easily processed and has high mechanical characteristics; kapron, which requires exact endurance of the technological mode of processing, a slight deviation from which leads to a sharp change in the viscosity and quality of the product; fiberglass, which is difficult to recycle, the basis of which is polyamide resin with properties that are close to those of kapron, and glass fiber sharply increases the viscosity of the material and, if it deviates from the technological mode of processing, leads to jamming of the auger.

In the process of research, the maximum was determined on the basis of recorded oscillograms $P_{\max}$ and the averageP_{m} pressures in the material cylinder in different periods of the work cycle. Average pressure value$P_{\mathrm{m}}$was determined by the formula:

$$P_{\mathrm{m}} = \frac{\int_0^t P(t)\mathrm{d}t}{t} \tag{4}$$

and is the ratio of the waveform area $P = f(t)$for a certain period t to the time spent on this period.

Results

Table 1 shows the results of experimental studies of the maximum and average values of pressures in the material cylinder, which occurred during the periods of injection and loading of the D 3328 thermoplastic machine, during the processing of various plastics.

Table 1

Results of experimental studies of pressures in the material cylinder during the processing of various plastics.

Material	Injection zone			Loading area			
	Injection time t, s	Pressure		Download time t, s	Quantity of revolutions auger *n*,rpm	Pressure	
		P_{max}, MPa	P_m, MPa			P_{max}, MPa	P_m, MPa
Polyethylene	1.5	125.0	91.2	13.5	25	70.0	47.0
Polystyrene	1.5	130.0	92.1	9.4	17.0	81.0	50.2
Kapron	1.6	120.0	83.0	19.8	35.6	80.5	45.1
Fiberglass	1.8	160.0	84.5	14.4	26.3	66.0	51.3

Table 1 shows that the maximum pressure in the material cylinder occurs in the melt zone at the end of the screw (injection zone) during the injection period during the processing of all the studied materials. The highest pressure occurs during the processing of fiberglass (160MPa). Its value reaches 183 MPa in extreme cases (jamming moment). When processing polyethylene, polystyrene and capron, the maximum value of pressure in this period is within 120-130 MPa. The injection time is the largest when processing fiberglass and is 1.8s, for other materials it is 1.5-1.6 s.

In fig. 3 shows samples of oscillograms of pressure changes during the injection period for various materials, from which it can be seen that in the initial period, the pressure during the processing of all materials is small and amounts to 45-50 MPa, and then reaches a maximum within 0.15-0.2 s. The maximum pressure is maintained for 0.4-0.5 s, after which it gradually decreases to a minimum value of 10-20 MPa, and remains so during the exposure period.

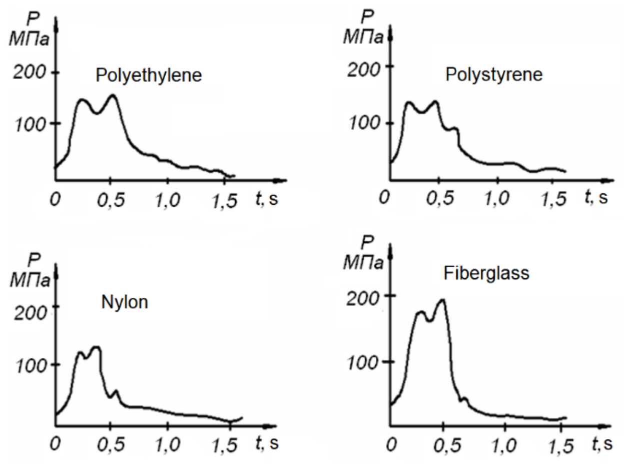
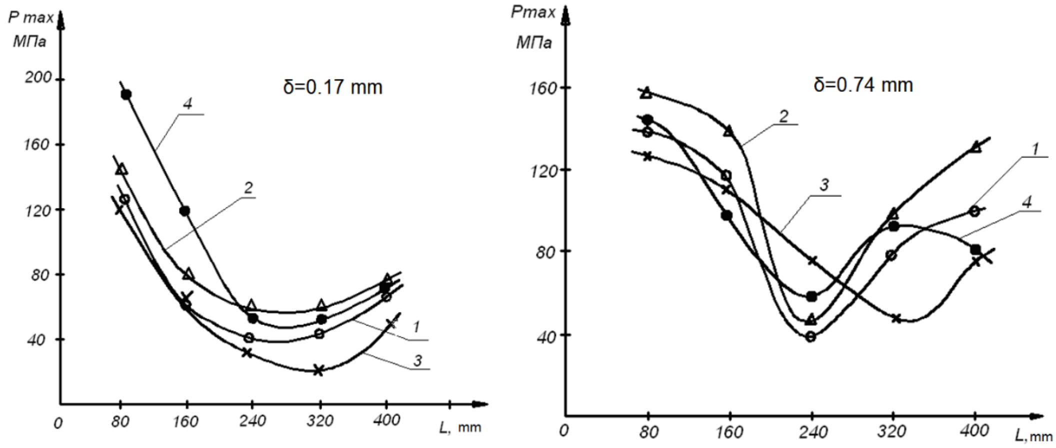


Fig. 3. Pressure oscillograms during the injection period of the D3328 injection molding machine during the processing of various plastics, with a diametral gap between the screw and the cylinder δ=0.17 mm.

During the loading period, the pressure in the loading zone is different for different materials. The maximum value (Table 1) occurs during the processing of kapron and polystyrene (91-92 MPa) in the area where the S5 sensor is located, with a gradual decrease in the direction of the S2 sensor to a value of 40 MPa. At the same time, the average value of the P_m pressure is 47-50 MPa. When processing fiberglass, the pressure difference in the loading zone between sensors S5 and S3 decreases, and the average value of pressure P_m is 51.3 MPa. The maximum time and number of revolutions of the auger during the loading period occurs when processing kapron, which is related to the physical and mechanical properties of this material and their sensitivity to temperature changes.

The nature of the pressure distribution along the length of the material cylinder during the processing of various materials is shown in fig. 4, from which it can be seen that during the injection period, the maximum pressure occurs in the melt zone (S1 sensor) with a subsequent sharp decrease in the middle zone (S3 and S4 sensors) and a slight increase in the S5 sensor zone (loading zone). At the same time, the nature of the pressure change for all materials is similar for the diametrical gap between the screw and the cylinder δ = 0.17 mm (Fig. 4a). With an increase in the gap δ up to 0.74 mm (Fig. 4b), the nature of the pressure distribution in the injection zone changes only during the processing of fiberglass, in particular in the area of effect of the S4 sensor, which is caused by the partial penetration of glass fibers into the gap between the screw and the cylinder.

During the loading period (Fig. 5), the nature of the pressure distribution along the length of the cylinder for all materials is similar to the injection period (Fig. 4a), but with the difference that the absolute value of the pressure in this period is 1.7-2 times smaller.



a *b*

Fig. 4. Distribution of the maximum pressure along the length of the material cylinder during the injection period of the D3328 thermoplastic machine during processing:
1—polyethylene; 2—polystyrene; 3—capron; 4—fiberglass.

The analysis of the time t and the number of revolutions n of the screw during the loading period (Table 1), which are necessary for taking a portion of plastic, shows that the thermoplastic machine has the highest productivity when processing polystyrene, and the lowest - when processing kapron.

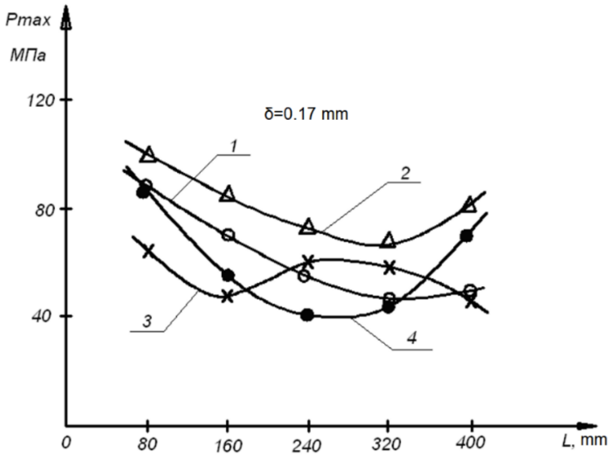


Fig. 5. Distribution of the maximum pressure along the length of the material cylinder during the loading period of the D3328 thermoplastic machine during processing:
1—polyethylene; 2—polystyrene; 3—capron; 4—fiberglass.

This is explained by the physico-mechanical and rheological properties of processed materials, which largely depend on the processing temperature.

Conclusions

The following conclusions can be drawn on the basis of the conducted research:

1. The pressure in the material cylinder of thermoplastic machines is distributed unevenly along its length. Its size and the nature of the distribution along the length for different materials are different and depend on the physical, mechanical and rheological characteristics of these materials, the design of the screw and the technological modes of processing.

2. The maximum pressure occurs in the melt zone during the injection of the material into the mold for 0.4-0.5s, and its value when processing fiberglass reached 183 MPa.

3. Research on the wear of the material cylinder of the DB3328 thermoplastic machine after processing fiberglass showed that there is a complete correlation between the amount of wear and the amount of pressure along the length of the cylinder.

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Гончар В.А. Дослідження зносостійкості матеріального циліндра термопластавтомата при переробці пластмас

В статті приведені експериментальні дослідження тиску в матеріальному циліндрі термопластавтомата Д3328 при переробці різних пластмас, а також експериментальні дослідження зносу по довжині матеріального циліндра термопластавтомата ДБ3328 після переробки склопластику ПС 68-30. Застосовано спеціально розроблені тензометричні датчики тиску. Сигнали від датчиків через підсилювальну апаратуру виводилися на осцилограф і записувалися на осцилограму. Величина та розподіл тиску по довжині матеріального циліндра буде суттєво впливати на величину зносу як шнека, так і циліндра. Встановлено тиск в матеріальному циліндрі термопластавтоматів розподіляється нерівномірно по його довжині. Характер розподілу тиску по довжині матеріального циліндра при переробці різних матеріалів: в період вприску максимальний тиск виникає в зоні розплаву з послідуючим різким зменшенням в середній зоні та незначним збільшенням в зоні завантаження. При цьому характер зміни тиску для всіх матеріалів подібний при діаметральному зазорі між шнеком і циліндром δ=0,17мм. Зі збільшенням зазору δ до 0,74мм характер розподілу тиску в зоні вприску змінюється лише при переробці склопластику, що зумовлено частковим попаданням скловолокон в зазор між шнеком і циліндром. Його величина і характер розподілу по довжині для різних матеріалів різні і залежать від фізико-механічних і реологічних характеристик цих матеріалів, конструкції шнека та технологічних режимів переробки. Максимальний тиск виникає в зоні розплаву в період вприскування матеріалу в пресформу на протязі 0,4-0,5с.

Ключові слова: знос, скловолокно, циліндр, тиск, датчик