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Analysis of Changing Wear Assembly Screw-Engine with the use of Automatic Systems

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Abstract

Waste recycling in Russia merely reaches 5% to 7% versus up to 60% of MSW in the EU, and over 90% of waste in Russia is delivered to waste landfills and unauthorised dumps so that waste accumulation is increasing. This environmental situation is a national priority. The Decree of the President of the Russian Federation dated 5 January 2017 announces 2017 the Year of Ecology in Russia. Most environmental reforms stipulated by amendments to laws are enacted from 1 January 2017. These are primarily measures aimed at emissions and discharges control using best available technologies and breakthrough provisions of the Industrial and Consumer Waste law. The Clean Country, priority project of the Russian Government, will be implemented from 2017 to 2025 with the key aim of reducing the environmental footprint from municipal solid waste disposal and mitigating environmental risks of an accumulated environmental damage. The priority project involves the construction of five environment-friendly facilities for the thermal processing of municipal solid waste (waste incineration plants), four of them to be built in the Moscow Region and one facility to be built in the Republic of Tatarstan. An alternative to waste incineration is municipal waste recycling by moulding in extrusion machines to make pellets to be further used in the fuel or construction industries. The profitability of a waste recycling facility is dependent on a sound choice of extrusion equipment with the best value for money.

Keywords: Automatic systems; Screw-engine

Introduction

An increase in the reliability of extrusion machines used to shred and extrude refractory materials (plastics, hard food waste, and couched paper) is subject to rational use of the extrusion force inside the machine frame. It requires automatic gauges and mechanisms capable of seamlessly increasing or reducing the effort and rotation speed at the right time to preserve the engine life and prevent failures [1-5].

When producing fuel pellets or construction materials from waste, an extrusion machine is exposed to significant loads on its main operating elements such as: inside the frame, on the auger shaft, coupling, connecting auger to the engine shaft, and inside the matrix.

The most common extruder failure in the extrusion process is matrix clogging with a moulded stock (Figure 1), formation of a tight clog impeding auger rotation, loss of efficiency, and engine emergency shutdown. A failure response takes one to two hours to dismantle and clean the auger.

The above loads need to be reduced to not only minimise machine assembly wear but to reduce power consumption, and enhance the reliability of the engine which accounts for 30% of the machine value. Currently, the set-up of a waste recycling facility requires a thorough review of power consumption per 1kg of product. Energy saving on the machine makes extrusion equipment more affordable in regions with high energy cost.

Figure 1: Clogged matrices reduce palletising to 50% matrix holes.

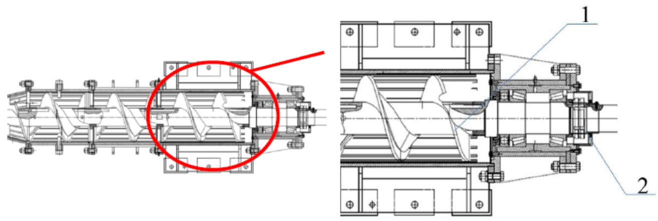

Figure 2: The most common deformed elements of the auger machine when clogged: 1 – weld location of an auger head and shaft, 2 – box coupling on the rotation shaft.

An operating body of the auger machine is an auger rotated by the engine through a box coupling. Clogging increases pressure from a moulded feed both on a welded auger head (Figure 2) and on the box coupling. These are main machine operating elements, and a reduction in their strength will result in the production of defective pellets (less tight and more friable).

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Statistically, without engine emergency shutdown, these elements develop microcracks and are deformed. Twisting deformation can be assessed as twisting of a beam with a non-round cross-section. If we consider an auger to be a circle with a flattened surface, the maximum effort is applied at the middle of the flat cut: τ_{max} = h/2 [6,7], i.e., the maximum effort is in the middle point at the location where the auger diameter changes and the auger has a cone shape (Figure 3).

We will calculate the moment of resistance for the maximum overload force at the shaft when it is clogged and a contingency situation develops [8].

$$W_k = \frac{b^3(2,6\frac{h}{b}-1)}{8(0,3\frac{h}{b}+0,7)} = \frac{113^3(2,6\frac{115}{113}-1)}{8(0,3\frac{115}{113}+0,7)} = 297\text{кН}\cdot\text{м} \quad (1)$$

Therefore, estimates were sufficient to determine the moment of resistance as 238.04 kN/m. When exceeded, the auger would be exposed to microcracks and deformation.

Materials and Methods

The extrusion moulding process was studied using waste from dumps and wastewater treatment facilities, non-marketable TPP products and wood processing waste [9]. Clogging processes were researched using a newly built auger-type machine (MN-3) with heating elements (Figure 4).

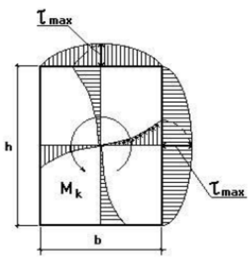

Figure 3: Curve showing shaft moment of resistance with auger narrowing, h=115 mm, b=113.

Figure 4: MN-3 extruder.

Figure 5: Stopper clog removed from the machine when the frame was cleaned.

Figure 6: Uniaxial compressive strength test of the clog.

Test No.	Max. load (N)	Destruction shift (mm)	L, mm	P, kg/m²
Sample 1	3,907.600	2.902	115	56.38050057
Sample 2	4788.900	14.090	125	69.09626859

Table 1: Results of uniaxial compressive strength test of the clog.

The ingredients of the mixture to be palletised with a moisture content of 45% were as follows:

1. 20% of cardboard.
2. 15% of plastic.
3. 40% of coal charge.
4. 10% of sawdust.
5. 15% of waste from the wastewater treatment facilities (sludge).

The feed was loaded into the hopper of MN-3 auger-type machine which started to produce pellets 20 minutes after pre-heating of its heating elements and ramp-up. The process was going for two hours when machine performance began to decrease. The auger rotation speed was increased using a frequency converter, but that raised power consumption by 20%. After three hours of operation, a decision was made to shut the machine down since its performance was minimum with the maximum rotations per minute of the engine.

During the experiment, the frequency converter helped to control engine and, therefore, auger rotation speed. However, speed was adjusted manually by an operator depending on pellet output. Clogging of the auger was not controlled since it was mounted in a metal frame and the process could not be seen. Such actions were random and chaotic. Temperature was not switched off, either, heating bundles were operated in the normal mode so that the edges of the clog in the auger melted and became harder. When the frame was dismantled, the cause of the loss of efficiency could be identified. It was a clog consisting of a compacted waste feed which blocked the auger and resulted in the emergency shutdown (Figure 5).

A decision was made to study the clog at the destructive press:

1) For uniaxial compressive strength test;

2) For split test; and

3) To determine a normal effort at the auger shaft in ParaView software by comparing it to the estimated effort of 238.04 kN and to visually monitor the clogging process.

This data was needed to determine the range of action of a pressure gauge to be later mounted in the extruder frame to alarm of the start of the clogging process. By interacting with the frequency converter, the gauge will prevent emergency shutdown which reverses the engine through a change in poles. A shaker may also be used inside the auger to reduce stock adhesion to the auger and prevent clogging.

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Results

The uniaxial compressive strength test required to split the clog mechanically into two parts to prepare for testing at Testometric 500 press in the Geomechanics and Mining Issues Centre of the Mining University. The diameter and height of produced samples were duly measured (Figure 6).

A cone sample (Sample 1) was compressed at the press first followed by a cylinder sample (Sample 2) (Table 1).

Figure 7 shows graphically how changes in deformation (mm) depend on the load (N). Sample 2 apparently has better performance (by 881.3 N) as compared to Sample 1.

These were followed by the uniaxial compressive strength tests of produced pellets (Figure 8 and Table 2).

Clogging was analysed then in a 3D simulation model of the extrusion machine in ParaView software. The simulation included similar machine parameters with its matrix split using the finite elements method. A type of an approximation function is randomised per element. The simplest case is linear polynomial (Figure 9).

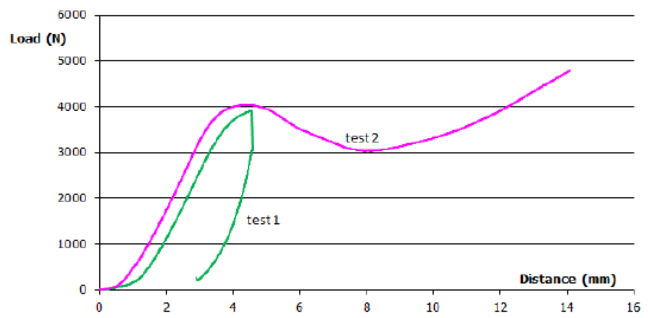

Figure 7: Deformation of Samples 1 and 2 during uniaxial compressive strength test.

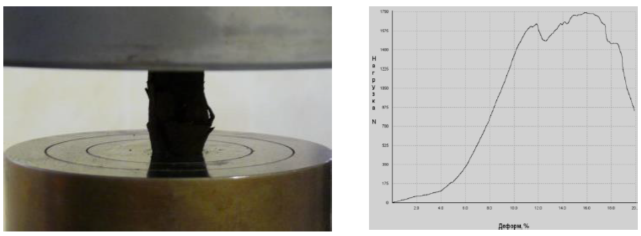

Figure 8: Uniaxial compressive strength test of the pellets.

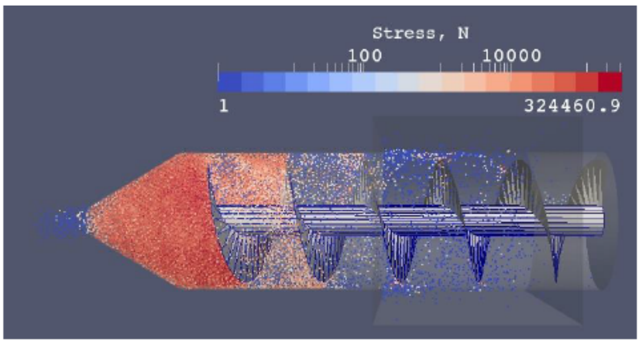

Figure 9: Simulation of the clogging process.

Item No.	D, mm	N, mm	m, g	Max. load (N)
1	33.5	53.5	40.65	1720
2	35.5	51.2	36	1300
3	31.5	38	28	1400

Table 2: Results of uniaxial compressive strength test of the pellets.

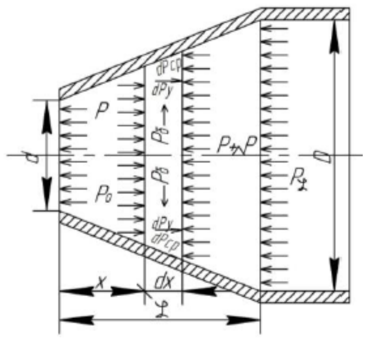

Figure 10: Visual representation of pressure summation inside the matrix.

Discussion

The studies completed revealed several important parameters required to set automatics cut-off values:

1) Moment of resistance of the auger according to Formula 1 is 297 kN/m. When it is exceeded, the auger is subject to microcracks and deformation. When simulated in ParaView software, the moment at the auger shaft during clogging reaches 324.46 kN. In this case we will take the effort range between 297 and 324.460 kN;

2) Uniaxial compressive strength test shows the difference between the cone and cylinder parts of the auger as 3907.6 N and 4788.9 N which demonstrates the difference of 800N and supports I.N. Chisty's theory [10,11] of pressure summation in the middle point of the cone output (P+▲P) after which the clog is hard to destroy (Figure 10).

This experiment enabled to determine the pressure summation point as 115 cm – the length of the cone part of the clog (Table 1). It is the point where a leap certifying to clogging takes place.

Conclusion

The experiments facilitated the collection of information on clog location and hardness in different parts. The studies formed the basis for the upgrade of the existing MN-3 extruder which was re-equipped with pressure gauges 115 cm off the matrix edge and a strain gauge capable of recognising an effort on the auger between 297 kN and 324.5 kN. The main function of the two gauges is to start auger in the reverse for the clog to "roll away' and destroy. The auger was also upgraded with a vibrating element reducing feed stuck to the coils and minimising clog development and matrix clogging.

This area of research will be effective means of creating "transparent" extruder control systems for automatic monitoring of the clogging process and protection against machine breakdown and loss of reliability.

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