doi: 10.18323/2782-4039-2024-4-70-1

Influence of roller characteristics on powder layer applying in additive technologies

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Received 08.05.2024 *Revised 18.09.2024* *Accepted 07.11.2024*

Abstract: In the study and analysis of additive technologies, special attention is paid to increasing the productivity and quality of printed products. However, to improve the 3D printing productivity, it is impossible to increase simply the speed of the squeegee without changing its shape or type. In this case, the quality of the powder layer may suffer, which will lead to a deterioration in the qualities of the final part. To study the effect of roller characteristics on the powder layer deposition, a series of computer simulations of simulation models was carried out. The effect of roller characteristics on the powder layer applying, was assessed, for roller diameters of 30, 50, 70, 100, 150, 200, 250, 300 mm. The simulation was carried out with three application methods: by a rotating and non-rotating roller, as well as by a rotating roller with additional powder feed. It was determined that when applying a layer with a rotating roller with additional powder feed, it is possible to achieve constancy of the forces acting on the roller. This can positively affect the homogeneity of the applied layer. The application of a layer by a rotating roller with additional powder feed is most suitable for 3D printers with a large print area. This method allows avoiding the movement of a large mass of powder over the previous layer, which positively influences the quality of the final part. The study revealed the influence of roller characteristics on the deposition of a powder layer. In particular, with an increase in the roller diameter from 30 to 300 mm, the peak force value also increases. With an increase in the roller diameter by 7.9 %, the powder layer density also increases. It was found that the non-rotating roller is affected by the greatest force, and the forces acting on the rotating rollers differ slightly. A rotating roller, without adding powder, creates the densest layer and allows achieving a powder layer compaction of 5.35 %.

Keywords: roller characteristics; powder layer; additive technologies; additive manufacturing; roller diameter; powder layer levelling; powder layer applying; powder layer density; squeegee.

For citation: Bogdanov V.M. Influence of roller characteristics on powder layer applying in additive technologies. *Frontier Materials & Technologies*, 2024, no. 4, pp. 9–18. DOI: 10.18323/2782-4039-2024-4-70-1.

INTRODUCTION

Additive technologies are advanced technologies at the current stage of mechanical engineering development. They allow creating complex products that are impractical or impossible to produce using traditional methods. In the study and analysis of additive technologies, special attention is paid to increasing the productivity and quality of printed products. Increasing requirements for the accuracy of a part leads to an increase in the time for its creation. The time of creating a part, consists of the time of applying the powder layer, and the time of its fusion. Powder deposition is a fundamental aspect of additive manufacturing, and requires great research efforts to improve the reliability and repeatability of the process, and consequently, the quality of printed components.

The main device for applying and levelling the powder layer in additive installations is a squeegee. Currently, two squeegee designs are used, most often as a levelling device: in the form of a plate (blade) and in the form of a rotating roller. Roller application mechanisms are used when applying finely dispersed, or highly cohesive powders, to ensure the desired technological characteristics and/or properties of components. The blade-type squeegee has a simpler design and can be used to apply powders with high flowability, that do not require large applied forces to overcome interparticle adhesion.

To increase productivity, it is impossible to increase simply the squeegee speed without changing its shape or type. This may affect the quality of the powder layer, which will lead to a deterioration in the quality of the final part [1]. Therefore, the main trend in the field of powder applying and levelling, is to study possible squeegee designs to find a design with the highest deposition rate without losing the quality of the layer.

Research shows that a high powder layer density is required to produce a high-quality layer, and a metal powder with the smallest average particle size should be used [2]. To improve the powder layer density, the author proposed technologies for powder layer compaction [3; 4], vibration application [5; 6], and repeated passing by rotating rollers [7; 8]. The geometry and speed of the levelling device have the greatest influence on the powder packing density [9; 10]. The following squeegee profiles were considered – a square with a chamfer, a rotating and fixed roller [9], a parallelogram, a triangle and a square [10]. Research shows that by optimising the squeegee geometry, it is possible to achieve higher packing density values, and lower roughness of the applied powder layer [10; 11].

The author considered 48 models with different parameters of the squeegee edge profile [11]. As a result, the optimum values for these parameters were determined. When comparing the optimised profile with the roller, it was noted that the squeegee with the optimised profile created a slightly lower powder layer density (0.4 %) at the lowest speed (0.03 m/s). However, it turned out to be much less sensitive to increasing the squeegee speed, so that when the speed was increased to 0.06 m/s, the powder layer density was 2 % higher for the squeegee with the optimised profile. This is a significant advantage and means that the speed can be increased (which means higher productivity) while maintaining quality. When comparing the roughness of the powder layer surface, it was found that the new squeegee profile is superior to the roller at all tested speeds, and has an average of 15 % lower roughness values [11].

A distinctive feature of the considered studies [3–11] is that the powder layer is applied to a smooth, hard surface. The literature does not consider the case of applying a new layer to the previous powder layer, and no studies have been found on the effect of the rotating roller diameter on the applied layer. The force acting on the roller from the powder side, and the distribution of this force over the surface, as well as the dependence of the compressive force and powder density on the roller diameter and on this application method are of interest.

The purpose of the work is to identify the optimal method for applying a powder layer, by studying the influence of the rotating roller diameter on the quality of the applied layer using simulation modelling.

METHODS

Simulation model creation

The simulation of the process of powder material applying and levelling was carried out using the Altair EDEM 2021 software package. This is software for modelling bulk and granular materials. EDEM software package is based on the discrete element method (DEM) and is applicable to modelling and analysing the behaviour of coal, mined ores, soils, fibres, grains, tablets, powders, etc.

Most additive technologies included in the PBF (Powder Bed Fusion) group have a similar process of powder layer applying. Fig. 1 shows the basic diagram of the process.

The cycle of building each layer begins with raising the feeder platform and lowering the build platform by the layer thickness. Then, the squeegee moves along the platforms, simultaneously applying and levelling the powder material. Since only one powder layer will be applied during the process simulation, a feeding hopper is not required. To simplify the simulation model, the preparation stage is limited to creating the previous powder layer and powder for applying a new layer.

The created simulation model consists of two sections (Fig. 2). The first section is a hard surface simulating a feeder with metal powder, which will need to be applied as a new layer using a squeegee. The second section is a hard surface simulating a build platform lowered to the height of the layer being applied. This section contains an imitation of the finished applied layer.

Metal powder applying to the finished layer imitation is performed in three ways: 1) by a non-rotating roller; 2) by a rotating roller; 3) by a rotating roller with additional powder feed (Fig. 3).

Identification and selection of modelling parameters

First, it is necessary to select the application speed V_{ROL} and the roller rotation speed V_{ROT}. The application speed affects the powder layer roughness [12] (Fig. 4), which is one of the characteristics of the powder layer quality. Based on Fig. 4, we assume that the permissible roughnessof the applied layer surface is δ=7.5 μm. To obtain the powder layer surface of the required quality, the roller

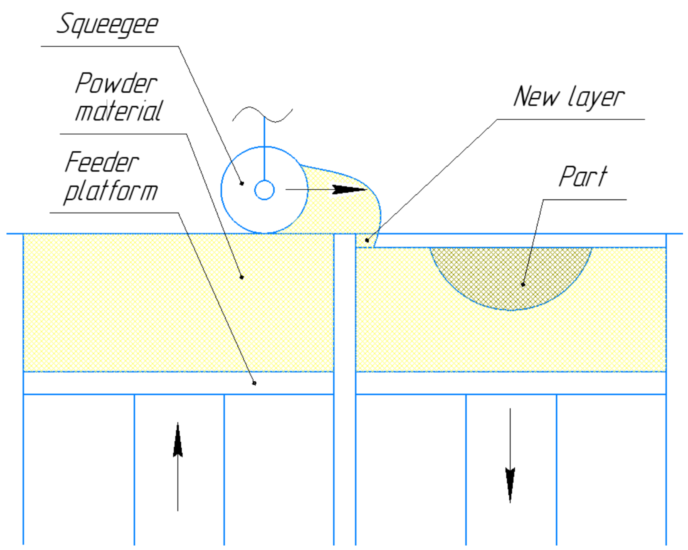

Fig. 1. *Basic diagram of the process of applying a powder layer*
Рис. 1. *Принципиальная схема процесса нанесения порошкового слоя*

linear speed V_{ROL} must not exceed 60 mm/s. In studies, the application speed was most often chosen equal to V_{ROL}=50 mm/s [10; 13; 14], which meets our requirements. The rotation speed V_{ROT} was chosen equal to 60 rpm assuming that the roller rotation speed has little effect on the powder layer density, however, at high speeds, powder particles begin to be thrown above the surface, which can lead to the previous layer damage [15].

To identify the optimal method for applying a powder layer, studies were conducted on a simulation model with different roller diameters: a non-rotating roller Ø50 mm, a rotating roller Ø30, 50, 70 mm, a rotating roller with the addition of powder Ø30, 50, 70, 100, 150, 200, 250, 300 mm.

The diameter of the powder particles used in 3D printing varies from 20 to 100 µm. However, the available

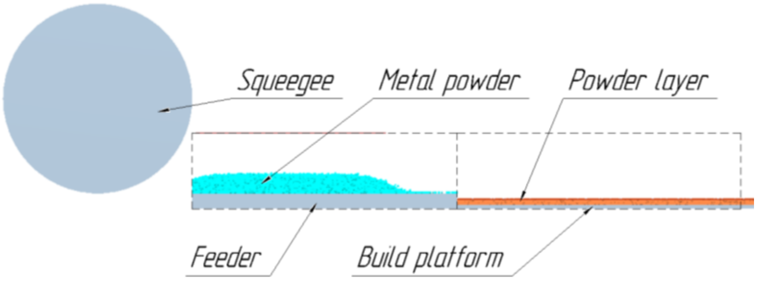

Fig. 2. *Simulation model*
Рис. 2. *Имитационная модель*

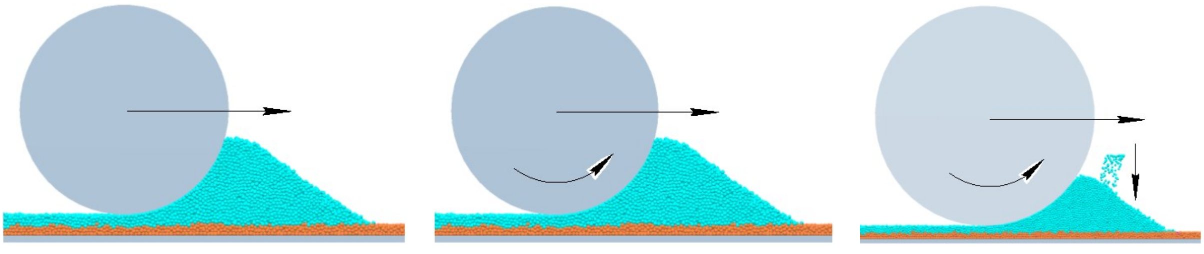

Fig. 3. *Ways of applying a powder layer:*
a *– a non-rotating roller;* ***b*** *– a rotating roller;* ***c*** *– a rotating roller with additional powder feed*
Рис. 3. *Способы нанесения порошкового слоя:*
a *– невращающийся ролик;* ***b*** *– вращающийся ролик;* ***c*** *– вращающийся ролик с подачей дополнительного порошка*

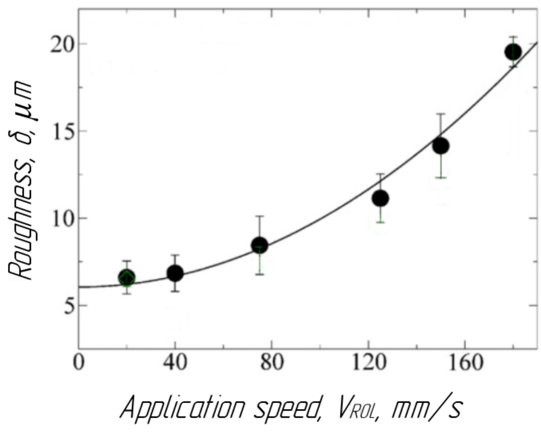

Fig. 4. *Dependence of layer roughness on application speed*
Рис. 4. *Зависимость шероховатости слоя от скорости нанесения*

computer processing power will not be enough to simulate particles of such a small size in a short time, because when the particle diameter decreases, it is also necessary to decrease the time step, and therefore, the calculations will be more time-consuming. DSL 05 365 GOST 11964-81 shot was chosen as the powder material.

For the study, the powder granulometric composition having a normal distribution with a mean value of m=0.5 mm and a standard deviation of σ=0.05 was chosen, because wider ranges of particle sizes lead to greater fluctuations in density and surface roughness due to the uneven distribution of particles [16].

The computer for the simulation has an Intel Core i3-6100 3.70 GHz processor, 8 GB of RAM, and an NVIDIA GeForce GTX 1050 Ti video card.

Processing the simulation results

To measure the force acting on the roller, the entire study area was divided into layers. The height of each layer is equal to the diameter of the particles (0.5 mm). Data on the force acting on the roller from the powder along the X and Z axes were obtained from each separately selected area (Fig. 5).

In the analysis, we will assume that the force is applied to the roller at the centre of the selected layer. After calculating the force, it is necessary to plot the force distribution over the roller surface. To do this, we will analytically calculate the dependence of the angle α on the layer height. The calculation scheme is shown in Fig. 6.

Calculation of the dependence of the angle α on the layer height:

$$\cos\alpha = \frac{R-t}{R} \rightarrow \alpha = \arccos\left(1-\frac{t}{R}\right).$$

Now, we can associate the obtained force values with the angle α, and apply them to the roller. As a result, you will get a graph of the force distribution over the roller.

RESULTS

From the graphs of the total force acting on a non-rotating roller with a diameter of 50 mm, depending on the pressure angle, one can see that the force acting on the roller becomes smaller over time (Fig. 7). This is

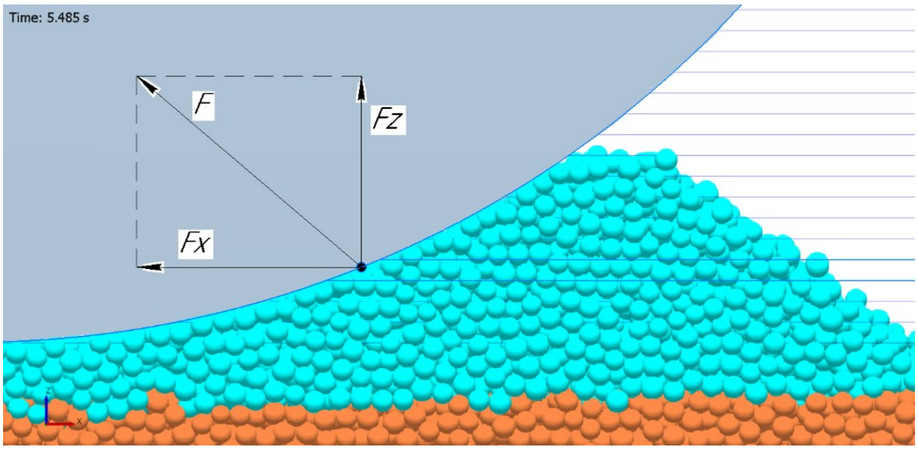

Fig. 5. *Calculation of the total force of powder pressure on the roller in each layer*
Рис. 5. *Расчет общей силы давления порошка на ролик в каждом слое*

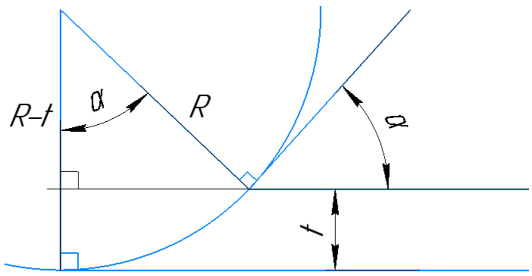

Fig. 6. *Scheme for calculating the pressure angle α.*
R – roller radius; t – layer height; α – pressure angle
Рис. 6. *Схема для расчета угла давления α.*
R – радиус ролика; t – высота слоя; α – угол давления

explained by the fact that the amount of powder applied by the roller decreases over time.

One of the most important parameters of the powder layer is its density. The maximum value of the powder layer density during application reached 4.573 g/cm^3, which corresponds to a layer compaction of 1.61 %. According to GOST 11964-81, the bulk density of steel powder should be greater than 4.2 g/cm^3, with a particle diameter of 0.5 mm and a density of the particles themselves of more than 7.2 g/cm^3. The result obtained satisfies this condition, which indicates the proximity of the characteristics of the simulated and real powders.

From the graphs of the total force acting on a rotating roller with diameters of 30, 50 and 70 mm, depending on the pressure angle, it is evident that with an increase in the roller diameter, the peak force value also increases (Fig. 8). This can increase roller wear and reduce its service life. For a better understanding of the meaning of this graph (Fig. 8), the curves were applied to the roller, which allowed obtaining a visual representation of the force distribution over the roller (Fig. 9). Analysing the maximum density values for the studied roller diameters, one can notice a clear dependence manifested in an increase in density, with an increase in the roller diameter (Table 1).

From the graphs of the total force acting on a rotating roller with additional powder feed, depending on the pressure angle, it is evident that with an increase in the roller diameter from 30 to 300 mm, the peak force value increases, and the pressure angle decreases (Fig. 10). From Table 2 it is evident that as the roller diameter increases, the powder layer density also increases, and after overcoming the roller diameter of *D*=200 mm, it reaches a plateau and stops growing significantly.

DISCUSSION

The EDEM software package has proven itself as a promising tool for predicting the behaviour of bulk media [17]. The results of computer modelling using the discrete element method, qualitatively correspond to the data obtained in experiments [18]. Based on this, the obtained modelling results can be considered to correspond to reality.

To identify the best application method, the graphs of the total force acting on a roller with a diameter of *D*=50 mm, depending on the pressure angle for each application method were compared (Fig. 11). As a result, it can be concluded that the non-rotating roller is affected by the greatest force, and the forces acting on rotating rollers differ slightly. When comparing the maximum density values for the studied application methods, it can be concluded that a denser powder layer can be achieved when using a rotating roller without adding powder (Table 3).

Based on the analysis of a series of computer simulations of powder layer application, it was found that the total force acting on the rollers, without additional powder supply, becomes smaller over time. This is explained by the fact that the amount of powder applied by the roller decreases over time. This application method is suitable for 3D printers with a small printing zone. As the printing zone increases, the amount of powder that needs to be applied also increases. This poses two problems. First, the powder bed height with a large printing zone may exceed the roller diameter, making it impossible to form a layer. Second, moving a large mass of powder over the previously applied layer may damage it, and adversely affect the quality of the final part.

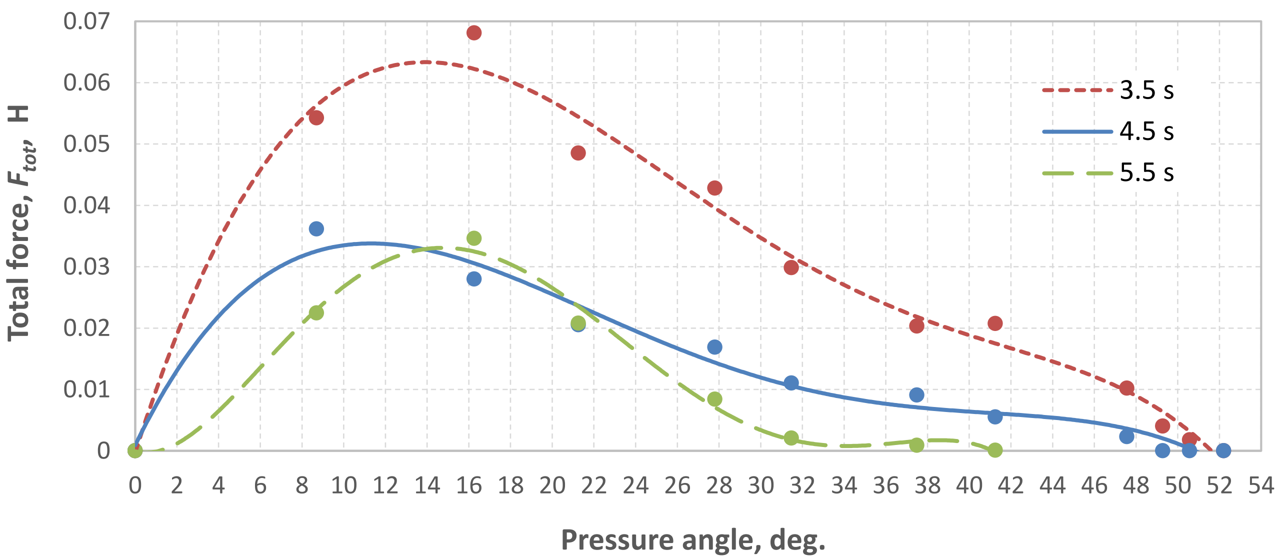

Fig. 7. *Dependence of the total force acting on a non-rotating roller with a diameter of 50 mm on the pressure angle. Three time points of the steady-state application mode are given: start – 3.5 s, centre – 4.5 s, end – 5.5 s*

Рис. 7. *Зависимость общей силы, действующей на невращающийся ролик диаметром 50 мм, от угла давления. Приведены три временные точки установившегося режима нанесения: начало – 3,5 с, центр – 4,5 с, конец – 5,5 с*

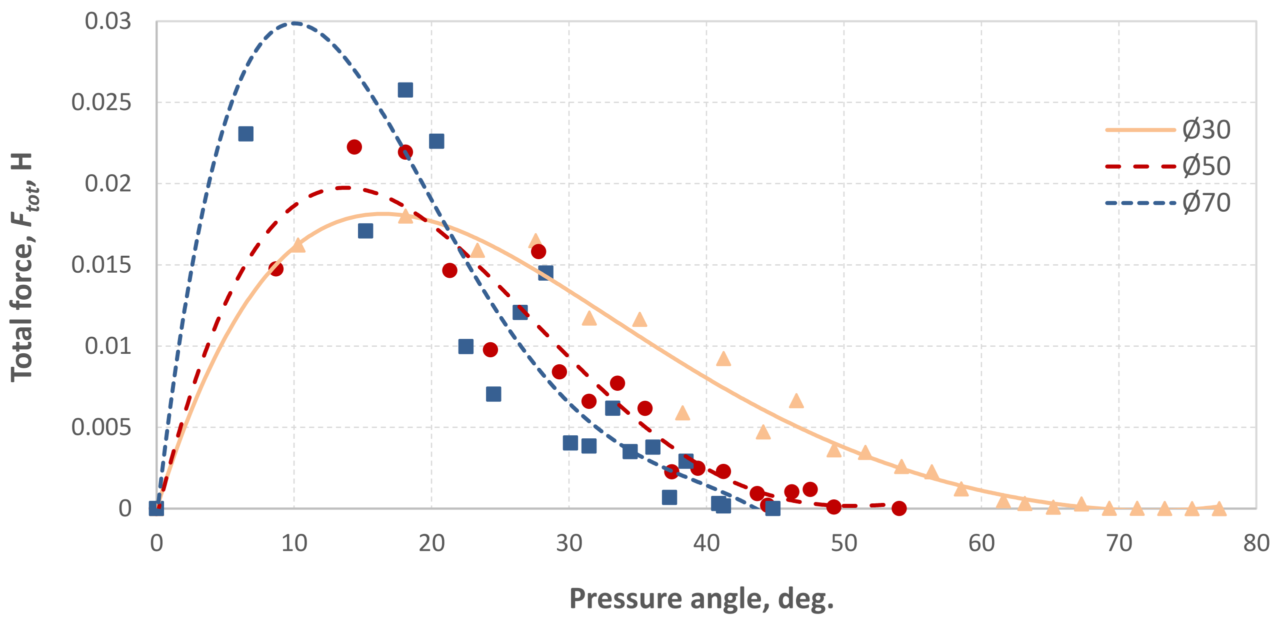

Fig. 8. *Dependence of the total force acting on a rotating roller on the pressure angle.*
Graphs are given for three roller diameters: 30, 50, 70 mm
Рис. 8. *Зависимость общей силы, действующей на вращающийся ролик, от угла давления.*
Приведены графики для трех диаметров ролика: 30, 50, 70 мм

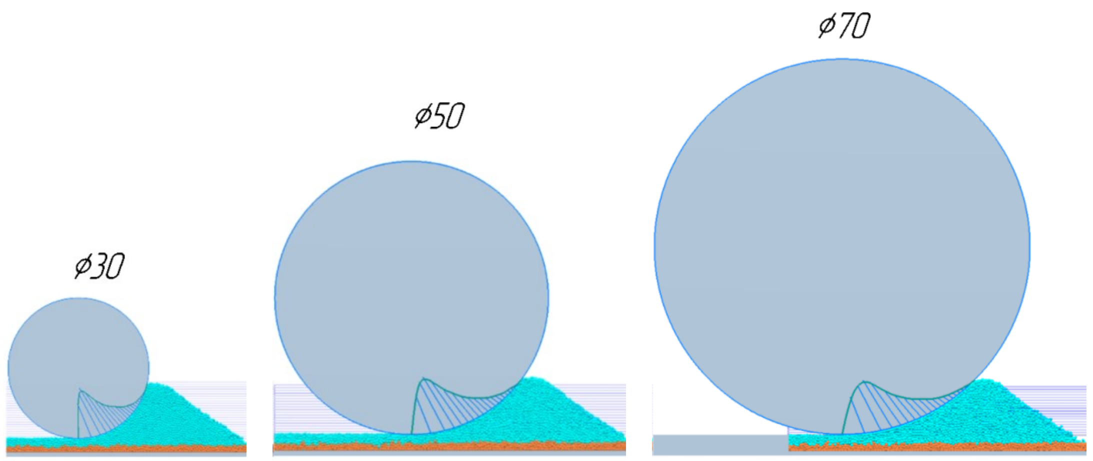

Fig. 9. *Force distribution over the rollers with the diameters of 30, 50, 70 mm*
Рис. 9. *Распределение силы по роликам с диаметрами 30, 50, 70 мм*

Table 1. *Powder layer density and compaction for rotating rollers*
Таблица 1. *Плотность и уплотнение порошкового слоя для вращающихся роликов*

Roller diameter, mm	Layer density, g/cm^3	Layer compaction, %
Before application	4.500	–
30	4.692	4.26
50	4.740	5.35
70	4.796	6.59

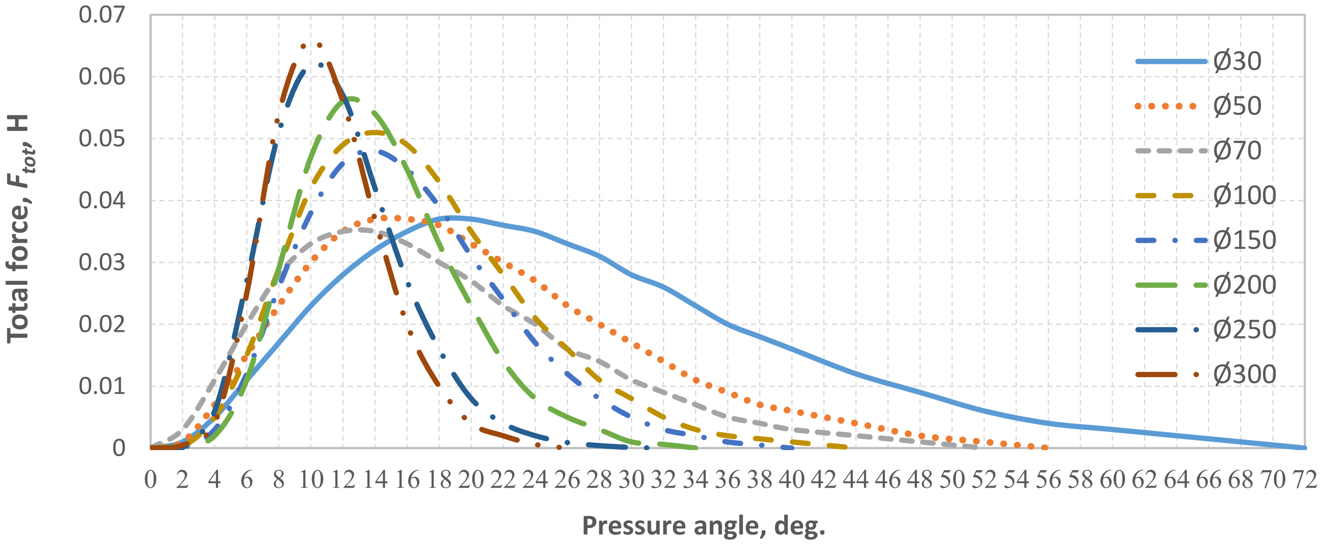

Fig. 10. *Dependence of the total force acting on a rotating roller with additional powder feed on the pressure angle. Graphs are given for eight roller diameters: 30, 50, 70, 100, 150, 200, 250, 300 mm*

Рис. 10. *Зависимость общей силы, действующей на вращающийся ролик с дополнительной подачей порошка, от угла давления. Приведены графики для восьми диаметров ролика: 30, 50, 70, 100, 150, 200, 250, 300 мм*

Table 2. *Powder layer density and compaction for rotating rollers with additional powder feed*

Таблица 2. *Плотность и уплотнение порошкового слоя для вращающихся роликов с дополнительной подачей порошка*

Roller diameter, mm	Layer density, g/cm^3	Layer compaction, %
Before application	4.500	–
30	4.675	3.89
50	4.679	3.98
70	4.682	4.04
100	4.800	6.66
150	4.810	6.89
200	4.854	7.87
250	4.849	7.75
300	4.855	7.90

When applying a layer with a rotating roller with an additional powder feed, it is possible to achieve a constant force acting on the roller, since there is the same amount of powder in front of the roller during application. This can have a positive effect on the homogeneity of the applied layer.

It has been found that when the roller diameter increases from 30 to 300 mm, the peak force value also increases. This can increase roller wear and reduce its service life. With an increase in the roller diameter, the powder layer density also increases by 7.9 % and after overcoming the roller diameter of D=200 mm, the powder layer density reaches a plateau and stops growing significantly.

Summarising the data, we can conclude that the non-rotating roller is affected by the greatest force, and the forces acting on the rotating rollers, differ slightly. It was also found that a rotating roller without adding powder, creates the densest layer and allows achieving compaction of the powder layer by 5.35 %. The obtained data contradict the study, which revealed that a non-rotating roller creates a 5 % denser layer than a rotating roller [9]. This discrepancy can be explained by a significant

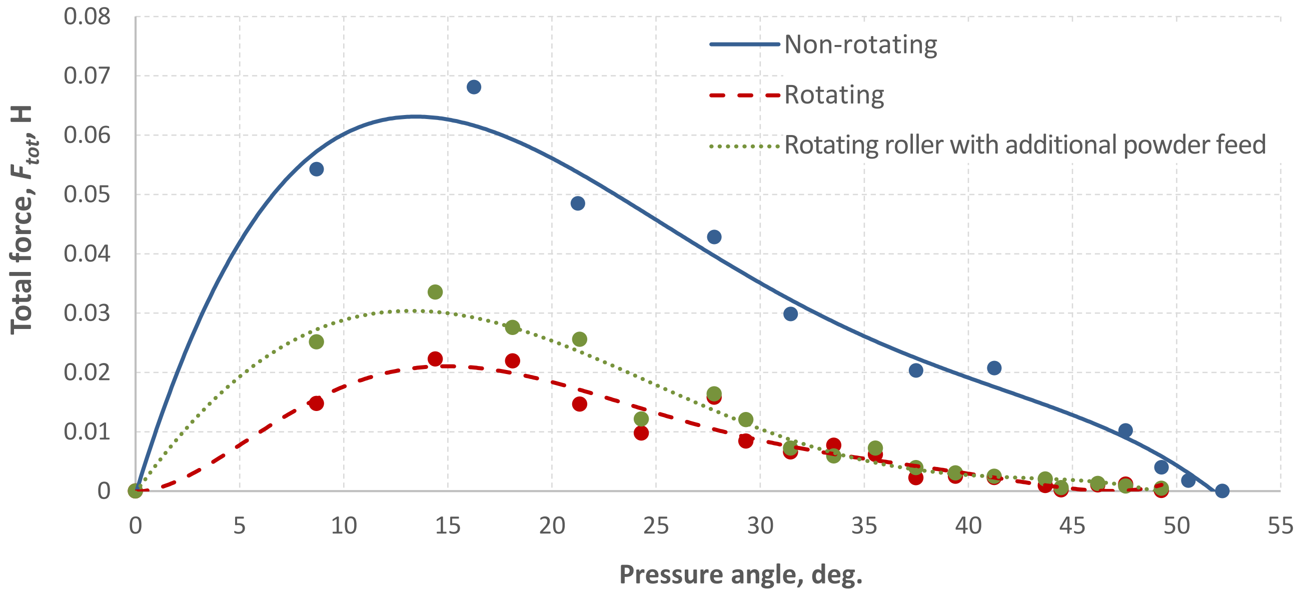

Fig. 11. *Dependence of the total force acting on a non-rotating roller and a rotating roller with additional powder feed on the pressure angle. Graphs are given for the roller with a diameter of 50 mm*
Рис. 11. *Зависимость общей силы, действующей на невращающийся ролик, вращающийся ролик и вращающийся ролик с дополнительной подачей порошка, от угла давления. Приведены графики для ролика диаметром 50 мм*

Table 3. *Powder layer density and compaction for various methods of application*
Таблица 3. *Плотность и уплотнение порошкового слоя для различных способов нанесения*

Method of application	Roller diameter, mm	Layer density, g/cm³	Layer compaction, %
Before application	–	4.500	–
Non-rotating roller	50	4.573	1.61
Rotating roller		4.740	5.35
Rotating roller with additional powder feed		4.679	3.98

difference in the powder layer application speed (0.5 and 50 mm/s). When analysing the effect of application speed on powder layer density, it was found that with an increase in application speed, the powder layer density tends to decrease linearly [9].

In a study on optimising squeegee geometry, when comparing an optimised profile with a roller, it was noted that the squeegee with an optimised profile created a slightly higher powder bed density (0.7 %) at an application speed of 50 mm/s [11].

The study was the first to examine the influence of roller diameter on powder bed density. The data obtained indicate that the correct choice of application method can significantly affect the quality of printed products.

CONCLUSIONS

1. The dependences of the roller characteristics on powder layer application were revealed. In particular, with an increase in the roller diameter from 30 to 300 mm, the peak force value also increases. With an increase in the roller diameter by 7.9 %, the powder layer density also increases, and after overcoming the roller diameter of D=200 mm, it reaches a plateau and stops growing significantly.

2. When studying the application methods, it was found that the non-rotating roller is affected by the greatest force, and the forces acting on the rotating rollers differ slightly. A rotating roller without adding powder creates the densest layer, and allows achieving compaction of the powder layer by 5.35 %.

3. When optimising powder layer application for 3D printers with a large printing area, it is recommended to select layer application using a roller with additional powder feed, since this helps to avoid moving a large mass of powder over the previously applied layer, which has a positive effect on the quality of the final product. This can also have a positive effect on the homogeneity of the applied layer.

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Влияние характеристик ролика на нанесение порошкового слоя в аддитивных технологиях

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Поступила в редакцию 08.05.2024 *Пересмотрена 18.09.2024* *Принята к публикации 07.11.2024*

Аннотация: При исследовании и анализе аддитивных технологий особое внимание уделяется повышению производительности и качества напечатанных изделий. Однако для повышения производительности 3D-печати нельзя просто увеличить скорость перемещения ракеля без изменения его формы или типа. Из-за этого может пострадать качество порошкового слоя, что приведет к ухудшению качеств конечной детали. Для исследования влияния характеристик ролика на нанесение порошкового слоя проведена серия компьютерных моделирований имитационных моделей. Оценка влияния характеристик ролика на нанесение порошкового слоя проводилась для диаметров ролика 30, 50, 70, 100, 150, 200, 250, 300 мм. Моделирование проводилось с тремя способами нанесения: вращающимся и невращающимся роликом, а также вращающимся роликом с подачей дополнительного порошка. Определено, что при нанесении слоя вращающимся роликом с дополнительной подачей порошка можно достичь постоянства сил, действующих на ролик. Это может положительно повлиять на однородность наносимого слоя. Нанесение слоя вращающимся роликом с дополнительной подачей порошка наиболее пригодно в 3D-принтерах с большой зоной построения. Данный способ позволяет избегать перемещения большой массы порошка по предыдущему слою, что положительно влияет на качество конечной детали. Выявлено влияние характеристик ролика на нанесение порошкового слоя. В частности, при увеличении диаметра ролика с 30 до 300 мм увеличивается и значение пиковой силы. При увеличении диаметра ролика на 7,9 % увеличивается и плотность порошкового слоя. Выявлено, что на невращающийся ролик действует наибольшая сила, а силы, действующие на вращающиеся ролики, незначительно отличаются. Вращающийся ролик без добавления порошка создает наиболее плотный слой и позволяет добиться уплотнения порошкового слоя на 5,35 %.

Ключевые слова: характеристики ролика; порошковый слой; аддитивные технологии; аддитивное производство; диаметр ролика; разравнивание порошкового слоя; нанесение порошкового слоя; плотность порошкового слоя; ракель.

Для цитирования: Богданов В.М. Влияние характеристик ролика на нанесение порошкового слоя в аддитивных технологиях // Frontier Materials & Technologies. 2024. № 4. С. 9–18. DOI: 10.18323/2782-4039-2024-4-70-1.