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Denis Chemezov
Vladimir Industrial College
M.Sc.Eng., Corresponding Member of International Academy of Theoretical and Applied Sciences, Lecturer,
Russian Federation
https://orcid.org/0000-0002-2747-552X
chemezov-da@yandex.ru

Danila Zubatov
Vladimir Industrial College
Student, Russian Federation

Evgeniy Vakhromeev
Vladimir Industrial College
Student, Russian Federation

Valeriy Shchetnikov
Vladimir Industrial College
Master of Industrial Training, Russian Federation

Vladimir Goremykin
Vladimir Industrial College
Master of Industrial Training, Russian Federation

Alexey Kuznetsov
Vladimir Industrial College
Student, Russian Federation

Daniil Zavrazhnov
Vladimir Industrial College
Student, Russian Federation

SURFACES QUALITY OF PLASTIC GEARS MADE BY 3D PRINTING

***Abstract**: Description of the experiment for manufacturing of plastic gears by 3D printing was given in the article. Comparison of surfaces quality of the plastic gears when changing of the print speed, the layer height and other 3D printing parameters was performed.*

***Key words**: a 3D printer, quality, 3D printing, a gear, temperature.*

***Language**: English*

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Introduction

Development of the engineering industry has led to creation of 3D printers. A part of any configuration can be gradually manufactured without using of special devices on the 3D printer. This is especially true in the conditions of the experimental production. The materials range for 3D printing varies from gypsum to metal powders. Dimensions of the 3D printer table and ability of the parts manufacturing only from one type of materials on the specific model of the 3D printer are limitations for 3D printing.

Plastic is one of main materials for 3D printing. The various machine parts are made of plastic in mechanical engineering, including the gears for slow speed transmissions. Precision casting and machining (effective in the mass production) are the other methods of the gears manufacturing. The fitment bore and the tooth profile are the most accurate elements of the gear. Let us consider the contact surfaces quality of the gears after 3D printing.

Materials and methods

Comparison of the surfaces quality of the plastic gears made on the 3D printer in the conditions of changing of the printing modes was carried out.

Manufacturing of the parts was carried out on the 3D printer WANHAO Duplicator i3 v. 2.1. The general views of the 3D printer and the control box are presented in the Fig. 1. The technical specifications of the 3D printer are presented in the table 1.

A *B*

Figure 1 – The views of the 3D printer (*A*) and the control box (*B*).

Table 1. The technical specifications of the 3D printer.

Printing	
Print technology	Fused filament fabrication (FFF)
Build volume	200×200×180 mm
Layer resolution	0.1 – 0.4 mm
Positioning accuracy	X 0.012 mm
	Y 0.012 mm
	Z 0.004 mm
Extruder quantity	Single extruder
Nozzle diameter	0.4 mm
Print speed	10 mm/s – 70 mm/s
Travel speed	10 mm/s – 70 mm/s
Supported print materials	WANHAO branded PLA, ABS, PVA, HIPS, wood, flex, conductive
Temperature	
Ambient operating temperature	15°C – 30°C
Operational extruder temperature	170°C – 240°C
Operational print bed temperature	30°C – 70°C
Software	
Slicer software	Cura WANHAO edition 15.04
Cura input formats	.STL, .OBJ, .DAE, .AMF

Cura output format	.GCODE
Connectivity	Micro SD card, USB port (expert users only)
Electrical	
Input rating	100-240 V AC, 50/60 Hz, 3.5 A
Physical dimensions	
Printer frame dimensions	400×410×400 mm
Weight	10 kg

On the first stage, the three-dimensional solid model of the part "Gear" was built. The finished model of the gear was imported into the Cura special computer program for 3D printing (the Fig. 2). The printing modes of the part were set (the table 2) and created the control program (the table 3) in the Cura. The gear model had the following dimensions: the number of the teeth – 17 pieces, circumference of the teeth tops – 33.6 mm, circumference of the teeth cavities – 27.3 mm, the diameter of the fitment bore – 15.5 mm, the width of the groove – 5 mm, the depth of the groove – 2.3 mm, the gear width – 15 mm.

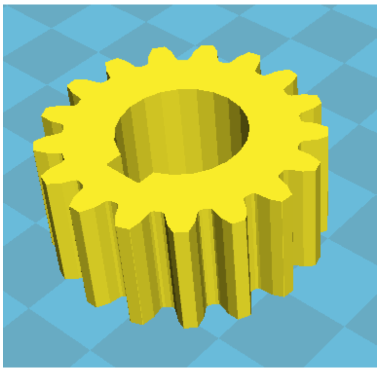

Figure 2 – The imported gear model into the Cura program.

The parts were made of polylactide (PLA). PLA has the following properties: the melting point – 173…178°C, the softening temperature – 50°C, the Rockwell hardness – 70…90, tensile strain – 3.8%, bending strength – 55.3 MPa, tensile strength – 57.8 MPa, the modulus of elongation – 3.3 GPa, the Young's modulus in bend – 2.3 GPa, the glass-transition temperature – 60…65°C, density – 1.23…1.25 g/cm³, printing accuracy – ±0.1%, shrinkage when the part manufacturing – no, moisture absorption – 0.5…50%.

The parts manufacturing was carried out on two modes. Manufacturing time of the part was 62 minutes, the required wire length was 1.99 m, and the part weight was 6 g on the first mode. Manufacturing time of the part was 170 minutes, the required wire length was 1.74 m, and the part weight was 5 g on the second mode.

Table 2. The modes of 3D printing.

Parameter	**1 mode**	**2 mode**
Quality		
Layer height, mm	0.2	0.1
Shell thickness, mm	0.8	
Enable retraction	yes	
Fill		
Bottom/top thickness, mm	0.6	
Fill density, %	20	
Speed and temperature		
Print speed, mm/s	60	30
Printing temperature, °C	210	

Bed temperature, °C	50	
Support		
Support type	Touching build plate	
Platform adhesion type	Raft	No
Filament		
Diameter, mm	1.75	
Flow, %	100.0	
Machine		
Nozzle size, mm	0.4	
Retraction		
Speed, mm/s	40.0	
Distance, mm	4.5	
Quality		
Initial layer thickness, mm	0.2	
Initial layer line width, %	100	
Cut off object bottom, mm	0.0	
Dual extrusion overlap, mm	0.15	
Speed		
Travel speed, mm/s	80.0	40.0
Bottom layer speed, mm/s	8	
Infill speed, mm/s	50	25
Top/bottom speed, mm/s	15	7.5
Outer shell speed, mm/s	15	7.5
Inner shell speed, mm/s	30	15
Cool		
Minimal layer time, s	5	
Enable cooling fan	yes	

Layer height.

The thickness of the each printed layer is known as the layer height. The smaller layer height, the smoother curves will appear. The larger layer heights are better for bridging and overhangs. The smaller layer heights will also increase print time, as it will take the more layers to complete an object.

Shell thickness.

This defines the number of vertical walls that comprise the outside of this model. The WANHAO 3D printer is equipped with the 0.4 mm nozzle.

Enable retraction.

Retraction tells this printer to pull filament out of the extruder upon travel moves. Travel moves are when this print head moves from one area of print, to another without laying down filament.

Bottom/top thickness.

Also known as the surface layers; this will determine how thick the top and bottom layers are. The larger number here will create a thicker top and bottom, which can be helpful for strength, bridging, and quality purposes. Eg: If using the layer height of 0.2 mm, set the thickness to 0.4, 0.6 or 0.8 mm.

Fill density.

This number is expressed as percentage. 0% will give completely hollow print, while 100% will give the completely solid object.

Print speed.

This overall printing speed can be adjusted here. If no the other speeds determined in the later sections this printer will automatically default to this speed. This speed will be different.

Printing bed temperature.

Any temperatures specified here will be used to automatically set both the extruder and the heated print bed. This print will not begin until these temperatures are met.

Support type.

The some models will require the support material in order to print properly. This will usually occur when the object has the angle in relation to the heated print bed between 0 to 45 degrees. It is highly recommended to orient the object so that it minimizes or eliminates a need for the support.

Touching build plate. This causes support material to build up between the heated print bed and the object.

Everywhere. This prints support material between the heated print bed and the object as well as between the object and itself.

Platform adhesion type.

The some models have the small surface area contacting the plate. This can create adhesion issues causing this part to pop off at the some point during print. To fix this, use either «Brim» or «Raft». The raft is better used when the model has the small contact points with the heated print bed and overhangs.

Diameter.

The filament diameter setting is one of the more important settings. While this filament may be referred to as 1.75 mm, it is more likely going to be near 1.7 mm +/- 0.1 mm.

Flow.

This controls how much filament this printer is extruding in relation to the speed. This setting is mainly used to adjust for filament density variations. Leave this value at 100% as changing it can lead to the surface quality issues.

Nozzle size.

This defines the nozzle size. The slicing engine uses this value combined with the other settings to determine how quickly to feed filament into this extruder. The WANHAO 3D printer uses the 0.4 mm nozzle.

Speed.

The retraction speed determines the speed at which this filament is reversed out of the extruder for travel moves and when changing direction during printing.

Distance.

Retraction distance determines how much filament is pulled out of this extruder on travel moves and when changing direction. Higher thermal retaining filaments such as PLA behave better with longer retraction distance. Anywhere from 1 mm to 3 mm is the good starting range.

Initial layer thickness.

This will control how thick this first printed layer height is printed onto the heated print bed. Having the larger initial layer height will help prevent this part from popping of the plate. The WANHAO 3D printer auto leveling system could be affected.

Initial layer line width.

This will control how wide this first extruded filament path is for the initial layer. The wider line width will help with the bed adhesion. For the models with moving printed in the place parts, the smaller initial layer line width is recommended.

Dual extrusion overlap.

This will determine how far these dual extruders will overlap when laying down material. This will help adhesion between two different colours or the types of filament. This setting is not applicable to the WANHAO 3D printer; it is only for the printers with the dual extruders.

Travel speed.

This setting will determine how fast this print head moves while not extruding filament. The normal travel speed of 125 – 150 mm/s is recommended.

Bottom layer speed.

This will control of the initial layer speed. In general, the slower initial layer speed will help with the first layer adhesion.

Infill speed.

This is how fast this print head speed will be while laying down the interior portion of this model. The faster speeds are usually tolerable here, as none of infill will be visible from the outside of this object.

Outer shell speed.

This will be the outermost surface of the model. This is the most important setting, as it controls the speed of this print head on the visible layers.

Inner shell speed.

This affects vertical walls that are in between the outer shell and infill. This will not be visible but will help support the outer shell and infill.

Minimal layer time.

This will determine a minimum amount of time this printer will spend laying down the each layer. If this layer print time falls below this printer will automatically slow down to reach this time before moving onto the next layer. Tweaking this can help get cleaner, crisper prints.

Enable cooling fan.

The enables operation of this extruder is active cooling fan.

Table 3. The fragment of the control program for printing of the gear on the 3D printer.

```
M190 S50.000000
M109 S210.000000
;Sliced at: Wed 02-10-2019 09:14:34
;Basic settings: Layer height: 0.2 Walls: 0.8 Fill: 20
;Print time: 1 hour 6 minutes
;Filament used: 2.293m 6.0g
;Filament cost: None
;M190 S50 ;Uncomment to add your own bed temperature line
;M109 S210 ;Uncomment to add your own temperature line
```

```
G21 ;metric values
G90 ;absolute positioning
M82 ;set extruder to absolute mode
M107 ;start with the fan off
G28 X0 Y0 ;move X/Y to min endstops
G28 Z0 ;move Z to min endstops
G1 Z15.0 F4800 ;move the platform down 15mm
G92 E0 ;zero the extruded length
G1 F140 E30 ;extrude 3mm of feed stock
G1 X20 Y0 F140 E30
G92 E0 ;zero the extruded length again
G1 F4800
;Put printing message on LCD screen
M117 Printing...
;Layer count: 75
;LAYER:-2
;RAFT
G0 F4800 X84.009 Y85.080 Z0.400
;TYPE:SUPPORT
G1 F480 X85.835 Y84.272 E0.49810
G1 X86.528 Y82.628 E0.94314
G1 X89.065 Y81.057 E1.68751
G1 X90.177 Y80.315 E2.02098
G1 X92.433 Y80.214 E2.58431
G1 X93.788 Y78.909 E3.05359
G1 X96.688 Y78.367 E3.78952
………………………………..
G0 F4800 X111.471 Y90.257
G1 F900 X112.587 Y91.374 E2293.71445
G0 F4800 X112.779 Y91.001
G1 F900 X111.868 Y90.089 E2293.75732
G0 F4800 X112.349 Y90.004
G1 F900 X112.972 Y90.627 E2293.78663
M107
G1 F2400 E2289.28663
G0 F4800 X112.972 Y90.627 Z20.000
;End GCode
M104 S0 ;extruder heater off
M140 S0 ;heated bed heater off (if you have it)
G91 ;relative positioning
G1 E-1 F300 ;retract the filament a bit before lifting the nozzle, to release some of the pressure
G1 Z+5 E-5 X-20 Y-20 F4800 ;move Z up a bit and retract filament even more
G28 X0 Y0
G90
M84 ;steppers off
G90 ;absolute positioning
```

Results and discussion

The 3D printing processes of the gears on the first and second modes are presented in the Fig. 3. Filling of the parts was carried out in the form of stiffeners distributed in the grid variant on all volume. This filling of the gear volume will be sufficient when small loads. Accuracy of 3D printing was ensured by the careful setting of the gap of 0.1 mm between the table surface and the nozzle of the 3D printer extruder.

The manufactured surfaces of the plastic gears are presented in the Fig. 4. The manufactured gear on the first mode is noted by the rough flat surfaces. The some volumes of plastic extending beyond the contour of the part are observed after separation of the raft from the surface of the gear. The layers of plastic in some places were not applied on the contour of the part. The gear teeth have the correct shape (according to the model), but the surfaces roughness is high. The manufactured gear on the second mode is noted by the denser flat surfaces. The surfaces are smooth, without plastic residues. The gear teeth have the correct shape, the surfaces roughness is low. The fitment bores of the gears have the imperfect circle shape, lobing is observed.

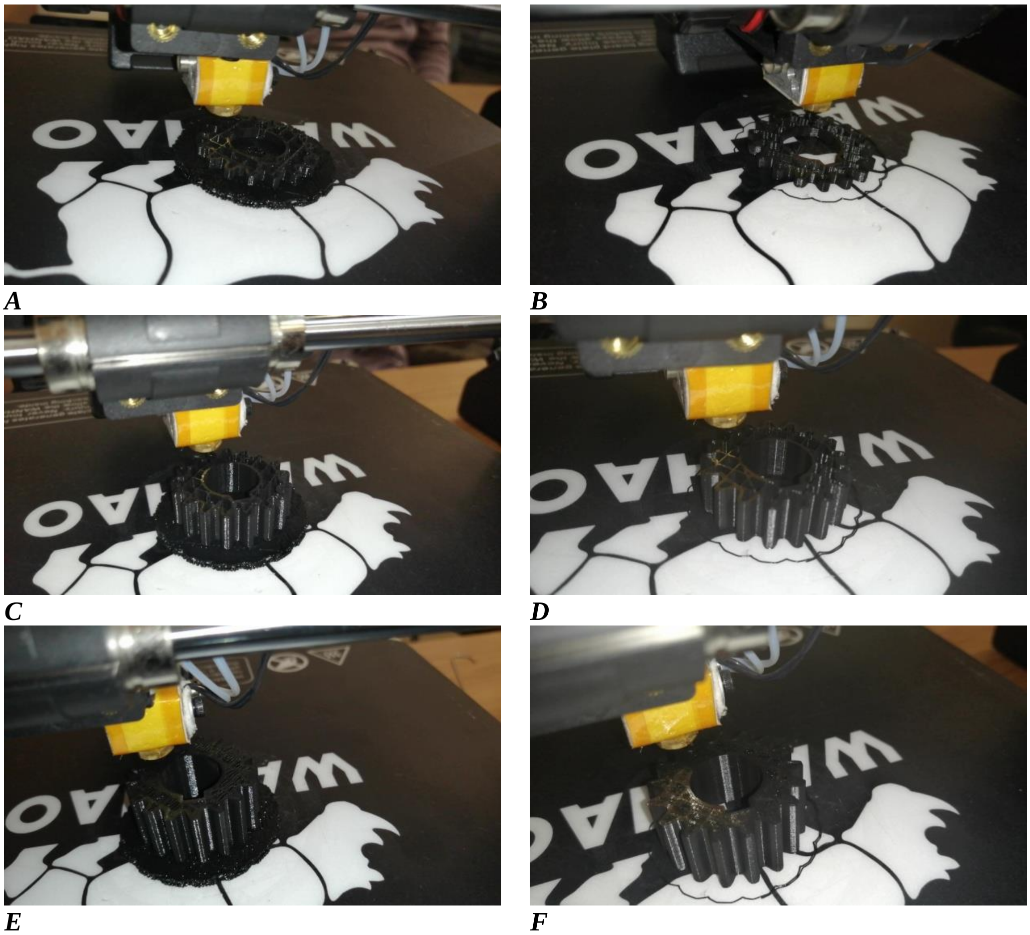

Figure 3 – 3D printing of the gears: *A* and *B* – 20% on the first and second modes, respectively; *C* and *D* – 65% on the first and second modes, respectively; *E* and *F* – 96% on the first and second modes, respectively.

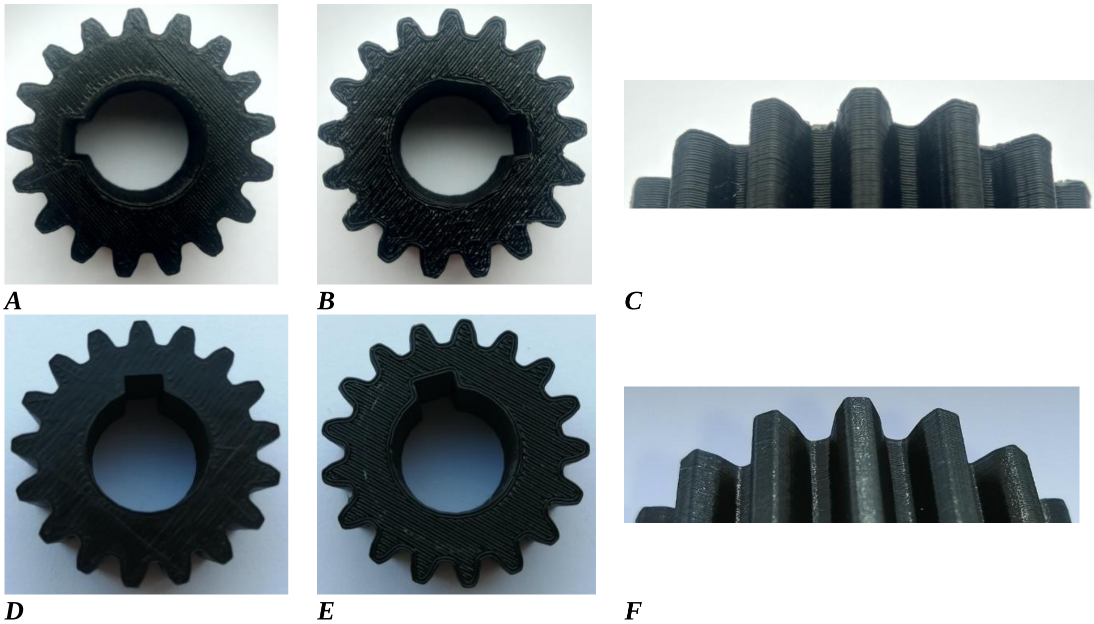

Figure 4 – The surfaces quality of the gears after 3D printing: *A*, *B* and *C* – the top, the bottom and the teeth when manufacturing on the first mode, respectively; *D*, *E* and *F* – the top, the bottom and the teeth when manufacturing on the second mode, respectively.

Conclusion

The low speed of 3D printing contributes to the denser surface of the part. The surfaces quality of the gears along the *Z* coordinate axis is higher than along the *X* and *Y* coordinate axes. The computer model must be built in the special programs with high accuracy of drawing of the geometric shapes for elimination of lobing of the fitment bores of the gears. For comparison, this model of the gear was built in the KOMPAS-3D software environment.

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