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.

![Figure 1 – The views of the 3D printer (A) and the control box (B).](image)

**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 |
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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.](image)

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    |        |
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### Support

| Support | 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 other speeds are 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.

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**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 | |
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**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.
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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.
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**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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