WELDING METHODS OF FILAMENTS USED IN FFF/FDM 3D PRINTING TECHNOLOGY

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The paper discusses methods of welding or joining of two separate filaments for FFF/FDM Technology of 3D printing. Article also concerns advantages and disadvantages of mentioned methods. Various materials used in this printing technology are described, their welding capability and physical properties such as working temperatures and their suitability. The article describes various devices and prototypes used in solving the above mentioned problems. The aim of the article is to point out the efficiency and ecological recycling of filament shavings for non-degradable materials used in 3D printing, such as Acrylonitrile butadiene styrene (ABS).

KEYWORDS

3D printing, filament, ABS, PLA, FDM, FFF

1 INTRODUCTION

Nowadays is 3D printing a common part of production. To a certain extent, it also affects almost all branches of industry. As 3D printers are very widespread, there are few devices that allow them to use the filament efficiently. In many cases, filament residues are discarded due to printing inefficiencies. It is better to use a new disc as the last meter of filament on the used one. It also produces cutoffs of small dimensions which can be further recyclable [Cehelský 2017].

The work aims to evaluate this issue and implement them in the design of solutions for joining these cuttings and the remaining parts, in order to reuse them. It helps both financially and ecologically, which is one of the world's major topics [5]. The work can be used to further address this issue.

The most used material for filament is ABS (acrylonitilbutadiene styrene). It is a low-cost thermoplastic that has been used since the early days of 3D printing and its popularity has not declined to this day due to its low cost and good mechanical properties. It is highly resistant to mechanical damage and is resistant to acids. Its disadvantage is its nature to reduce its volume during cooling and problems may already occur during printing. This is eliminated by the heating pad under the product being printed.

The full name acrylonitrile butadiene styrene, is an amorphous thermoplastic formed by the polymerization of styrene and acrylonitrile in the presence of polybutadene. The ratio of substances may vary depending on the copolymer manufacturer [Dyadyura 2016, Panda 2017, Duplakova 2018, Jurko 2012, 2016, Monkova 2013, Gombar 2013, Mrkvica 2012, Leššo 2010, 2014, Balara 2018, Krehel 2013, Krenicky 2012, Olejárová 2016, Panda 2011, 2016, 2018, Prislupcak 2014, 2016, Ragan 2012, Valíček 2016]. The composition approximates 15 to 30% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadene that is crossed with poly (styrene-acrylonitrile) chains. These adjacent chains forming nitrile groups attract each other, are polar and bind common chains. This implies that ABS is stronger than pure polystyrene. Polybutadene is a rubber material that assists in the toughness of the material. It maintains this toughness even at lower temperatures. The styrene of the material provides an impermeable and glossy surface. ABS is used in practice in the range of -20 ° C to 80 ° C. The mechanical properties of the material vary with changing temperature. Properties are produced by curing, fine particles of elastomer are scattered in the matrix. The melting point is about 105 ° C, but since it is amorphous and different companies vary the exact composition, its actual melting point is also different. However, it is processed at temperatures around 210 ° C-250 ° C [Cehelský 2017].

ABS polymers are resistant to mineral oils, animal oils, vegetable oils, acids and bases, concentrated phosphoric and hydrochloric acids, and alcohols. They react with aromatic hydrocarbons, acetic acid and carbon tetrachloride. Concentrated sulfuric acid and nitric acid are aggressive for ABS. Soluble in esters, ketones and ethylene dichloride.

ABS is flammable when exposed to high temperatures. After thawing, it starts to boil and the vapors will burst into intense flames. Pure ABS does not contain any halogens, its ignition does not normally produce any organic pollutants. The most toxic substances that the polymer produces are carbon monoxide and hydrogen cyanide [Cehelský 2017].

Abs is a recyclable material, but is not accepted by all recycling companies.

Another commonly used filament is PLA. Polylactic acid is a very widespread thermoplastic material. It is the base material for most home printers because it does not require a heated printer pad and is processed at a lower temperature of around 180-220 ° C. PLA is ideal for beginners due to its low price, easy printing requirements and good final quality. A minor drawback is the lower temperature at which the PLA begins to melt, already around 60 ° C. The clear benefit is the impact on the environment [Rimar 2016, Vojtko 2014, Zaborowski 2007, Straka 2013, 2014, Markulik 2016, Michalik 2014, Janekova 2014, Sebo 2012, Bielousová 2017, Panda 2012, 2013, Dobránsky 2019, Pandová 2012, Mačala 2012, Pollák 2018]. PLA is a bio-material made from corn starch, so it degrades in nature by nature, yet it has properties similar to petroleum plastic. The bonus is a sweet aroma during the printing process [Rogers 2015, Cehelský 2017].

2 WELDING DESIGNS

These semi-automatic and manual solutions are similar to each other due to filament supply and withdrawal, but the principle is different. Each of these solutions has its strengths and weaknesses depending on the problem being solved and the desired result of the user. In principle, they are all applicable. The structures are designed in the PTC CREO parametric system [Cehelský 2017].

2.1 1ST DESIGN

The idea of designing this embodiment is based on the principle of hot pressing. Unlike conventional press machines that do not directly heat the material, the press parts are equipped with heating cartridges. Another idea that has been implemented is the mobility and practicality of the device. Instead of complex, impractical packaging and bases, the design is designed to be easy to operate and hold in one hand [Cehelský 2017].

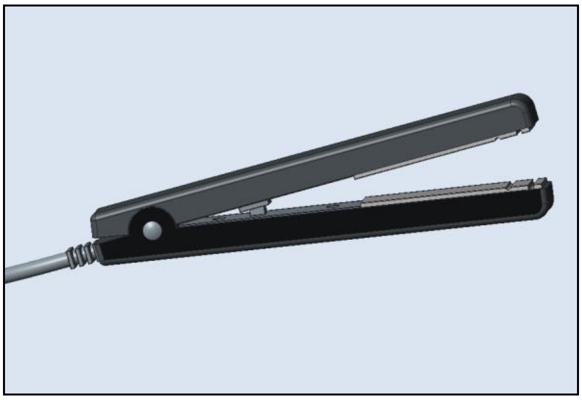

Figure 1. Desine of press clamps

PARTS OF DESIGN

The design consists of two profiles clamped together at one point. At opposite ends, there are heater cartridges positioned in profiles with good thermal conductivity such as aluminum. The profiles are fitted in the end section. The surfaces of these profiles should be tangent to each other as possible. Accurate seating is important because of the precision of the molded portion of the filaments. On these profiles there is a filament pressing groove [Cehelský 2017].

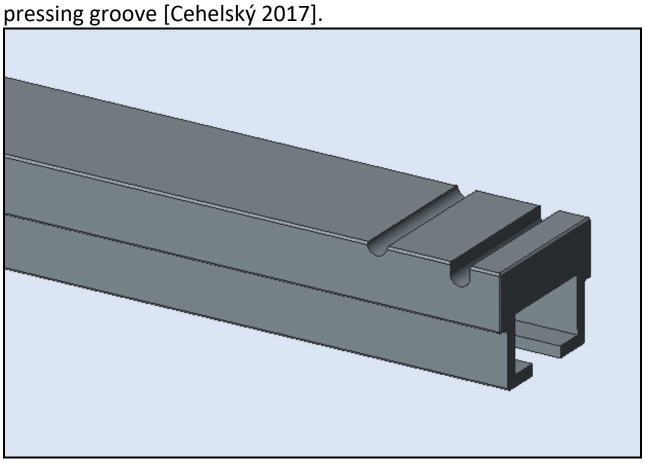

Figure 2. Front detail of profile

When designing the groove, it is important to pay attention to the accuracy of the position with the groove on the profile from other side of device. Inaccuracies can cause the material to melt outside the grooves, resulting in an inaccurate joint that requires subsequent adjustments. Another important factor is the radius of curvature of the groove. This should be slightly smaller than the radius of the filament. The material prints, is better bonded and has no problem passing through the printer extruder. If a groove of a larger diameter is used, the same errors can occur as if the groove is inaccurate. Clumsy alloys are formed which require further treatment.
At the end of the profile there is a second groove with a deeper slot, but the diameter of the bottom radius is the same as the shallower groove. This cut-out serves for manual work with both pieces of processed material or for fine-tuning of roundness of the filament. This option is optimal and does not affect the functionality of the design.
The other side of the profile is intended to fit the heater cartridge. There are different cartridges of different cross-sections and diameters. The illustration shows a standard 6mm diameter circular insert used in most FFF 3D printers.
These cartridges are affordable, simple, and there are a huge variety of variations to meet the exact needs of users. The most commonly used are 12/24 V 50W. There are also cartridges that can be connected directly to the socket after simple diode control, thus solving problems with electronics and powering of more sensitive parts. The profiles are seated in the end parts of the design. This cover and at the same time functional part has a cavity for accommodating the conductors, switch, diode as well as the profiles mentioned [Cehelský 2017].
When choosing the packaging material, it is necessary count with increased temperatures at the end parts. For some materials, however, the loss of strength and elasticity properties due to the exposure to a constant high temperature is reflected in time. Which can result in inaccurate pressing, inefficient results, difficulty in use or even injury. Therefore, many materials used in conventional 3D printing are out of the question because their temperature at which they lose their functional properties is lower than that at which they are normally melted onto models [Cehelský 2017].

WELDING METHOD

The principle of filament welding consists in placing two cuttings together and then pressing them together with the proposed product. It is important to ensure the cleanliness of the materials and remove impurities that may degrade this process.
For a better effect, it is advisable to align the individual ends with a trimmer, as fibers are formed at the ends of the excess pieces of filament, which can also degrade this process. Also, there is no complete contact of the connected parts.

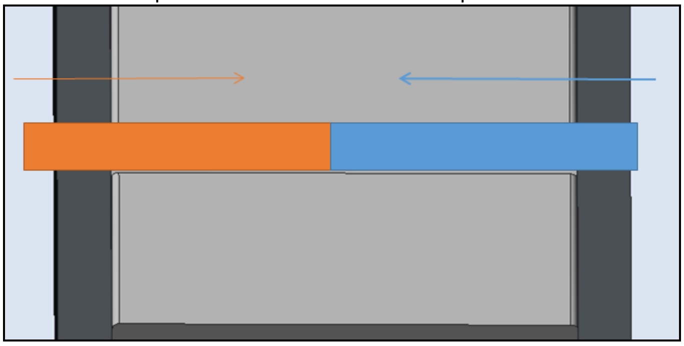

Figure 3. Joint of filament with perpendicular cut

However, oblique filament cutting is more ideal. Melting and pressing of the material takes place not only next to each other but also above each other. This helps to better mix and join the cuttings. It also helps in joining different filaments. However, it is not recommended to combine filaments of different brands and not at all of different types of composition.

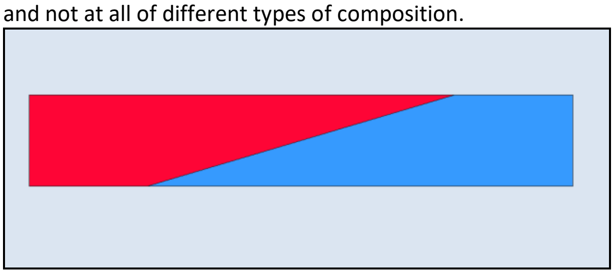

Figure 4. Join of filament with oblique cut

It is good to hold the filaments in the clamps or otherwise prevent them from moving. If the filament is glued to the heating press surfaces, a simple baking paper can be used to prevent the material from sticking [Cehelský 2017].

2.2 2ND DESIGN

This design is more like a station with general filament joining options. The difference with the first proposal is mainly in its mobility. This variant is stable and is intended to be firmly attached to the workbench. Another difference is the possibility of immediate cooling of the bonded filament which the first variant did not have in its design [Cehelský 2017].

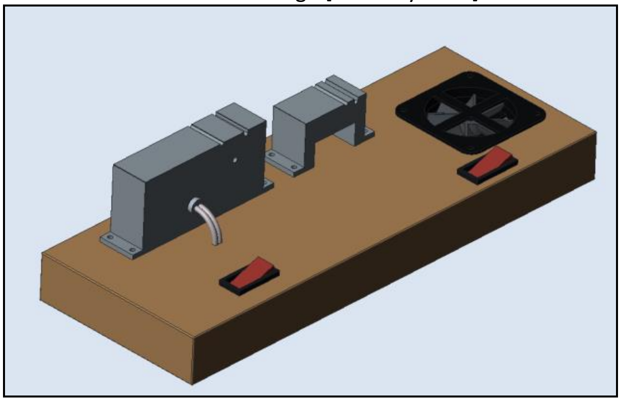

Figure 5. Design of welding station

DESIGN PARTS

The proposal consists of a base with all the electronics and parts placed on it. The main parts of this design are two blocks and a cooling fan. Each of these parts has a role, the last two in principle in function. The device comprises two similar blocks on which a transverse groove is situated similar to the previous design. These blocks are made of well thermally conductive materials. The first block serves to heat the material. Its construction is in principle simple. It contains an opening for a heater cartridge and an opening for a thermistor for possible automation of the block temperature. The temperature is controlled by a two-state switch. For optimization, the circuit-breaker can be replaced by a possible potentiometer for self-regulation of the temperature, or a combination of a potentiometer and feedback from a thermistor can be maintained to maintain a constant required temperature.
The second block, the so-called cold block, on the other hand, does not heat up from the first block. It maintains the ambient temperature and is mainly used to form the heated filament into a cylindrical form. However, its construction is a little different than the first block. Includes a cutout at the bottom for better heat dissipation. At the top there are grooves for forming. When looking at their detail, it can be seen that the cross-section narrows at the second groove. However, the lower radius of curvature of the groove is as large as the groove with a shallower cutout. This is only for easier handling and entry into the groove [Cehelský 2017].

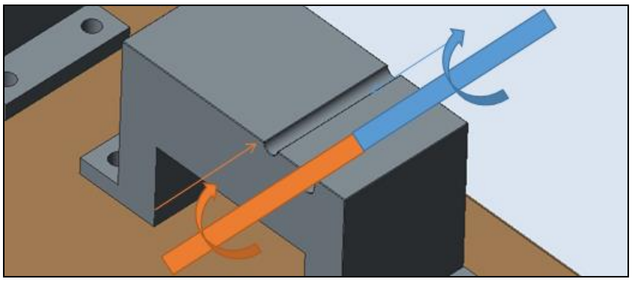

Figure 6. Forming of joint

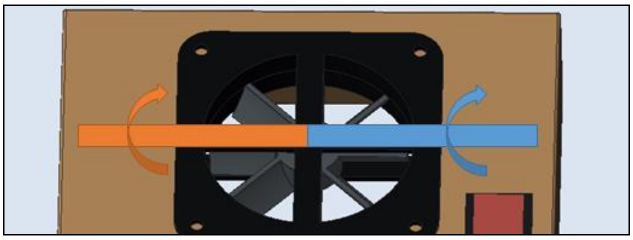

Figure 7. Cooling of joint

The last part is the fan. This component has the sole purpose of free cooling of the formed joined filament. The trigger is controlled by the respondent switch [Cehelský 2017].

WELDING METHOD

The joining methods can be different. Many things remain common to the first model, such as the cleanliness of the environment, the cleanliness of the filament or the cut hairpins after the previous print. What makes them different is that design number 2 does not have a pressing capacity. On the other hand, he has a cooling that he can make up for in certain cases [Cehelský 2017].
An interesting method of melting and joining the filaments is to pre-heat the filaments by the sides of the first heating block. Since in this method we have a cut in each hand, we can gently melt them by simply placing on the sides.
The partially melted filament is then formed in a cooling block. For this, it is good to use a deeper groove where, after applying to the bottom, the filaments are pushed together, or rotated to obtain the required shape.
We will use a fan for complete cooling and curing. If inaccuracies are found, we can return to the groove in the first heating block and fine-tune the join.

2.3 3RD DESIGN

This design is already a semi-automatic solution. The basis is a melting block into which filament enters from one side and exits from the other. One part of the filament is set in the melting part so that the other part being pressed will push out the first and thus form a joint. This filament is pushed by a nema 17 stepper motor, which are commonly used in simple or home-made 3D printers.

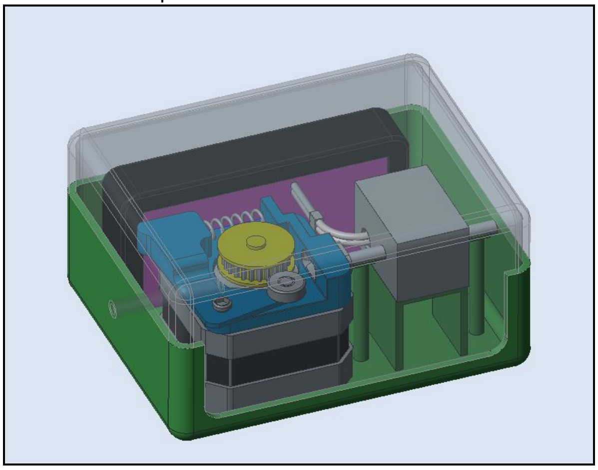

Figure 8. Design of motorized station

DESIGN PARTS

The base part is a block of well-conductive material with a drilled part for filament passage. Outside this part, there are holes on the block for heating components and a thermistor for heat regulation. This component already requires heat control as the entire through filament is melted. The principle is similar to the 3D printing head where the filament is melted to a smaller required diameter.

In this case, however, the hole diameter is only slightly narrower. The normal thickness of ABS filament is 1.75mm, this diameter is 1.6mm. This is also because the resulting filament is not much thinner or deformed. Open this thickness only in a certain part in which it joins the other material. Later, the diameter increases. It is important to consider a non-stick layer or materials [Cehelský 2017].

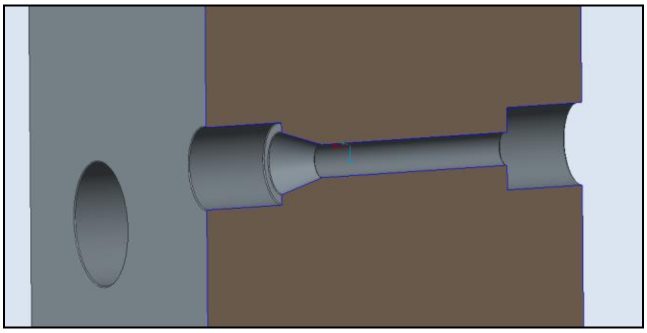

Figure 9. Cross-section of melting block

The smooth process is ensured by guide tubes inserted into the diameters at both ends of the melting block. They ensure a stable supply of filament during its entire path from the outer opening of the housing of the entire device, through the drive of the stepper motor, by the melting component to the outside of the whole device. These pipes are selected from heat-resistant material. It is important that they do not change their properties and dimensions and that they do not heat the filament. This can bend it and subsequently clog the melting hole and subsequently degrade the whole process and the part itself.

The drive of the whole device is a stepper motor Nema 17. These motors are commonly used in home-made and simple 3D printers. These motors are mainly used because of their socket which is compatible with a number of other components and devices. They have the possibility of various variations and are a valuable contribution to many prototypes and projects. Plus is their simplicity and reliability. They are available in various online stores or sites dealing with things from the Asian market and their price is also not high. An important part of the engine is the pressure part. Together with the engine and the pan, it forms an extruder. In this case, instead of the nozzle, we have a melting block. This design theoretically consists of a modified extruder for 3D printing. This pressure component facilitates the smooth progress of the filament by means of the motor. There is a gear wheel on the motor, on which this component pushes through the inserted filament and together they ensure movement [Cehelský 2017].

storage the entire system is an important factor in any more complex system. Whether for safety or to prevent unwanted external factors and impurities. case should be helpful to the system, resistant to temperature changes and resistant to higher temperatures. With such a system, it is best if the entire structure dissipates undesirable heat.

WELDING METHOD

the filament is fed to the inlet where it is taken over by the gear of the stepper motor. This is further guided into the canal and thus to the melting block. Here it meets the second filament cut, joins and pushes the whole part out through the guide canal.

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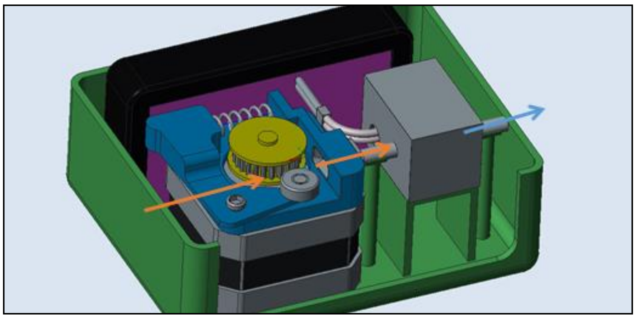

Figure 10. Way of filament motion

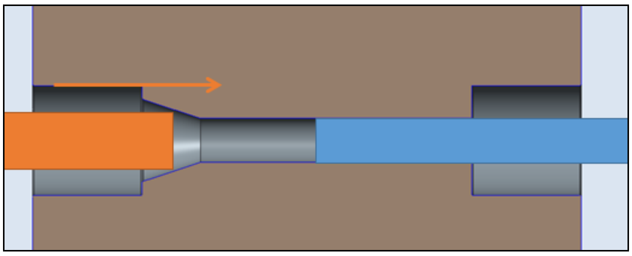

Figure 11. Principle of extrusion

3 CONCLUSION

3D printing affects every aspect of industry. It is necessary to look at the environmental impact of this activity. To save residual material after 3D printing, 3 devices were designed.

The first design is the principle of manual pressing. The model takes the form of two oppositely built profiles with clamping at one point. This proposal is simple and that is its advantage. The design meets the conditions of pressing without complicated mechanisms and automation. It is mobile, compact, and easy to repair in case of problems.

The second design is a station for manual joining. The model consists of molding blocks mounted on a base with electronics. At the rear is a cooling fan. This solution is also simple enough, but requires manual skill. Mobility is not so good and compactness as well. Ease of repair is also present in this model.

The third design is a semi-automatic extruder. component melts the entire filament and connects it to the filament at its other end. In this model, an engine is already implemented whose automation is not necessary but recommended. Advantages are automatic filament shifting. The ease of repair in case of malfunctions depends on the location of the damage. Some parts can be easily replaced as a whole without the need for mechanical intervention in some of the components [Cehelský 2017].

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