DIMENSIONING RULES FOR 3D PRINTED PARTS USING ADDITIVE TECHNOLOGIES (FDM)

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In this article we propose a synthetic presentation of the general principles of dimensioning applied to 3D printing parts using FDM (Fused Deposition Modeling) process. The 3D printed tests have been performed on an "Ultimaker 2" machine, while the 3D modelling was made with Autodesk's AutoCAD application. The material used in the printing process is ABS (Acrylonitrile-Butadiene-Styrene). The proposed set of rules will ease the design of parts with different functions, thus helping the users of such technologies.

Keywords: 3D modelling, 3D printing, FDM, dimensioning rules.

1. Executive summary

Achieving the functionality of a part depends on the way this is manufactured, in this case the FDM (Fused Deposition Modeling) process. Any additive manufacturing (AM) process starts from a 3D virtual model of the part, which is then sliced with parallel planes, the cross sections thus obtained being physically materialize in different manners (depositing filaments of material – FDM process, solidifying a photo-curable resin using UV light - stereolithography process, etc.) This way, parts with complex geometry can be manufactured.

Despite the opening towards the AM technology, these are still considered expensive. Moreover, they are thought as slow and sometimes inaccurate, even though the materials used in the manufacturing process are not more expensive than the ones used in classic technologies (for example, for plastic injection molds - the amount of the ABS type plastic used for injection is the same as for 3D printing of the same part using the same material)

Thus, the manufacturing options for these complex parts on 3D printing machines are limited by the manufacturing speed, tolerances, wall thickness and the properties of printing material, depending on the technology.

2. Establishing the set of dimensioning rules

The past years we have seen a raise in 3D printing process productivity by increased output speeds with the same accuracy that is afforded by this process. Printing speeds have increased allowing a much higher material flow in FDM process. Increasing speed means to deal with the problem of the increased temperatures created by deposition filament with high speed which can cause increased surface tension, structural alteration and chemical reactions of the medium material. Printing speed is the contributing factor for base contraction on the printing base plate, when optimum printing conditions are not met, and is one of the challenges of the FDM process.

According to [1], geometrical features can be found in three main domains [2]:

• Specification domain, where designers image representations of the future part;
• Physical domain of the part;
• Inspection situation, where a representation of a given part is used through sampling of the part by measuring instruments.

The designer defines a part in terms of fundamental manufacturing features, such as chamfers, through slots, blind slots, etc. - Fig.1. In model-based object design, mechanical parts are decomposed in geometrical components which describe various geometric properties of the model [2].

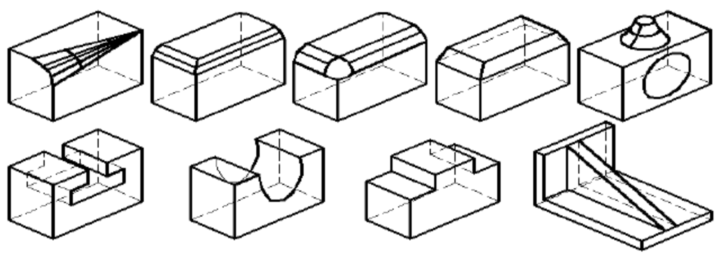


Fig.1. Manufacturing features [2].

1. Establishing reference surfaces;

If, in case of the traditional manufacturing technologies, dimensioning is not allowed using unfinished surfaces as reference surfaces (Fig.2 a)) [8], dimensioning FDM parts can be done as a reference to the way the model is being manufactured, and it is preferred that the reference surface to be the printing surface in xy plane (Fig. 2 b)).

Fig. 2 d) shows printed part dimensions. Fig. e) and f) show the part in a wrong printing position. Image e) represents the STL model from CURA software, where it shows the printing time (29 min), the part weight (3g) and the filament length necessary for printing (40m); image f) highlights the part defects as a result of the wrong printing position.

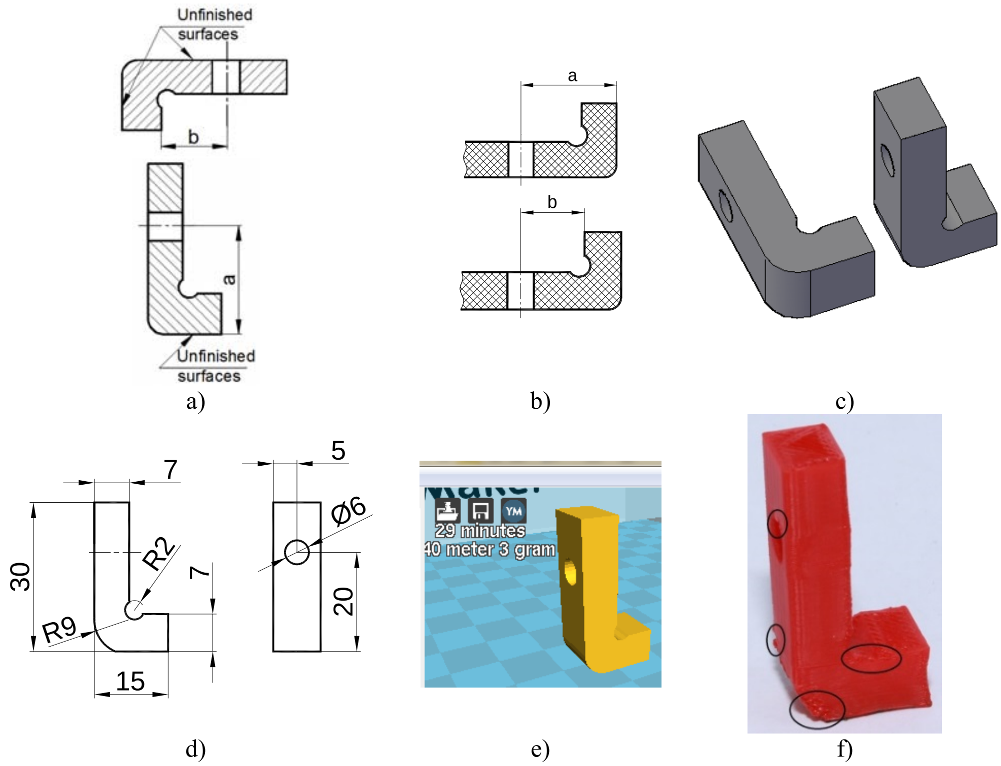
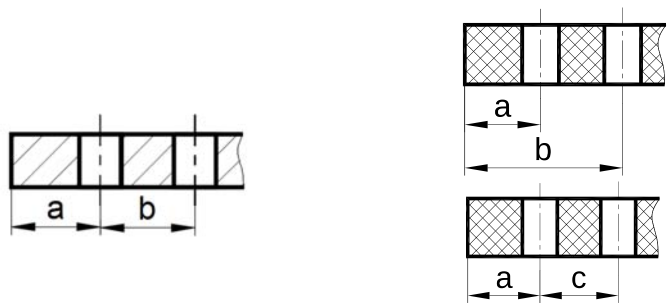


Fig. 2. Reference surfaces.

2. Direct dimension indication;

Important dimensions (such as: distance between two holes, Fig.3) can be indicated directly (b) or they can be the result of the difference between two dimensions (a). Additive printing does not affect the positioning precision.



a) Classic manufacturing technologies

b) FDM

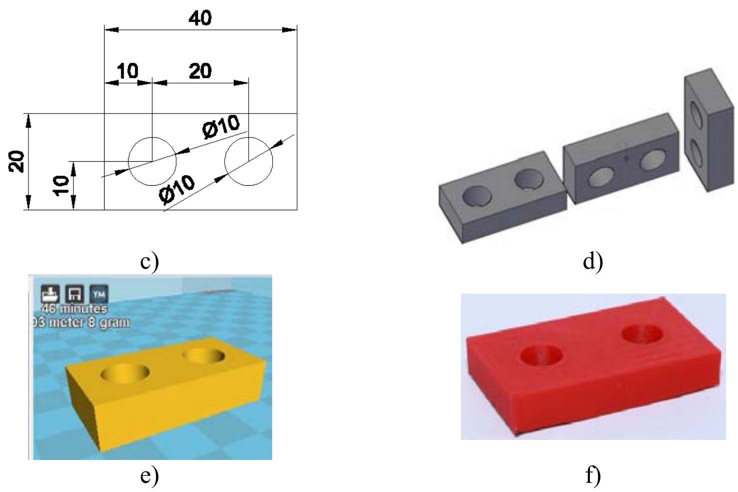


Fig.3. Direct dimension indication vs difference between two dimensions.

Fig. 3 d) shows three possible printing positions for this part. Fig. 3 c) presents the minimum required dimensions for the printed part. Images e) and f) show the part in a correct printing position; e) contains information from the CURA software of the STL model as to necessary printing time (46 min), part weight (8g) and filament length for orienting (103m). Image f) presents the printed part in a correct position.

3. Dimensioning symmetrical holes with respect to the symmetry axis;

Because of printing layer by layer, the parts' geometric shapes are manufactured simultaneously [4]. To achieve holes' symmetry to an axis, it is no longer needed to dimension from the axis (Fig. 4 a)) whose plane was to be used as the reference. Dimensioning in 3D Printing can be made using the edge as reference (Fig. 4 b) and c)), which increases the accuracy of the output.

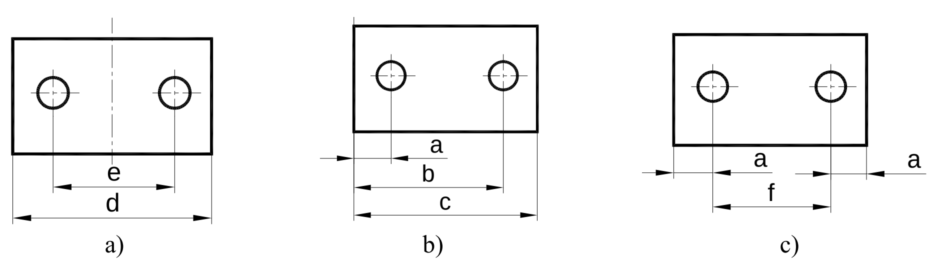
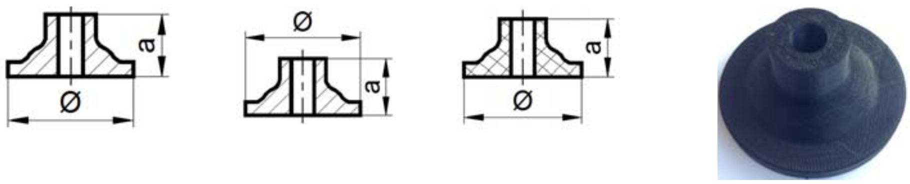


Fig.4. Holes symmetry.

4. Visibility of dimensions;

The dimensioning rules regarding the visibility of dimensions, by placing them as close as possible to the reference surface and with extension lines as short as possible (min 10mm contour to the dimension line and between lines), are still valid for additive manufacturing design.

Fig.5 a) is to be preferred to Fig.5 b).

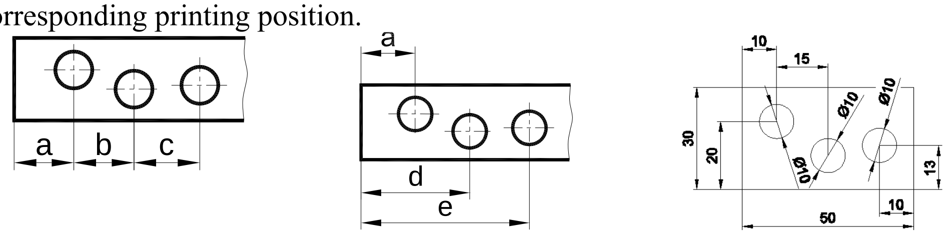


a) Classic manufacturing technologies | b) Wrong | c)FDM | d)FDM

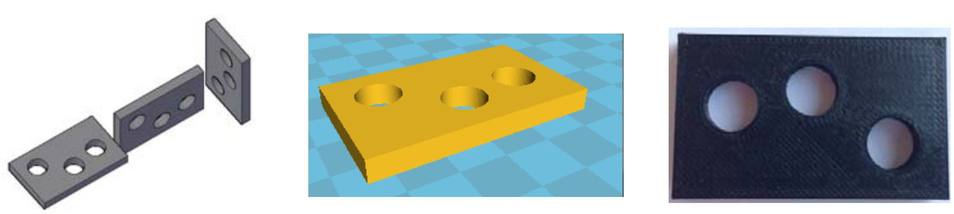
Fig.5. Dimension visibility.

5. Chain dimensioning;

In additive technologies, chain dimensioning can be used as the risk of summing up the tolerance of each dimension (Fig. 6 a)) no longer exist. Therefore, both dimensioning variants can be used. Fig. 6 c) shows printing part dimensions. Image d) presents different options for 3D model positioning. Fig. 6 e) and f) presents the part in the correct printing position; figure 6 e) is a STL model from CURA software, while f) presents the printed part in the corresponding printing position.



a) b) c)



d) e) f)

Fig.6. Baseline and chain dimensioning

Usually, the chain dimensioning method is not recommended for mechanical parts because the addition of tolerances can affect the closing dimension. But in the case of FDM parts, using a dimension chain is preferable as the tolerance of each dimension cannot be added (Fig.7 a)). A dimension is placed only once in a drawing (fig. 7 b)). Fig 7 c) shows the printed part dimensions, d) printing options, and e) f) the part in the optimal position; e) is a STL model from CURA software, while f) presents the printed part in the corresponding printing position.

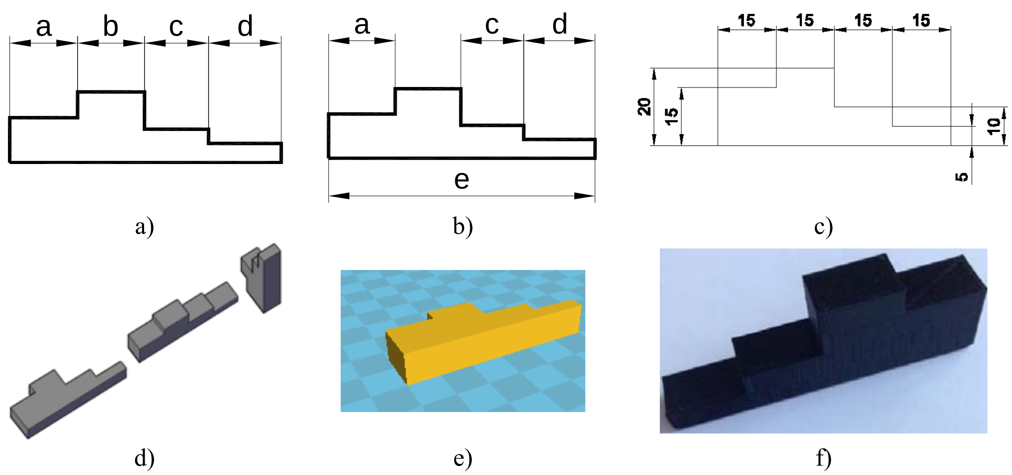
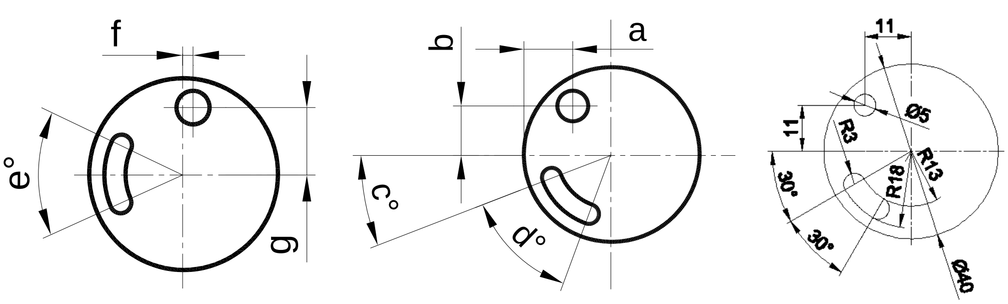


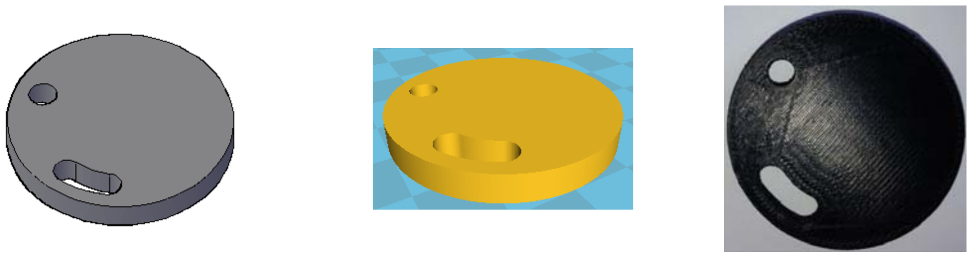
Fig. 7. Positioning chain dimensions

6. Dimensioning circular parts

When dealing with circular parts, in order to simplify the dimensioning process and drawing comprehension, the reference plane should be only one of the axis planes (Fig.8 a)) [8]. In case of FDM, circular holes can be represented also asymmetrical to the axis (Fig.8 b)).



a) b) c)

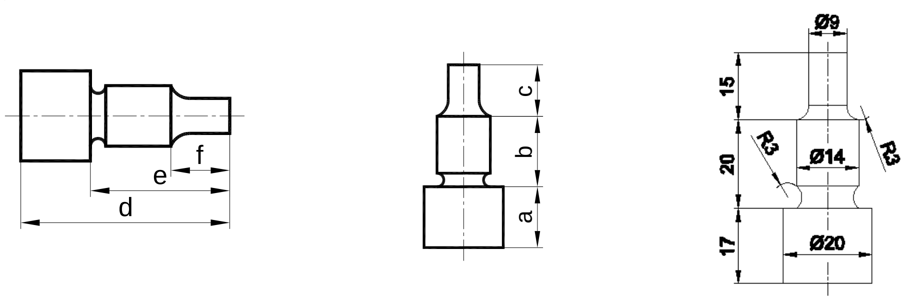


d) e) f)

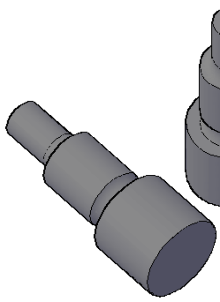
Fig. 8. Dimensioning circular holes.

7. Dimensioning shafts;

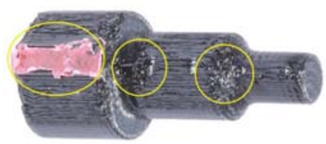
In order to machine a shaft from a bar, the proper methodology of dimensioning in case of using a subtractive technology is represented in Fig 9 a). First cut a long distance „e”, then „f” and finally cut „d” from the bar to create the final output. This dimensioning method requires the reference plane to be the right-most edge of the part (Fig. 9 a)). In FDM, dimensions are given as per Fig. 9 b), this being the correct modelling position. Fig. 9 c) shows minimum required dimensions for the printed part. Fig. 9 d) shows two feasible orientations of the part on the printing plate, while Fig. 9 e) and Fig. 9 f) illustrate the optimum printing position. Fig. 9 e) is a STL model from CURA software. Fig. 9 g) shows the part defects due to printing in the wrong position, meaning horizontal positioning (shaft axis is parallel to the printing plate). The defects are due to the support structure necessary during the printing process for securing the part to the printing plate. Fig. 9 h) shows another incorrect position, where the axis of the shaft is perpendicular to the printing plate and the shaft is built starting with the smallest diameter as a base, this type of printing process requires a support structure. Removing this support structure may cause shape defects in the printed part.



a) b) c)



d) e) f)

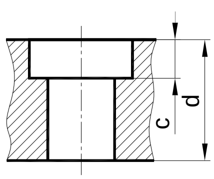


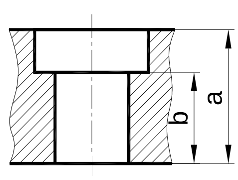
g) h)

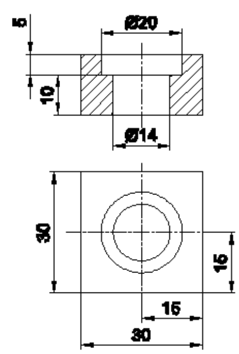
Fig. 9. Dimensioning shafts.

8. Dimensioning counterbored holes

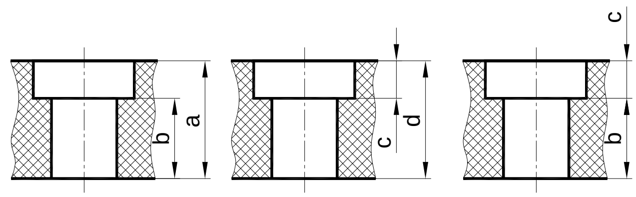
In a traditional manufacturing process, first the hole is drilled and then the counter boring is made and these two processes should be dimensioned. For FDM, Fig.10 d) this dimensioning is also acceptable, but there are also other options that could produce the proper output.



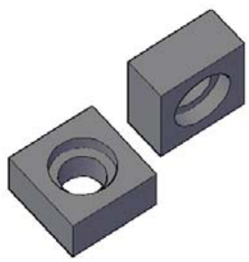




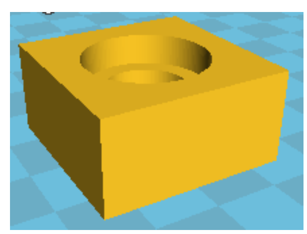
a) b) c)



d)



e)



f)

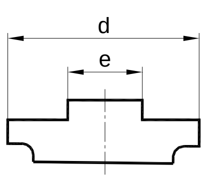
g)

Fig.10. Dimensioning counterbored holes.

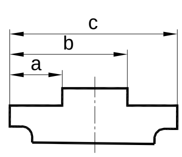
All options presented in Fig. 10 d) are acceptable for FDM parts. Choosing one over the other depends on the modelling approach. Fig. 10 c) presents the minimum required dimensions for the printed part, while Fig. 10 e) shows the possible printing orientations with the correct version presented in Fig. 10 f). The final part is presented in Fig. 10 g).

9. Dimensioning plane surfaces;

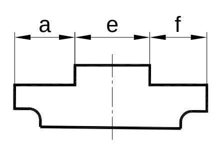
The geometric feature “e” must be symmetrical to the axis. If we dimension from one side, and the total length is not met, than section “e” will be asymmetrical to the axis (when using a classic technology). That is why the dimensions are given with the axis as a reference (Fig.11 a)). For 3D printing Fig.11 c) is to be preferred because it eases the 3D modelling.



a)



b)



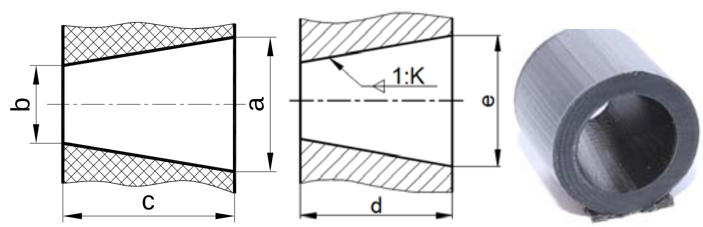
c)

d) e) f)

Fig.11. Dimensioning plane surfaces.

10. Taper dimensioning;

For conical surfaces, only three dimensions are needed as represented in Fig 12 a). For 3D modelling prior to printing, using dimensions as in Fig. 12 a) is recommended, although by indicating the two diameters, the taper is over dimensioned and it can only be manufactured on special machines. Because in most of the cases the smaller diameter is of no importance, the conical shapes in traditional manufacturing technologies are marked by the larger diameter and the taper (Fig.12 b)).

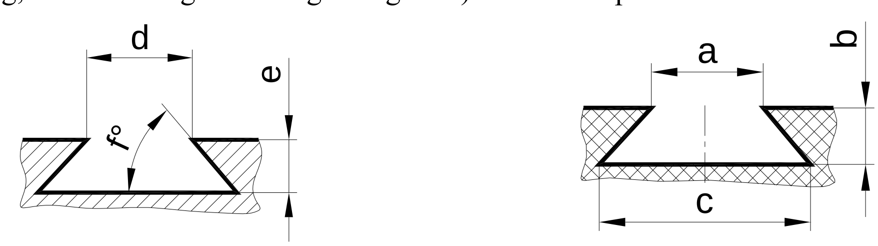


a) b) c)

Fig.12. Taper dimensioning.

11. Dimensioning profile;

In order to avoid over dimensioning of the profile, a single width (the easiest one to be measured), the depth and angle are indicated (Fig.13 a)). For 3D printing, dimensioning according to Fig.13 b) is also accepted.



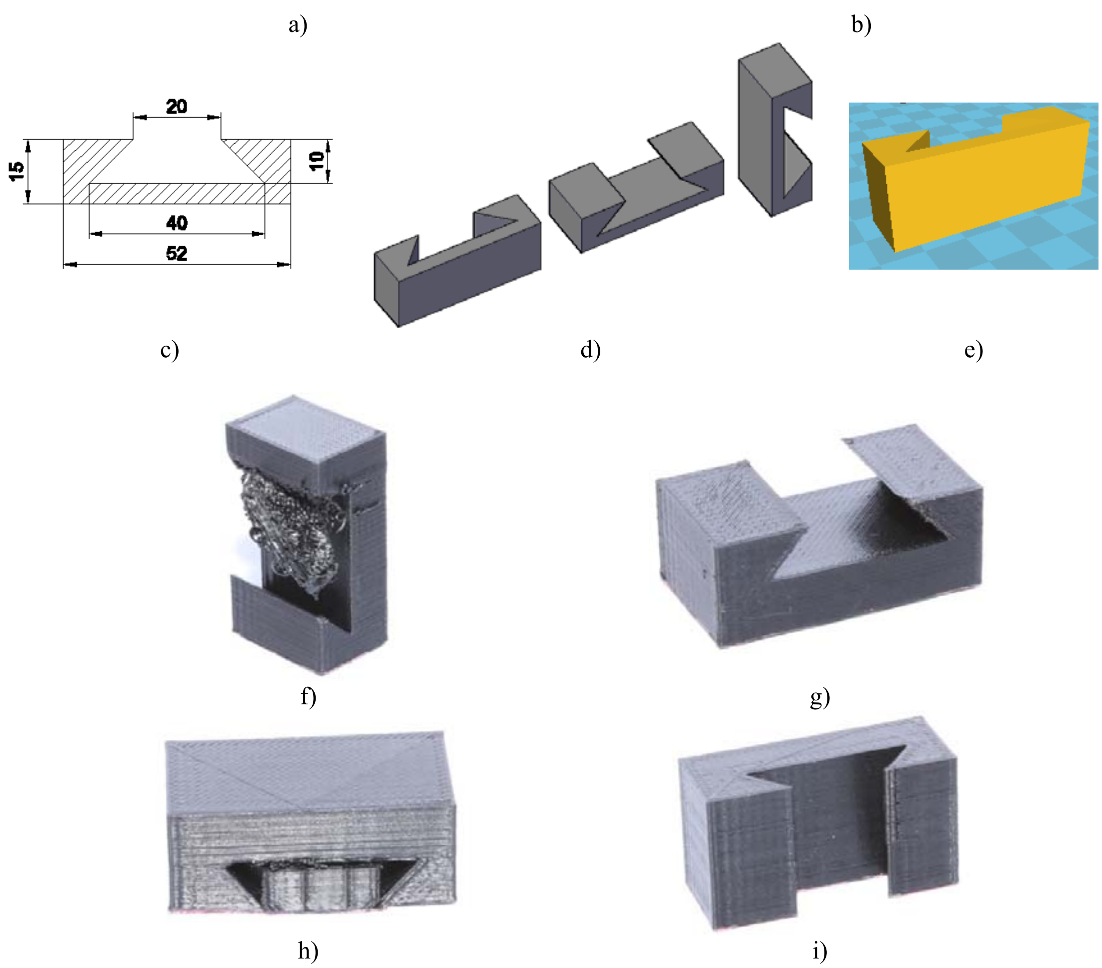


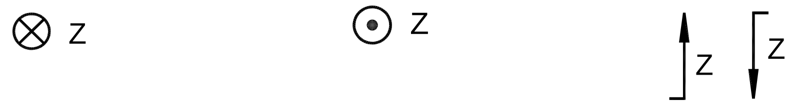
Fig. 13. Profile dimensioning.

CAD drawings used with FDM processes must include the following symbols:

1. Orientation on the printing plate. As a rule, the additive process is done along Z axis (Fig. 14);
2. Maximum thickness of each added layer, for the 3D printers which allow an adjustable thickness of layers (Fig. 15);
3. The hatching pattern (or raster) to be followed by the printing head during the process (Fig. 16).

If these three symbols are not present in the execution drawings, the part will be oriented a base a set of baseline variables with no support structures, layer thickness equal to the minimum dimension tolerance represented on the drawing, and manufactured based on a 45°/135° pattern.

In order to dimension the Z axis and build the part properly, we propose the following symbols to indicate the Z axis (Fig. 14):



a) b) c)

Fig. 14. Symbols to indicate the direction of additive manufacturing process.

The view followed by symbol in Fig. 14 a) suggests that all subsequent layers should be perpendicular to the base layer. The view followed by symbol in Fig. 14 b) represents the last layer in the process with the part being manufactured from the first layer up to its top layer (last layer in the process). The view followed by the symbol in Fig. 14 c) shows the direction in which the part should be manufactured.

Increasing the thickness of each layer has an impact on reducing the manufacturing time of the part, but at the same time, it increases the roughness of the surfaces perpendicular to the addition direction and, consequently, the dimensional tolerance (which is equal to the thickness of each added layer). To shorten the production time, in certain cases when a part has surfaces with lower functional, dimensional or mechanical tolerance, these surfaces can be manufactured with a thicker layer. Whereas surfaces which need to have more precise tolerances may be manufactured with thinner layers at slower manufacturing speeds. Therefore, in order to indicate the thickness of the layer, we propose to use the symbol in Fig. 15 followed by the value of the thickness of the layer in mm.

Fig. 15. Symbol to indicate the thickness of the added layer.

The path of the printing head can be altered in certain cases where different specific properties during the manufacturing process are needed (like removing "step" effect, or increasing the mechanical properties along a certain direction). The printing head follows a path which varies between two successive layers in the XY plane, first layer at 45°, and secondary layer at 135°. This can be modified by the user in different options (30°/120°; 0°/90°). As a rule, there is a 90° offset between two successive layers.

We propose the following symbol for the path of the printing head, followed by the values of the angles (Fig. 16).

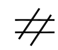


Fig. 16. Symbol to indicate the direction to be followed by the printing head.

Using the proposed symbols as well as the dimensioning method for the part to be manufactured using FDM, a dimensioning example is shown in Fig. 17.

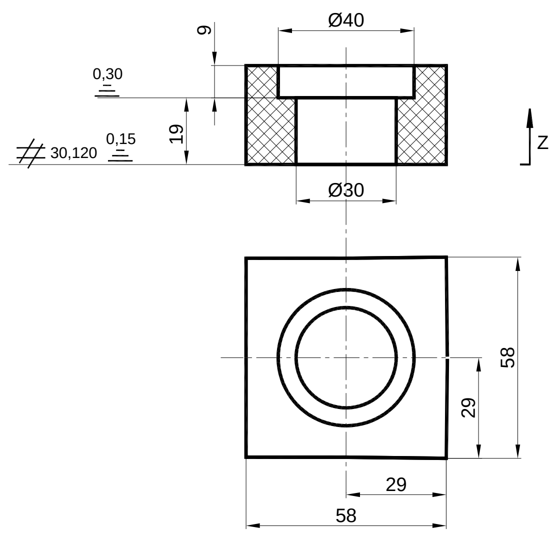


Fig. 17. Example on how to use the symbols

Fig. 17 shows: 1) the manufacturing direction proposed by the designer, 2) the direction of the printing head for successive layers (30°, 120°), and 3) the layer thickness. The defaults settings of the 3D printer are to be used when the above values are not explicitly mentioned on a drawing and the operator chooses the orientation of the part during the manufacturing process.

3. Conclusions

The design process of a 3D object/part plays a vital role in additive manufacturing using FDM process. Therefore the correct dimensioning and labeling of an execution drawing for the part is an important aspect for its final design and ultimately in the manufacturing process outcomes (tolerances and properties of the final part).

The rules presented in this article apply only to dimensioning. There are many differences between 3D printing processes and traditional manufacturing processes when it comes to dimensioning. Most of these differences have to do with the positioning of the part on the printing base plate [5], influencing the drawing symbols and dimensioning methods.

Moreover, specific symbols related to the additive manner of building are needed, and proposed in this study, in order to indicate the correct positioning and tolerances for manufacturing FDM parts.

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