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Cezary GRABOWIK[1*], Krzysztof KALINOWSKI[1*], Grzegorz ĆWIKŁA[1*],
Damian KRENCZYK[1*]

[1]Institute of Engineering Processes Automation and Integrated Manufacturing Systems,
Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice
[*] cezary.grabowik, krzysztof.kalinowski, grzegorz.cwikla, damian.krenczyk@polsl.pl

A REVIEW OF RAPID MANUFACTURED PARTS POST PROCESSING METHODS

Abstract: In spite of constant development of rapid manufacturing methods and apparatus, rapid manufactured parts still offer limited quality, both dimensional, and surface. Taking into account above there is still a need for additional product finishing. Currently used finishing methods include the two basic types; it is with or without material loss. In this paper a short review of both types of finishing methods is given.

1. Introduction

Rapid prototyping (RP) is a group of manufacturing methods that manufactures a product model layer by layer directly from a CAD/STL model. Application of rapid prototyping methods in comparison to conventional, it is removal processes allows shortening of the product lead time mostly by reducing of setup times. A manufacturing process realised with RP methods consists of several stages, it is acquiring of 3D product model geometry, conversion of the CAD model into STL file, selection of an appropriate manufacturing process, manufacturing process parameters selection. Each of previously mentioned stages has its own particular influence on a product quality. Thus, model geometry can be acquired in the two ways by modelling it in a CAD system environment (a new design modelling or making modifications of an existing design, a product CAD file available) or by application of reverse engineering techniques – 3D scanning. In case of a model geometry acquiring via 3D scanning the product quality might indicate some imperfections that result from 3D scanning process quality and further CAD model postprocessing (equipment, software, external process disturbances, for instance a scene illumination, human factors etc.). The product quality can be easily improved, with no expense, by proper selection of STL file conversion parameters. Selection of STL file conversion parameters differs depending on a CAD model type. Generally, there are the three types of CAD models, it is wireframe, surface and solid ones but for rapid manufacturing only the two last model types are acceptable. In case of solid models STL file conversion process consists of: (i) selection of the model being converted, (ii) selection of conversion parameters, (iii) selection of STL file type (text or binary), (iv) file saving. In that instance, conversion parameters are as follows: chordal tolerance/deviation, angle control. Where, the chordal tolerance is the maximum distance between the surface of the original design and the tessellated surface of STL triangles and angle control is the angular deviation allowed between adjacent triangles. This setting enables to increase tessellation, which is necessary for surfaces with small radii. The smaller radii, the more triangles are needed, and the smoother the resulting surface is. The STL conversion process of the surface model differs from the previous one; in case of surface models, some extra operations are needed. The conversion process starts from selecting of all adjacent surfaces, next each model surface is triangulated with triangles whose parameters are controlled via conversion parameters. The last stage of the surface model conversion consists in setting, for each plane, of the normal vector direction and sense, that are used for distinguishing internal and external parts of the model.

Each of above-mentioned factors, when not well prepared, would have a greater influence on a product quality than it would result from RP manufacturing process manufacturing capabilities.

In spite of the fact that RP manufacturing processes are continuously subjected to modifications, products that are manufactured with RP processes characterize very often insufficient surface manufacturing accuracy. The most common imperfections of the model surfaces include staircase, cylindricity, flatness, and straightness errors. As a result, some extra finishing operation has to be done in order to improve product quality [1,2,3].

2. A review of post processing techniques

There are some RP manufactured parts post processing techniques, it is gluing, thermal welding, sanding, bead blasting, electroplating, painting, vapour, or thermal treatment.

Gluing is a post processing technique applied when overall dimensions of a RP manufactured model exceed an apparatus building area. In that case, at the designing stage, it is necessary to make a project of a product design taking into consideration the most suitable model partition influenced by building orientation. The gluing process is most often applied for FDM models. There are several types of gluing process; it is adhesive (epoxy or cyanoacrylate), solvent, hot air plastic welding, and ultrasonic spot welding. The choice of the most suitable gluing process depends on model material, model mechanical properties, model application area etc.

Adhesive gluing consists in application of the thin layer of glue on proper faces of the bonded model sections. In such case, there are the two basic types of the adhesive gluing, it is adhesive – epoxy and adhesive – cyanoacrylate. The selection of the gluing process type depends on model material, desired bond mechanical properties, and its thermal and chemical durability. In case of epoxy adhesive gluing after application of a glue layer the bonded sections are mounted into a fixture to let epoxy cure. Taking into account epoxy properties – working time (maximum 70 minutes), it is possible to change bounded part sections position after initial mating but the tradeoff is longer curing time. So, in a room temperature the curing process lasts a couple of hours to five days. This process can be accelerated with heating. Depending on epoxy cure duration bond strength will differ but usually it offers very good mechanical strength, and typically exhibit good temperature and chemical resistance. Adhesive gluing with cyanoacrylate is a fast-curing process. It is usually applied for quick model repairs and small details bonding. Like epoxy, cyanoacrylate allows making changes in a mutual face mating but it is limited to a few minutes. The tensile stress for the cyanoacrylate is higher than for epoxy but from the other hand, their thermal and chemical durability is much smaller.

Solvent treatment in solvent treatment process a bond between product sections is made by chemical melting of adjacent faces. In this process, a solvent can be brushed on bonded faces or injected into pre-mated model sections. The solvent treatment is also used in case of product small repairs, in that case, the solvent is applied directly into tiny product cracks. After solvent application, as in the adhesive process, a product is mounted in a fixture to let a bond cure. There many solvents available in the market but some of rapid prototyping apparatus producers recommend using Same Stuff by Mico-Mark. Same-Stuff uses capillary action to weld and bond product sections. It is used for chemical welding of styrene, acrylic, butyrate, and ABS plastic. In opposite to previously mentioned methods, it is not necessary to apply a solvent between bonded faces; the solvent after putting them together is applied just onto the bond seam and hold tightly for about 15 seconds. In some cases, it is impossible to use a solvent treatment for FDM materials such as PPSF or ULTEM 9085 because of their chemical resistance to solvents. The main advantage of the solvent treatment over gluing is that after evaporation the bonded part contains only a native material, whilst the main drawback is weak heat resistance. Exposing of FDM manufactured products to temperatures exceeding 80^0 C would make blisters on their faces.

Thermal welding the process course in its nature is similar to a gas-welding process, but in this case a metal welding rod is replaced by a proper thermoplastic welding rod and instead of using oxy-acetylene mixture, a hot air stream is used. In comparison to other bonding methods, thermal welding is faster and cheaper. The low welding processes cost results from the low cost of welding rods, in workshop practice most often as a welding rod the native FDM material (filament) is used. Moreover, any other extra processing is not needed; the seam is made by heating of welded product sections edges and rod melting. In opposite to gluing that needs the bond to be curried, thermal welded parts can be put into service after cooling them down.

Ultrasonic spot welding consist in making a permanent bond between the two thermoplastics with ultrasonic waves, the process is similar to joining of metal parts with spot welding. The bond is made as a result of a point-wise material melting. On account of commercial availability of handheld ultrasonic spot welders there is no limitation in their application in the terms of batch production or even prototyping processes. Compared to previously mentioned techniques ultrasonic spot welding offer some advantages such as: (i) fast cycle time – typically less than one second, (ii) excellent high-strength bond, (iii) a lack of connecting members (screws, staples, rivets), (iv) good quality of joined surfaces, (v) welded spots are stronger than the native material. Since there is no need of a filler material application, product accuracy and material properties remain almost the same, which in the context of medical applications seems to be one of the most important features of ultrasonic spot welding. When high mechanical properties of the joint are needed there is a possibility of combining of ultrasonic spot welding with adhesive or solvents. Like in thermal welding, the part could be put into service immediately after the welding operation is finished.

To sum up, previously presented post processing methods are used only for joining of two or more product sections into one part. In consequence, the product quality measured by a product surface roughness is not changed resulting from the RP manufacturing process. Since there is a need of product quality improvement an additional finishing process has to be performed. The product surface roughness can be decreased by application removal techniques such as bead blasting, sanding, CNC machining or mass finishing.

Bead blasting is a kind of abrasive machining in which a product surface is smoothed with abrasive jet. The characteristic of bead blasting process is that during it, only a product surface roughness changes whilst its dimensional accuracy remains almost unchanged. As abrasive, glass or plastic (plastic blast media PBM) beads can be used. In case of PBM as a bead, a recycled material can be used. Particular PBM media differ in their abrasiveness and size. The optimal bead Mohs hardness is 3,5 with size of 0,58 mm. The bead blasting process starts with a model preparation. First, all model supporting structures are removed; next a masking type is applied for these model surfaces that should stay unaffected. Further, bead blasting working pressure is adjusted. Initially working pressure is set to the lowest efficient value and next increased to value that does not exceed 700 kPa. In order to achieve the best process results, it is suggested adhere to the following guidelines: (i) spray an abrasive jet at the 60^0 angle from the part surface, (ii) operate a spray gun like in painting applying light passes instead of one heavy pass, (iii) do not stop at the fixed point of the product surface (a danger of forming of cavity). After the blasting process, the blasted part is rinsed and checked for potential model failures. In case of damage, the product is fixed with formerly mentioned methods. The most important advantages of bead blasting are low processing cost, short processing time, and application ease. In the figure 1 an example of the model bead blasting is shown.

Fig.1. FDM model beat blasting [3]

Sanding is very often used post processing method especially for thermoplastic models, although metal parts can be process as well. As bead blasting, sanding process starts with removing the product supporting structures and sanding down support marks (left on the product surfaces). It is usually done with rotary tools or sand paper (220 grit is recommended). Next, all product surfaces are sanded down with sandpaper sheets or for getting of even better results, flexible sanding strips. During sanding process should not be used excessive force. It is suggested to start with sandpaper grit 220/320 and follow up with 400 up to maximum1200 grit. Labour and time consumption are the biggest process drawbacks. Sanding, as an initial process, very often accompanies other post processing methods like painting or electroplating. In the figure 2 an example of the model sanding is shown.

Mass finishing from its definition is a kind of manufacturing process that allows large quantities of product to be finished at once. The main goal of the mass finishing is to get better product quality or preparing it for subsequent finishing by burnishing, deburring, de-flashing, rust removing, polishing etc. There are two basic types of mass finishing it is tumble and vibratory finishing. Both of them work according to the same principle that consists in making a cyclical grinding contact among products surfaces with or without medium.

Fig.2. The FDM model sanding [5]

The process lasts from couple of minutes to a few hours depending on a product initial state, workpiece material hardness etc. The Stratasys has tested both mass finishing methods with a variety of media [4]. Basis on these tests they have drawn some important conclusions. First, by abrading a product its accuracy remains almost unaffected whilst surface roughness improves. The material loss is typically in 0,03 to 0,07mm range, which is lower than additive manufacturing processes accuracy. Second, vibratory mass finishing can be applied for all FDM materials. Stratasys prefers using bowl systems to tub systems. According to performed tests, bowl systems seem to offer gentler processing and uniform smoothing action whilst tub-shaped systems machine parts more aggressively with reduced cycle time (increased risk of potential product failures appearance). They have also performed some tests with centrifugal systems. These tests revealed that centrifugal systems are more suitable for finishing of small or delicate details. Another issue is proper media selection, if considering media, the size, density, and part geometry should be taken into account. For highly detailed and fine-featured small parts, small media with angular shapes should to be applied. Stratasys have tested influence of ceramic, synthetic, plastic and corn cob media on FDM parts with the following results. All of them are usable on all FDM materials but in case of full-scale production, some additional tests in order to choose the best alternative ought to be performed. Ceramic is the most aggressive media. It is the best choice for finishing of the toughest FDM materials like PC, ULTEM 1010 resin, ULTEM 9085 resin and PPSF. It allows to get a glossy surface on a FDM part but the part should not have delicate features. Plastic media is less aggressive then ceramic so it is used for parts smoothing. Synthetic media thanks to its lower mass density and Mhos hardness, if compare to ceramic and plastic, minimize the risk of part failure. That is way it is more suitable for finishing of thin walls and delicate features.

Vapour treatment is a kind of FDM parts smoothing with solvent application. Smoothing process consist in dipping of the part in heated solvent vapours. As a result, solvent dissolves part surface layers, and surface quality improves by elimination of staircase effect. There are two ways of FDM parts vapour treatment; it is traditional, performed in vapours only, and modified, proposed by Stratasys, in which a part is alternately cooled and heated in vapours. In smoothing process, as a vapour bath acetone vapours are most often used. The biggest advantage of this solution is its simplicity. It can be realized even at home. The project of the simplest home smoothing station consists of a glass jar, filled in tenth of acetone, and a heater. The process temperature (vapours temperature) should be kept at 56^0C level whilst processing time in 5-10 minutes range. The biggest drawback of such kind processing is weak process control, surface layers changes could progress in an uncontrolled way. Stratasys offers a commercial smoothing station. The station consists of the two chambers. The first chamber is used for a part temperature reduction; the part is kept in it for about 10 up to 30 seconds. Next, the part is transferred to the second chamber filled with hot vapours of acetone. Because of temperature difference between the part and acetone vapours, the acetone starts to condense and wash a part away. Once the first smoothing cycle is finished, the model is cured in the first chamber for about 20 minutes. The whole process repeats as long as the product surface quality is not satisfactory. Finally, the product surfaces get a glossy effect, if a matte finish is needed a part is additionally bead blasted. Once the process is finished the model is dry to the touch in 30-45 minutes, but the best process results are achieved when the part is dried for 12-18 hours. It is worth to note that the smoothing station can provide a surface finish from 32 up to 63 microns without changing a dimensional accuracy. In the figure 3 an example of the model smoothed in smoothing station is shown.

Fig.3. The model smoothed in smoothing station [4]

3. Conclusions

Despite the dynamic development of RP manufacturing methods, RP models still show limited both dimensional accuracy and surface quality. Currently, the surface quality can be improved in several ways; it is by application of removal or non-removal processes. The proper choice of finishing methods would decide about RP manufactured product market success. Presented paper gives ideas that would support the process of proper finishing method selection.

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