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Review Article

CHEMICAL POST-PROCESSING METHODS FOR ENHANCING SURFACE PROPERTIES OF PARTS FABRICATED BY ADDITIVE MANUFACTURING: A REVIEW

Nedim SUNAY*[1], Mert KAYA[2], Yusuf KAYNAK[3]

[1]*Department of Mechanical Engineering, Marmara University, ISTANBUL;* ORCID: 0000-0002-2957-1144
[2]*Department of Mechanical Engineering, Marmara University, ISTANBUL;* ORCID: 0000-0002-3644-7176
[3]*Department of Mechanical Engineering, Marmara University, ISTANBUL;* ORCID: 0000-0003-4802-9796

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ABSTRACT

Additive manufacturing is a rapidly developing field due to the production of complex geometry parts with rapid prototyping with a wide range of applications. In addition to the great advantages, Additive manufacturing produces components with relatively poor surface quality. For this reason, post-processing operations are inevitable to have ready-to-use products. Various post-processing operations including mechanical, chemical and thermal are being implemented to components fabricated by additive manufacturing processes. The purpose of this article is to review chemical post-processing operations and their effect on surface enhancement. This review study shows that chemical post-processing operations have great potential to improve surface aspects of components fabricated by additive manufacturing.
Keywords: Additive manufacturing, chemical post-processing, 3D printing, surface treatment.

Acronyms			
AM	Additive Manufacturing	ECP	Electrochemical Polishing
ABS	Akrilonitril Bütadien Stiren	CHE	Chemical Etching
SLM	Selective Laser Melting	PC	Poly Carbonate
SLA	Stereolithography	PMMA	Poly Methyl Methacrylic Acid
DMLS	Direct Metal Laser Sintering	PET	Polyethylene Terephthalate
FDM	Fused Deposition Modeling	UTS	Ultimate Tensile Strength

1. INTRODUCTION

Additive manufacturing (AM), also known as 3D printing, is the process of combining materials from 3D model data to make layered objects on a layer, unlike traditional manufacturing methods [1]. Producing without additional equipment, including tools, gauges or fixtures, this tool-free production approach can provide flexibility in design, personal customization, high precision in complex parts, reduce energy and material use, and shorten time to market [2]. On the other hand, one of the drawbacks of AM methods is to produce components with poor surface

* Corresponding Author: e-mail: nedimsunay@hotmail.com, tel: (541) 673 21 77

quality. In addition to surface roughness, dimensional accuracy, support structures, and staircase effect are all surface related issue and eventually prevent parts to be final product. Considering all these, it is obvious that post-processing operations are needed to have ready-to-use parts [3]. These post-processing techniques can be categorized as chemical post-processing (as seen in Figure 1), mechanical post-processing operations, and thermal post-processing operations. Each of them has its own advantages and disadvantages depending on applications and materials.

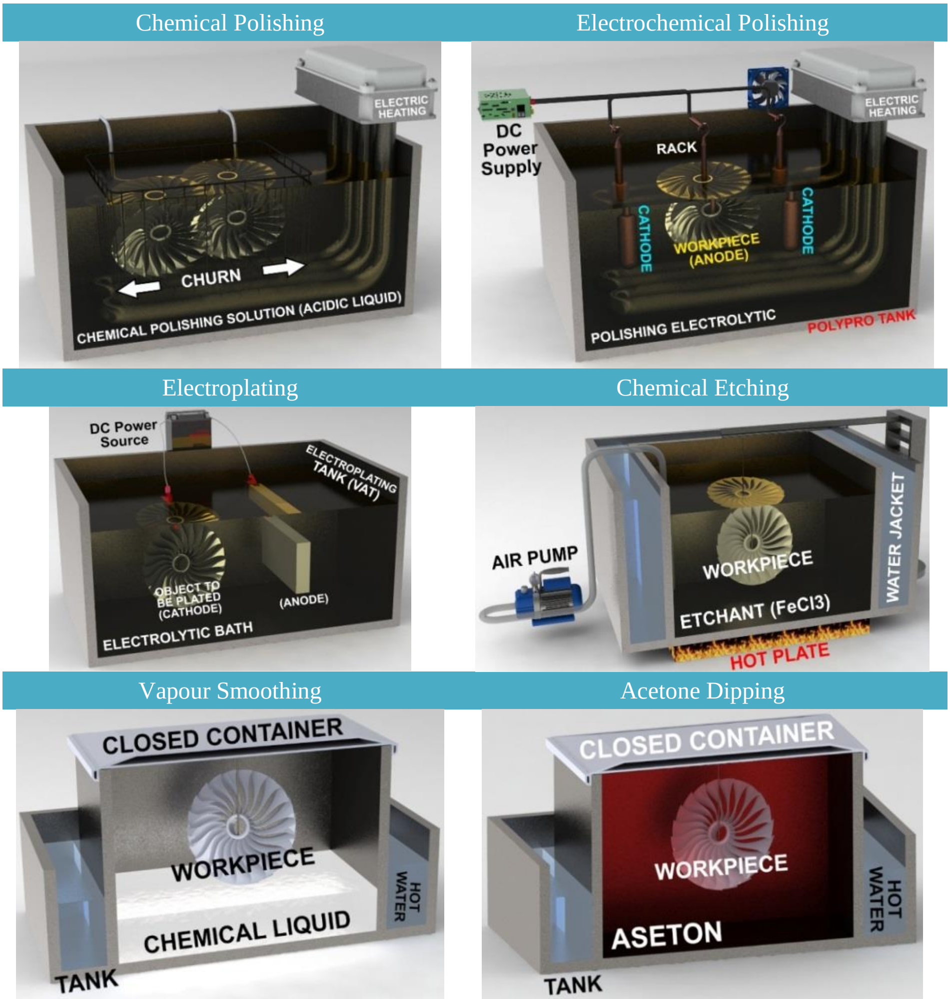


Figure 1. Schematic illustration of various chemical post-processing operations

Chemical post process methods are preferred due to their features such as improving the surface quality of the parts, being economic and easy to use [4]. Chemical post process methods are mostly used for surface cleaning and polishing of parts to be used in the biomedical industry [5]. Considering the literature, it is obvious that chemical post processing methods are generally applied to ABS (akrilonitril bütadien stiren) parts produced with FDM (Fused Deposition Modeling) since chemical solutions can penetrate the plastic parts better. Unfortunately, although there are some studies on post-processing and its impact on process performance [4,5] , there are limited number of works that present the current status and possible future directions. As can be understood from the studies in the literature, the first feature desired after production is to reduce the surface roughness. In addition to providing the desired roughness values, some post process methods provide features such as increasing water tightness, flexural strength and abrasion resistance [6]. The greatest priority of chemical post process methods compared to mechanical post process methods is that the tools do not have contact with the surface, which can provide better dimensional and geometric stability. However, it has been observed in studies that some chemical post-processing methods reduce tensile strength and cause deterioration in the part [7].

In this study, the strengths and weaknesses of chemical post-processing methods commonly used for the parts produced with AM have been presented by examining different studies.

2. CHEMICAL POLISHING

Chemical polishing is a post-processing method applied for a specified period to the part for increasing the surface quality with solutions determined according to the properties of the metal surface. In addition, chemical polishing is an effective method for removing partially melted powder particles on the surface of as-built parts fabricated by AM processes. Before the chemical polishing method, a number of surface preparation processes are applied to the samples. After polishing process, cleaning is also needed. The processes before and after the chemical polishing method are generally as shown in Figure 2.

Figure 2. General flow diagram of chemical cleaning process [8].

In the first step, AM samples are cleaned with soap solution, isopropyl alcohol, distilled water, ethanol etc. to remove dust and loose powder particles that may disrupt chemical polishing. In the second step, a bath is prepared at a temperature determined by a certain amount of chemical and then AM samples are immersed in the bath at a specified time. During chemical polishing, the dissolution rate of the upper surface of the passivation layer formed by the effect of galvanic couple and solution with a metal surface is different in the hills and valley areas of the surface. For this reason, the high effect of the passivation film, a glossy, smooth and oxid-free surface is obtained. Also, bubbles formed on the surface during the process reduce stagnation between the surface of AM samples and corrosive chemicals [9]. The last step is to remove the bath residue on AM samples and to dry the metal surface. At the end of these processes, mass and volume losses occur in AM samples and these are related to bath composition and polishing time. As a result, the chemicals determined for preparing the bath, the bath temperature and the residence time of the AM samples in the bath are determined by the AM metal surface on which the method is applied. For example; Baths containing hydrofluoric acid and nitric acid are more preferred for titanium alloys [10]. Łyczkowska et al. [8] implemented chemical polishing method to tissue scaffolds made of Ti - 6Al - 7Nb alloy produced with SLM. They reported that the loss of mass is related to removing partially bound, non-melted powder particles from the surface. Wysocki et al.

reported that the most effective homogeneous polishing was performed with bath solution 2.2 % HF / 20 % HNO3, as a result of the chemical polishing method for the treatment of titanium samples produced with SLM. In addition, the same researchers reported that as a result of the chemical polishing process performed with this solution, the young's modulus decreased by about 70% and the compressive strength by about 30 % [11]. Tyagi et al. [12] stated that by applying chemical polishing to the inner and outer surfaces of 316 stainless steel samples produced with DMLS, the outer surface roughness is reduced from 5 μm to 0.4 μm and the inner surface from 15 μm to 0.4 μm. For this post-processing process, AM samples were immersed for 30 minutes in the solution heated to 70-75 ° C consisting of 10-30 % phosphoric acid, 1-10 % hydrochloric acid, 1-10 % nitric acid and 1-10 % proprietary surfactant. As can be seen in Figure 3, chemical polishing solutions can be applied to hard-to-reach internal surfaces and complex structures because each surface it contacts enhances surface quality, which is a great advantage for the chemical method.

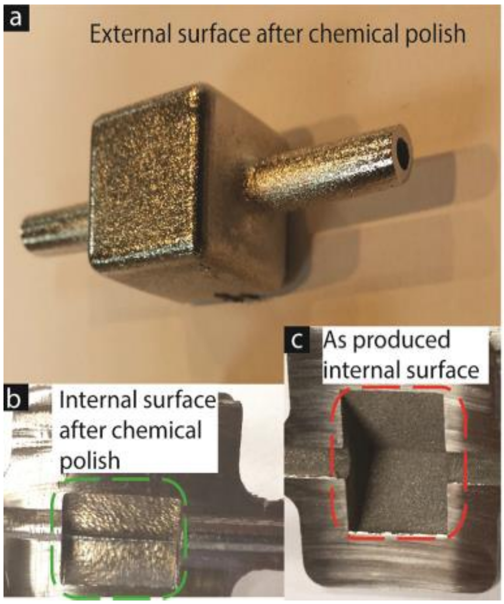


Figure 3. Magnified optical images of 316 stainless steel components (encircled by the dashed line) [12].

On the other hands, the drawback of this method is many variables induced from each metal parts and its materials used to be made of components fabricated by AM processes. For instance, there is no effective chemical solution for each AM metal and metal alloys. Although there are chemical solutions specified for most of the AM metal parts in the literature, the chemical abrasive flow polishing method, a combination of abrasive and chemical polishing techniques, can be used for some AM alloys without an effective chemical polishing solution [13].

3. ELECTROCHEMICAL POLISHING

Electrochemical polishing (ECP) is a low-level electrochemical dissolution process of an electrolytic cell of the electrode (cathode) and conductive metal samples (anode) produced by additive manufacturing methods or conventional methods. The process temperature is too low to cause any phase transformation of the material. In other words, the ECP process is the process of removing micron-sized pieces from the sample by immersing the sample and electrodes in the electrolyte for the specified time and applying a potential difference of 2 to 20 V DC between the electrodes [14]. In the ECP process, it is suitable for polishing complex shapes, fragile and hardened materials, which are difficult to mechanically process as there is no physical contact between the tool electrode and the samples. In the ECP process, electrolytes and electrodes are determined based on metal samples. Acidic electrolytes are generally used as electrolytes for AM metal samples and generally stainless steel, copper, lead, titanium are used for the electrode. For example, for Inconel 718, perchloric, sulfuric, phosphoric, acetic acid combinations are used for electrolyte, and titanium and stainless steel are used for electrolyte. In the ECP process, as in the chemical polishing method, AM samples are prepared before the process and after the process, the final cleaning is carried out and dried. According to the published literature, when surface of specimen is not cleaned before ECP treatment, it is observed that ECP treatment deteriorates the surface [15]. Jain et al. [15] reported the implementation of ECP method to SLMed as-built Inconel 718 samples. They considered various current densities, duty cycles and polishing times. According to their study, the best surface quality was obtained in parameters with a current density of 0.7 A / mm^2, 75 % duty cycle and 90 seconds. Baicheng et al. [16] reported that Inconel 718 samples produced with SLM reduced surface roughness by about 40 % , while nano hardness decreased by about 35 % and young's modulus by about 45 % after ECP was applied for 5 minutes at a current density of 50 A / dm^2. Tyagi et al. [17] reported that the ECP method significantly reduced the surface roughness of as-built 316L laser powder bed fusion samples. The same researchers reported that the ECP method is more effective in removing the outer surface roughness, but the chemical polishing is more effective in removing the inner surface roughness in the experiments performed with both the same samples and chemical polishing and ECP method. They reached the conclusion that the limited by the accessibility of the opposite electrode in confined spaces in complex shapes in case of the ECP method. In addition, Figure 4 shows the surfaces of 316 steel components produced by the additional production method of two different methods after they are applied to the inner and outer surfaces.

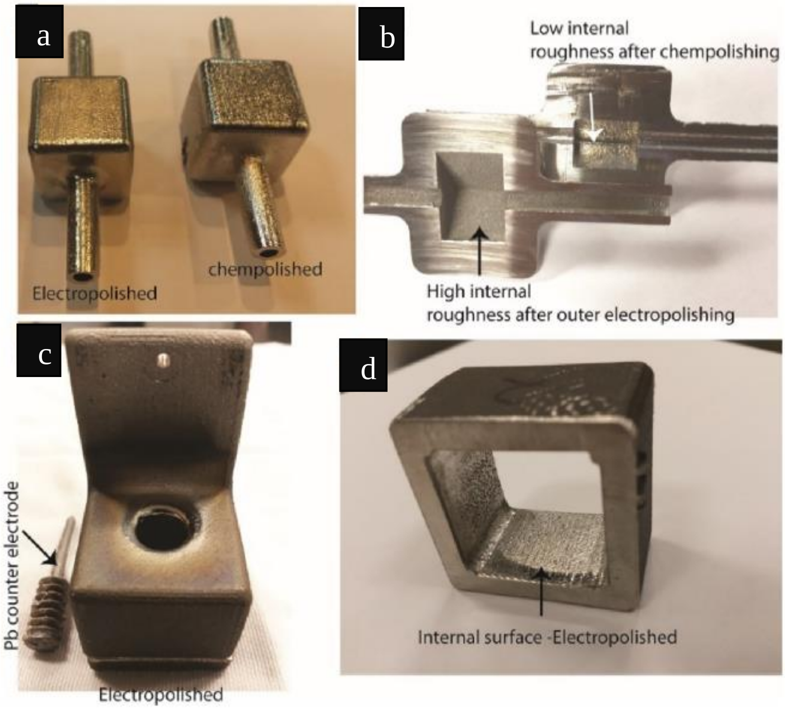


Figure 4. (a) Outer surface texture (b) internal surface texture of 316 steel components with internal volume after electrochemical polishing and chemical polishing. (c) 316 steel components designed to allow electrochemical polishing of internal surface by accommodating counter electrode. (d) Internal surface of electro-polished 316 steel components shown in Fig. 4c [17].

The experimental variables to be considered in the ECP method are: current density, electrode gaps, polishing time, electrolyte temperatures, type of electrolyte, and flow rate [14, 18]. In the literature, current density draws attention as the most effective parameter for ECP method [14]. Furthermore the size of the current to be used, as a general rule, it is recommended to provide a bath of 0.004 m^3 for every 2-4 ampere current to be electrolyzed at 65.5-93.3 ° C [19]. Three-dimensional imperfections - holes, cracks, slags - embedded above or just below the surface of the part may appear after ECP and worsen surface quality. For such cases or for better surface quality, it is recommended to use before ECP treatment if ECP method and another post-processing method will be used together (e.g. HIP) [15]. It appears that the ECP treatment removes the surface roughness of the samples and increases the corrosion resistance, as well as reducing its hardness and Young's modulus. Reducing the hardness and young modulus of polished samples can be associated with dissolution of precipitates during processing and removal of residual surfaces from the surface of the samples [16]. There is a situation that should not be neglected when AM alloys are subjected to the ECP process, which is that the non-conductive phases present in the AM alloys are not affected by the ECP treatment and this impairs the surface quality of the AM alloys [15]. Therefore, the ineffectiveness of the ECP method to the non-conductive phases and the fact that the ECP process has too many variables can be considered the disadvantages of this method. According to the literature, it is possible to reach the conclusion that increasing some input variables such as the current density, polishing time, the electrolyte temperature, and the electrolyte concentration flow rate, and reducing the electrode gaps contribute to enhancing surface quality of parts produced by AM. For example, in Figure 5 shows the contribution of increasing polishing time to reducing surface roughness of Inconel 718 produced by AM.

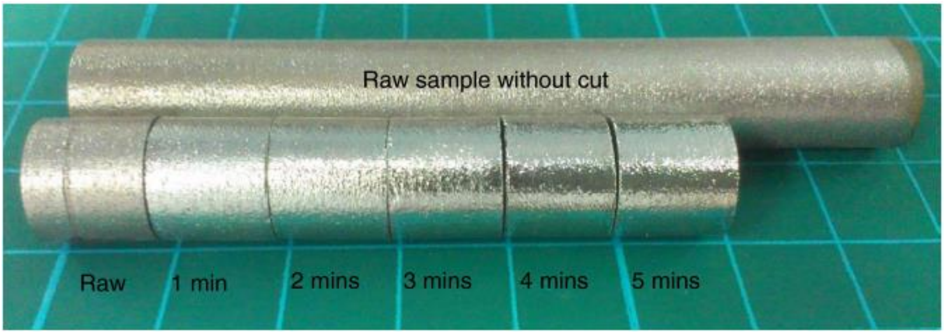


Figure 5. Photo of SLM-processed Inconel 718 tube samples and samples after ECP from 1 to 5 min [16].

In addition, comparison studies shows that the ECP is more successful than chemical polishing for decreasing the outer surface roughness. But the chemical polishing is more successful for the internal surfaces applications than the ECP method. Thus, the ECP post-process seems to be more effective on complex AM metal samples. However, since input variables in this process play great role on the final surface quality, further extensive studies considering various geometries and components made from various materials by additive manufacturing process should be performed.

4. ELECTROPLATING

Electroplating is the creation of a metallic film with electrochemical methods on a metallic or non-metallic material surface. Many products are used in our daily life, the surface of which is covered with electrolytic methods. It is known that a variety of electroplating methods are applied to watches, gold in glasses, car and aircraft parts [20] as they provide some of the desired surface and mechanical properties that cannot be obtained by the implementing other post-processing methods. The electroplating raises the Young's modulus of the parts, making the part more durable, preventing corrosion and can be used for aesthetic reasons (gold or silver plating) [21-23]. This method has also been commonly used in additive manufacturing as post-processing method. It is generally implemented to components made of polymeric materials to increase the strength and conductivity of parts [24] . The most commonly used coating materials in this method are gold, copper, silver, chrome, nickel, zinc, brass, etc. materials [25] . Coating with nickel and chromium are being commonly implemented. Nickel plating provides good corrosion and wear protection. Chrome has also better wear and friction properties than nickel [26]. The electroplating occurs in a solution of metal ions known as the electrolyte. There are two electrodes, usually an anode made of coating metal, and a cathode made of metal to be coated on [27, 28] .

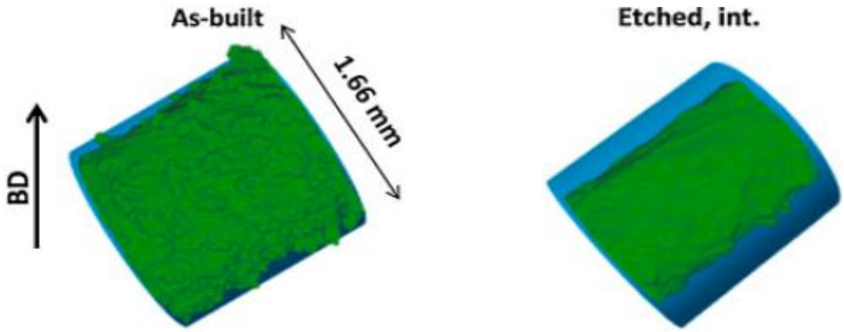
Figure 6. LAM manufactured test pieces. On the left without coating, middle chromium coated and right bright nickel coated [28] .

The fact that the electro coating method can be used mainly to change the surface properties of an object can be applied to parts produced by conventional methods, as well as to applicability to parts with complex and rough surfaces produced by additive manufacturing. Electroplating method, by applying on additive manufacturing parts whose surface quality is not at the desired level, improves the quality of the surface, as well as positively affecting the mechanical properties of the part, and it is widely preferred. For instance, Figure 6 shows stainless steel work pieces produced by additive manufacturing and followed by electroplating post-processing method.

Many studies confirmed that electroplating process has a positive effect on the parts produced with additive manufacturing [28,29]. Daneshmand et. al. [29] applied electroplating to improve the mechanical properties and surface roughness of the wing and tail of a wind tunnel test model with complex geometry produced by additive manufacturing, resulting in a hard, abrasion resistant and heat resistant surface of the parts. They also reported that hard chrome electroplating implemented to plastic parts provides high durability with relatively high brittleness. Mäkinen et al. [28] used nickel and chromium as well as electrolysis (autocatalytic) accumulated nickel in the electroplating process in order to improve the corrosion resistance, friction and wear properties of the parts produced by additive manufacturing. Wear resistance of electroless nickel layers is one of its important features. The hardness of electroless nickel depends on the amount of phosphorus and boron, and this hardness can be increased by heat treatment. Some typical applications where these coatings are used to reduce wear are: hydraulic cylinders, pumps, valves, shafts and gears [28]. Saleh et al. [22] coated additively manufactured parts with different thicknesses of copper and nickel and reported the obtained properties. Their experimental results showed that thicker coatings increase the ultimate tensile strength (UTS) and impact energy, but have a minimal effect on the ductility of the parts. They also compared the performance of electroplating on the properties of the parts produced by stereolithography (SLA) and selective laser sintering (SLS). The tensile tests show that increased coating thickness results in a lower elongation for SLS parts and an increase value for SLA parts. Elongation values for low coating thickness are unexpectedly similar to uncoated samples (5 percent for SLA and 8 percent for SLS) . However, when SLA parts are used in very wet conditions, they often fail within days due to swelling. Absorption of water leads to softening of the parts and therefore weaker mechanical properties [22]. This problem can be eliminated with metal coating. Shorrock et al. [30] reported that the application time of the electroplating process significantly changed the properties of the part. In that study, some of the parts produced by AM were subjected to electroplating for one day duration at low voltage, while the other parts were subjected to electroplating during four hours at high voltage. It was observed that the parts covered at a high voltage for a shorter period of time had high roughness values. The results showed a distinct advantage of slower coating. Overall assessment of this method shows that like previously discussed methods, Electroplating method is also efficient and implementable in additive manufacturing processes as a post-processing operation. However, again relatively limited studies are available in the literature. More work is required to see its effectiveness in various applications in additive manufacturing processes to reach concrete conclusion.

5. CHEMICAL ETCHING

Chemical etching (CHE) is the process that enables chemical reactions to occur between the chemical solutions and the surface to bring the surface roughness to the proper levels [31]. In chemical etching, diluted and concentrated aqueous hydrochloric (HCl), sulfuric (H_2SO_4), nitric (HNO_3) and hydrofluoric (HF) acid, concentrated aqueous solutions such as oxalic acid ($(COOH)_2$) and aqua regia (HCl + HNO_3) chemical solutions are used [32]. It was observed that this post-processing method was used to remove the roughness of the complex tools and equipment used mostly in the medical industry [33] .In the medical industry, additive manufacturing methods offer many advantages over traditional methods in producing complex porous structures designed specifically for the patient. However, particles adhering to the surface of the parts produced with AM may cause deterioration in the quality of the surface, thus putting the patient's health at risk. Chemical etching is known to have the ability to clean adhering particles, as well as maintain the fatigue performance of the scaffolds of the parts. When conducting chemical etching, firstly, the porous structures produced are cleaned in an ultrasonic bath in demineralized water for about 10 minutes, washed with ethanol and air dried to remove loose surface impurities and dust particles remaining from the pores. Afterwards, the parts are immersed in the chemical solution and this solution abrades the dust particles attached to the surface of the porous structure with a thin neck and causes the weakly bonded particles to fall [32]. Hooreweder et al. [33] developed a chemical etching process to improve the surface quality of the CoCr F75 scaffolds produced by SLM and examined the effect of the scaffolds on the fatigue properties of the scaffolds. In that study, 27 % HCl and 8 % H_2O_2 etchant proved to be effective in removing the adhering particles while maintaining the semi-static and fatigue performance of the scaffolds. It also shows that etched samples behave a little more fragile than untreated samples due to micro engraving. In the recent studies of Van Hooreweder et al. [33], a significant improvement in fatigue strength was observed compared to samples made after etching. However, it was observed in this study that the fatigue resistance of the scaffolds was not improved by chemical etching. It has been interpreted as the reason for this may be the low notch sensitivity of the CoCr material and the remaining porosity in the supports. Charlotte de Formanoir et al. [34] analyzed the microstructure and mechanical properties of Ti-6Al-4V lattice structures with various relative densities produced by Electron Beam Melting and applied an effective chemical etching process on these structures. Density measurements carried out by the Archimedes method affirmed that the parts with etching processes displayed a lower relative density compared to the as-built parts. This reduction in density is based to the reduction of the strut diameter caused by etching. As-built structures with an incipient densities of 28.5 %, 14 % and 7 % present 21 %, 7 % and 4 % densities after etching. The effect of chemical etching on the roughness of the lattice structures is presented in Figure 7. Another good implementation of chemical etching is presented in Figure 8 where various type of solutions were used and effectiveness of this approach on improving surface of titanium meshes fabricated by SLM [35].



Relative Density: 28.5%
R_a: 34.3 µm
R_t: 181.7 µm

Relative Density: 21%
R_a: 25.9 µm
R_t: 121.5 µm

Figure 7. X-ray microtomography of the effect of chemical etching on lattice structures [34].

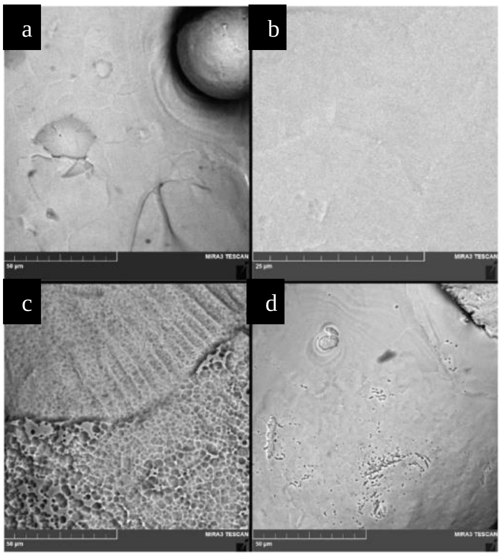


Figure 8. SEM images of as-prepared and chemical etched meshes: nontreated (a), H_2SO_4/HCl (b), NH_4OH/H_2O_2 (c), H_2SO_4/H_2O_2 (d) [35].

Dobrzański et al. [36] used different acid solutions and applied surface treatment with chemical etching at different times to reduce the rough surfaces of Ti6 and Ti6Al4V metallic scaffolds produced by selective laser sintering. Water and hydrofluoric acid solution (HF), mixture of hydrochloric acid (HCl) and FFF (SO4), aqua regia acid solutions were applied to the titanium and Ti6Al4V parts. It has been shown that water and hydrofluoric acid (HF) solution provides better roughness values compared to other solutions, but the percentage of mass loss with the use of this solution are 9.72 % and 7.6 %. On the other hand, the use of aqua regia solution provides good roughness values as well as mass loss is only 3 % and 1.8 % . In Figure 9, microscopic images of scaffolds before and after etching are shown.

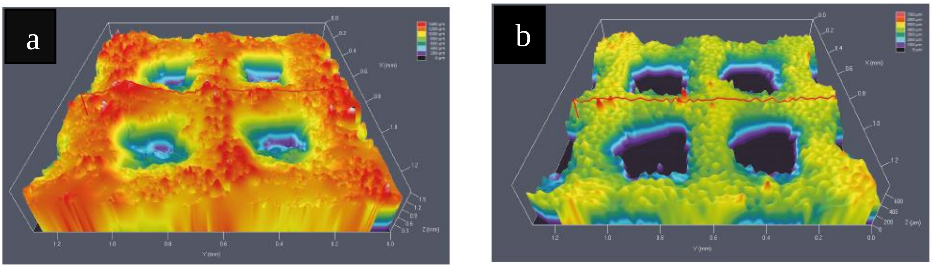


Figure 9. (a) Porosity measurement of Ti6Al4V scaffolds before etching, (b) Porosity measurement of Ti6Al4V scaffolds after etching with HF and water solution lasting 8 minutes [36].

Pyka et al. [32] applied chemical etching and electrochemical polishing method using HF based solutions to improve the surface qualities of Ti alloy open porous structures produced by additive manufacturing. In processes using HF solution, it was found that CHE (for 10 minutes) mainly removes bound powder grains, while ECP (for 8 minutes) further reduces roughness. However, as a result of these processes, the mechanical properties have decreased. Chemical etching seems to be more commonly used as post-processing operations for porous internal structure for scaffolds. As the literature summary presented, it has high potential to contribute this area although it sometimes leads to some undesired results.

6. VAPOUR SMOOTHING

Vapour smoothing is a post-processing technique that hot chemical vapour smoothes the surface of samples without tool work piece contact in a given time [37]. In other words, polishing thermoplastic materials such as acrylonitrile butadiene styrene (ABS), poly lactic acid (PLA) with certain amounts of chemicals such as acetone, dichloroethylene, tetra hydro flouride, ethyl acetate etc. [38]. Chohan et al. [37] reported that ABS samples produced with FDM significantly reduced surface roughness by applying vapour smoothing for 5 minutes with 90 % acetone and 10 % water, while also increasing their average weight by less than 1% while the samples shrank below 1%. Mu et al. [39] reported that the surface quality improved by increasing the exposure time and acetone ratio by applying the vapour smoothing method to the ABS samples produced with FFF with three different exposure times (10-30-50) min with acetone, ethyl acetate and their mixed steam. In addition, the same group suggested that acetone vapour is more active, the samples have better surface quality in processes using 100% acetone, but the surface of the samples is relatively softer, the weight of the samples is higher, the tensile strength of the samples is lower and the dimensional accuracy deviations of the samples are higher. Rao et al. [40] implemented various amounts of acetone and methyl ethyl ketone chemical vapours on ABS samples produced with FDM. They stated that solution concentration, concentration-temperature interaction and initial roughness are the most important factors. Rajan et al. [38] reported the most effective parameter with the lowest duration and the lowest amount in the vapour smoothing process performed in three different amounts of tetrahydrofuran (10-15-20) ml and three different exposure times (5-7,5-10) min to PLA samples produced with FDM. Espalin et al. [41] reported that pre-cooling is required for a few minutes before the vapour smoothing process to achieve better results on ABS samples produced with FDM. Singh et al. [42] stated that for the best surface roughness values of ABS samples produced with FDM, the temperature of the steam smoothing process should be in the range of 60 ° to 80 ° C. Fig.10 shows the as-built version of ABS parts produced with FDM and the vapour smoothed ABS parts.

Figure 10. (a) Acetone vapour smoothed ABS parts. (b) As-built [43].

Considering the literature, it is possible to reach conclusion that are effective parameters in the vapour smoothing method as solution concentration, concentration-temperature interaction, exposure time and initial roughness. However, increasing exposure time appears to impair the balance of tensile strength, weight and size of samples. Because all chemical vapour processes have caused the weight of the ABS samples to increase, and the reason for this is that the chemical is absorbed by the porous structure of the ABS samples. In addition, absorption of the chemical by ABS samples causes shrinkage in volume. In the literature, it is seen that most of the ABS thermoplastics are applied vapour smoothing using acetone and mixed with water to reduce the effect of acetone. The most frequently used acetone water mixing ratio is 90 % acetone and 10 % water. However, in the literature, poly carbonate (PC), poly methyl methacrylic acid (PMMA), polyethylene terephthalate (PET) etc. It has been observed that vapour smoothing is not applied to other FDM-produced thermoplastic materials. In the future, it is necessary to try the vapour smoothing method on different thermoplastic materials and to work with different chemical vapours at different rates.

7. ACETONE DIPPING

Acetone is one of the cleaning agents that penetrate deep into the surface of the material and to polish the parts. This process, which is applied to the ABS parts produced with the most FDM in studies, improves the surface quality of parts by dipping in the bath filled with acetone solution (90 per cent dimethyl ketone and 10 per cent water) for a certain period of time. In addition, Galantucci et al. [4] states that acetone is a fast and inexpensive treatment that can significantly improve the surface quality of ABS parts . However, it should be noted that acetone negatively affects the respiratory system. It suggests that the acetone dipping process applied by Percoco et al. [44], Colpani et al. [45] to ABS parts, has an increase of up to 90 % in reducing the surface roughness of the parts. Additionally, acetone dipping technique can improve flexural strength, wear resistance and water tightness, however, 1 % shrinkage can affect the accuracy of the part but is neglected [44, 46]. In this post process method, the application time and acetone ratio in the solution are important. Mccullough et al. [5] achieved the best results for the acetone dipping process by dipping the parts in an aqueous acetone solution ranging from 40-60 % acetone in a period of 1-8 hours. Havenga et al. [7] aimed to provide evidence that the acetone treatment provides better surface coverage of FDM-produced ABS parts and can be used to mount smaller manufactured parts to larger parts. In that study, the tensile strength of the parts subjected to acetone decreased from 0.027 kN / mm² to 0.008 kN / mm². Besides, the acetone dipping process is less invasive, so it caused a less decrease in tensile strength than acetone evaporation. In addition to this, in the acetone dipping process, acetone leaks into the cracks in the ABS parts, and as it evaporates very fast, the outer layers in the part close and acetone can get stuck in the fractures, causing distortion in the part. In addition, the use of dilute solution can prolong the immersion times and the prolonged periods may damage the part. In order to make more accurate and systematic finishing, the method must be controlled, automated and mechanized [47].

8. CONCLUSION

It is obvious that post-processing is an inevitable process, as the parts produced by additive manufacturing with today's technology do not meet the surface quality requirements. In this study, chemical post process methods applied to the parts produced with AM are examined. This current study shows that chemical post process methods can generally be used to reduce the surface roughness, which is the biggest problem of parts produced with AM. In addition, this study also revealed that most chemical post-processing methods can improve flexural strength, abrasion resistance and water tightness. However, it should be noted that chemical post-processing methods have also some drawback.. For instance, some chemical post processing methods reduce the tensile strength and cause deterioration on the surface of the part. In order to eliminate such disadvantages, chemical post-processing methods are used consecutively with different post-processing methods. In addition, the number of repetitions of chemical finishing methods has been increased to further improve the surface quality of the part. However, this increase in the number of repetitions has been observed to negatively affect the mechanical properties of the part. Further studies focusing on optimizing process parameters for these chemical post-processing operations are certainly needed to explore their maximized benefit to additively manufactured parts. This is an important as some of the chemical post-processing approaches are the only way that can be used for enhancing additively manufactured parts. Considering the number of studies in the literature in this area seems to be not sufficient as of now, but the overall trend shows that the interest of researchers to chemical post-processing increases. Thus, in the near future, it will be possible to eliminate majority of drawback chemical post-processing includes and increase their benefit.

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