https://dx.doi.org/10.22161/ijaers.711.41 ISSN: 2349-6495(P) | 2456-1908(O)

Recycling of plastic waste in the 3D printing process with the potential for stem production, mobile part of the facial protector: Literature review

Rosangela Rocha de Oliveira[1], Fabiana Rocha Pinto[2]

[1]Environmental Engineering; Fametro University Center, Brazil
[2]Forest Engineer; Fametro University Center, Brazil

Received: 4 Sept 2020; Received in revised form: 18 Nov 2020; Accepted: 21 Nov 2020; Available online: 02 Dec 2020

Abstract**—***When the health system goes into crisis and the lack of personal protective equipment becomes a reality, it is recommended to cancel all procedures that are not urgent, to carry out the contingency in the use of personal protective equipment. Besides for this scenario, the use of masks beyond the expiration date designated by the manufacturer and their reuse are actions indicated by the National Health Surveillance Agency (ANVISA) in a Technical Note released on March 31, 2020. To minimize the contamination of the mask, the health professional should use a face shield: The rapid technical evolution of additive manufacturing (AM) allows a new path to a circular economy using recycling and distributed production. This article aims to examine the current advances in thermoplastic recycling processes using additive manufacturing Technologies. After proposing the production of the stem using recycled material for DRAM, a comprehensive and in-depth review of the literature on the feasibility and state of the art of reusing plastic waste in materials using the Scopus, web of Science, and Springer databases. The results suggest that few works have been carried out for the recovery and preparation stages, while a major advance has already been made for the other stages to validate the technical feasibility, environmental impact, and economic feasibility. The development of each proposed stage using the open-source approach is a relevant way to dimension the DRAM to reach the technical potential for producing the stem.*

Keywords**—Additive manfacturing; Individual protection; Plastic recycling.**

I. INTRODUCTION

The WWF study [1],indicates that the volume of plastic that leaks into the oceans each year is approximately 10 million tons, which is equivalent to 23,000 Boeing 747 planes landing in the seas and oceans each year.To tackle this problem of waste accumulation, the european strategy for recycling plastics and the increase in the circular economy, highlights the political and business debate around the sustainable development of industrial production [2]. The circular economy addresses a central question of society about the current principle "take, make, dispose" (linear economy) and its negative effects caused by the depletion of natural resources, waste generation, loss of biodiversity, pollution (water, air, soil) and not sustainable economy [3].

The validation (technical, economic, legislative) of plastic waste as a secondary raw material in industrial processes is now considered a central objective to integrate the EC in the plastic value chain [4]. Open and closed loop recycling strategies, as well as upcycling and downcycling functionality approaches can offer ways to validate secondary raw materials [5].

Recycled materials have also been used in additive manufacturing (MA). In this process, the pieces are made by the consecutive deposition of layers of material guided by a three-dimensional (3D) model of computer aided design (CAD). With the end of the FDM process patent in

https://dx.doi.org/10.22161/ijaers.711.41 *ISSN: 2349-6495(P) | 2456-1908(O)*

the 2000s, the development of self-replicating machines known as RepRap (Replicating Rapid Prototyper) began. These printers have open source software and hardware available for anyone to download the software and projects, building their own version. In economic terms, the global additive manufacturing market is expected to reach US $ 23.33 billion by 2026 [6]. However, determining when and how to reap the benefits is a challenge for traditional means of production.

From the point of view of society, [7] product development may change from traditional stage-gate models to iterative and agile processes, changing the scenario by 2030. A large number of products can now be manufactured with additive manufacturing, which affects the geographic distribution and density of supply chains. global values [8]. It is expected that the range of products produced by additive manufacturing to date is printable and that in the near future it will be much greater, since the production of multi-material and built-in functionalities (for electronic products) is already possible in large quantities. In addition, the production of spare parts can be carried out on site, changing the role of suppliers in the production lines [9]; [10] explored the stages of distributed model factories and types of decentralized production ranging from distributed resources to cloud production. Thus, the need for transportation will be much more careful due to the fact that additive manufacturing allows the decentralization of production to locations close to customers or in the most extreme scenario distributed at the customer's premises [12]; [13]. In addition, this technology makes it possible to reduce barriers to market entry, reduce capital requirements and achieve a minimum efficient production scale to promote distributed and flexible forms of production [14]. This allows an alternative option from an economy of scale to an economy of scope, where products are highly personalized.

A better understanding of the different steps required to transform plastic waste into secondary raw materials for additive manufacturing is needed. Therefore, this work presents a study of systematic literature review. Addressing some important points regarding the problem in relation to the polymeric mixture, polymers versus additive manufacturing and environmental issues.

II. METODOLOGY

Five reviews have been identified in the literature [15], which address the qualitative and quantitative environmental impact of 3D printing in order to provide a comprehensive understanding and better guide research on the subject. A framework has been proposed to assess and improve the sustainability of 3D printing processes through the integration of CAD and LCA software, followed by a review [16]. The environmental performance of additive manufacturing was analyzed, showing that most authors are concerned with the energy consumption of additive manufacturing equipment. [17] describes the evolution, advances and predictions of the 4D printing life cycle, focusing on intelligent materials and associated characteristics as their response to stimuli, along with future challenges. The review of [18] analyzed the state of the art of sustainable additive manufacturing and classified 63 articles in three areas: environment, economy and society. Finally, a review conducted by [19] assesses the economic and environmental sustainability of additive manufacturing techniques by analyzing different sources in the literature, including standards proposed by different regulatory bodies located around the world, highlighting the importance of models for the construction of indicators risk.

In several studies examined in this literature review, comparisons have been made between conventional machining processes in the additive manufacturing process using LCA software as a comparison tool.

[20] assessed supply chain delivery times, primary energy consumption in the life cycle, greenhouse gas emissions and the life cycle costs of a product produced by additive manufacturing. [21] compared the environmental impact of conventional additive manufacturing using carbon fiber composite material in production. [22], assessed the environmental impact of additive manufacturing and rapid prototyping to assess manufacturing time and the cost of manufacturing metal components. [23] compared a centralized manufacturing system on a conventional mass scale for the production of a glass frame, with a distributed manufacturing system compatible with 3D printers. [24] carried out a study of the environmental impact of different impeller manufacturing methods, by immersion milling (CM), laser coating formation (MA combined with CM) and remanufacturing of additives (RM).

[25] related energy consumption and the environmental impact of direct energy deposition with traditional machining processes. [26]; [27] compared the environmental impact of the machining process taking into account a conventional approach using single scale or batch production. [28] studied the effects of recycling up to four extrusion cycles on electronic waste and the production of virgin plastic filaments, proposing a mechanism for integral semi-quantitative degradation supported by FT-IR and TGA results. [29] indicated the

https://dx.doi.org/10.22161/ijaers.711.41 ISSN: 2349-6495(P) | 2456-1908(O)

different approaches to manufacturing aluminum alloy components manufactured by additive manufacturing and other traditional processes. The results revealed that, for the case studies analyzed, additive manufacturing is a sustainable solution for the production of aluminum components for the following specific scenarios: when creating highly complex shapes, when significant weight reduction is necessary and when be used in transport systems. [30] assessed the environmental impact of additive manufacturing based on the robotic welding process, a 3D metal printing technique, and compared it with the green sand casting process and Computer Numerical Control milling. Through the literature and databases, they concluded that the results can vary significantly according to the shape of the product, its function of the materials used and the configuration of the process.

The rapid prototyping technique has also been used to assess environmental issues related to additive manufacturing. [31] showed additive manufacturing processes through the sintering process and selective laser fusion, identifying their most significant environmental impacts. Subsequently, [32] developed a method considering all the flows involved (material, fluids, electricity) in order to obtain the environmental impact study. This method was developed based on a predictive model of flow consumption to produce a certain part that was defined by the manufacturing route and the CAD model.

III. RESULTS AND DISCUSSION

The European Commission, plastic materials are a priority area aiming to make all packaging made of recyclable material by 2030 [33]; [34]. In addition, it is a key enabler for circular economy, to close the polymer waste cycle [35]. However, mechanical recycling encounters several obstacles, since management and collection are complex technical considerations of plastic degradation [36]; [37]. The incompatibility between most polymers makes the classification process essential for satisfactory properties [38]. The separation of flexible laminated structures (for example, food packaging) for recycling, not economically, which explains that packaging applications, the biggest contributor to the production of plastic waste, are sent to landfills [39].

From a logistical point of view, the recycling process is less economically viable and the complex heterogeneity of the waste mixture that implies an investment in means of transport, storage and sorting. In addition, the price of recycled plastic is a function of the prevailing oil price [40]. Therefore, creating a context that improves the economy and quality of plastic recycling are essential issues to be resolved in order to create value from these secondary resources. Specifically, assessing the quality of materials, components and products upstream and downstream from the point where they are disposed of as waste are the most important aspects to be determined [41]. Where, chemical recycling appears as a preferable option for complex and contaminated waste [42]. "Fig.1" presents data on production, use and destination of all plastic [43].

Additive manufacturing is defined as a process of joining materials to make objects from 3D models, where the manufacturing process is done layer by layer [44]. Accordingtothe ISO standard, thesevenmainprocesscategories are: (1) binderjet, (2) directenergydeposition, (3) extrusion material, (4) material jet, (5) powder, (6) sheetlaminationand (7) light curing.

Polymeric materials are by far the most used material [45]; [46]: Thermoplastics, thermosets, elastomers, hydrogels, functional polymers, mixtures of polymers, compounds and biological systems. Recent work has presented a complete review of polymeric materials [47], additive manufacturing with a focus on 4D printing [48]. Elastomers [49]. Based on additive principles that apply to all manufacturing technologies, depending on the construction principle of each technique, it requires attention, since there are different physical aspects for the union of the material. Such a procedure generates different requirements for functionality and other parameters need to be considered to ensure a holistic technical understanding of the material, processes and properties. Most of the thermoplastics processed by the extrusion process are amorphous. The technical requirements of the material extrusion process include interfacial adhesion and undisturbed polymer entanglement to manufacture non-porous objects with mechanical properties similar to products made by conventional techniques [49]. In addition, rheological, thermal and mechanical properties need to be characterized to validate the use of a particular material. In the scientific literature, there have been many advances in the three-dimensional control of parts produced by the additive manufacturing process [50], mechanical properties, such as traction [51]; [52]; [53], fatigue [54]; [55], flexion [56], thermal properties [57]. In addition, several applications have successfully used polymeric materials, including dentistry [58].

However, from a technological point of view, different challenges have been identified for the development of additive polymer manufacturing in order to improve its competitiveness [59]. This competitiveness is related to the functionality of the printed object, evolving from rapid prototypes or tools to the user's final product. Efforts have been made to reduce the anisotropy of printed parts [60]. Often, products produced by the additive manufacturing process have inferior mechanical properties compared to other manufacturing techniques in many cases, especially in the direction of construction [61]. In addition, manufacturing speeds are lower than traditional processing, such as injection molding. On the other hand, the current development of 4D printing is an important way to develop smart polymer materials. Polymers with shape memory, hydrogels or compounds based on active polymer are currently explored in several studies in order to evolve the 3D printed static part to change its shape, given a specific trigger or environment [62]. Objects with complex shapes, compositions (multimaterials), gradients (multicolored) and multifunctional (hard-soft) in a single step are advanced systems of additive manufacturing.

In the environmental aspect, the clear advantage of additive manufacturing has the strong point of delivering more complex, optimized components and reducing assembly operations. It has greater flexibility in relation to traditional manufacturing, thus reducing it with less time, cost and improving the product development cycle [63]; [64]; [65]. However, other factors such as operational requirements do not meet the process have restrictions and limitations on absolute geometric freedom [66]; [67].

In the production phase, three main aspects stand out: resource consumption, waste management and pollution control. In consumption, several studies have measured the energy consumed by 3D printer equipment and its auxiliary subsystems [68] Material consumption [69] and comparison between traditional and additive processes [70]. Considering waste management in comparison between the weight ratio of the final product versus the weight of the input material. [71] reported a complete review on zero waste manufacturing, in which additive manufacturing represents an opportunity to implement this work. The mentioned challenges of plastic waste shape a scope of recycling and a loop framework of the closed loop recycling structure for Recycling distributed via the 3D manufacturing process is proposed in order to identify the scientific literature at each stage based on the literature on polymer recycling [72]. This will allow us to identify advances in the global value chain that enables the production of the face shield stem with recycled polymer.

Redistributed to manufacturers that use manufacturing technologies such as additive manufacturing or 3DP as part of a circular and sustainable production and consumption system.

IV. CONCLUSION

In the present work, a review of the literature on additive manufacturing processes was carried out, seeking to recognize and identify the relevant aspects in relation to the recyclability of materials currently used in additive manufacturing and the environmental aspects in relation to production by additive manufacturing. Likewise, this study highlights the importance of considering some aspects in relation to the circular economy and sustainability in relation to the production processes related to additive manufacturing.

The increase in the number of publications on the topics presented in this study shows that researchers are paying more attention to the sustainability of the additive manufacturing process. This suggests that the limitations of manufacturing in terms of reusing and recycling materials for rod manufacturing, the mobile part of the face shield will be quickly reduced.

Materials with better recyclability will be more favorable for the production of the stem, the mobile part of the facial protector in a short period of time since production by additive manufacturing is the evolution and further studies in this area will consolidate this process.

ACKNOWLEDGEMENTS

I thank God for being with me on this beautiful journey of challenges and overcoming the teachers during the teaching day, my parents who encouraged and believed in my dreams and goals, the close friends who supported me and my children who are my strength.

REFERENCES

[1] Comissão Europeia, 2018. A European Strategy for Plastics in a Circular Economy, COM (2018). Bruxelas. https://doi.org/10.1021/acs.est.7b02368.

[2] Geissdoerfer, M., Savaget, P., Bocken, NM, Hultink, EJ, 2017. The Circular Economy - A new sustainability paradigm? J. Clean. Prod., 2017, 143, p 757e768. https://doi.org/ 10.1016 / j.jclepro.2016.12.048:

[3] Van Buren, N., Demmers, M., van der Heijden, R., Witlox, F., 2016. Towards a Circular Economy: The Role of Dutch Logistics Industries and Governments. Mdpi Sustainability journal, 2016, 8, 647. https://doi.org/10.3390/su8070647:

[4] Simon, B.. What are the most significant aspects of supporting the circular economy in the plastic industry? Conserv. Recycl. 2018 Elsivier, 141, p 299e300. https:// doi.org/10.1016/j.resconrec.10.044.

[5] Zhuo, C., Levendis, Y.A..Upcycling waste plastics into carbon nanomaterials: a review. J. Appl. Polym. Sci. 2014, 131. https://doi.org/10.1002/app.39931.

[6] Data, RA, 2019. Additive Manufacturing Market to Reach

USD 23.33 Billion by 2026. http://www.globenewswire.com/news-release/2019/03 /18/1756526/0/ pt / Additive-Manufacturing-Market-To-Reach-USD-23-33-Billion-By-2026.html:.Acessado em: 13 de agosto de 2019.

[7] Jiang, R., Kleer, R., & Piller, F. T. Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing for 2030. Technological Forecasting and Social Change, 2017, 117, p 84–97. https//doi. org/10.1016/j.techfore.2017.01.006.

[8] Laplume, AO, Petersen, B., Pearce, JM,. Gobal value chains from a 3D printing perspective. J. Internacional Business Studies. 2016, p595e609. https://doi.org/10.1057/ jibs.2015.47.

[9] Zanoni, S., Ashourpour, M., Bacchetti, A., Zanardini, M., Perona, M., 2019. Supply chain implications of additive manufacturing: a holistic synopsis through a collection of case studies. Int. J. Adv. Manuf. Technol. 102, p3325e3340. https://doi.org/10.1007/s00170-019-03430-w.

[10] Matt, D.T., Rauch, E., Dallasega, P., 2015. Trends towards distributed manufacturing systems and modern forms for their design. Procedia CIRP 33, p185e190. https://doi.org/10.1016/j.procir.2015.06.034.

[11] Bonnín Roca, J., Vaishnav, P., Laureijs, R.E., Mendonça, J., Fuchs, E.R., 2019. Tech- nology cost drivers for a potential transition to decentralized manufacturing. Addit. Manuf. 28, p136e151. https://doi.org/10.1016/j.addma.2019.04.010.

[12] Petersen, E., Kidd, R., Pearce, J., 2017. Impact of DIY home manufacturing with 3D printing on the toy and game market. Technologies 5, p45. https://doi.org/10.3390/technologies5030045.

[13] Wittbrodt, B., Glover, A., Laureto, J., Anzalone, G., Oppliger, D., Irwin, J., Pearce, J.,2013. Life-cycle economic analysis of distributed manufacturing with open-source 3-D printers. Mechatronics 23, p713e726. https://doi.org/10.1016/j.mechatronics.2013.06.002.

[14] Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S., Garmulewicz, A., Knowles, S., Minshall, T., Mortara, L., Reed-Tsochas, F., Rowley, J. 2017. Unlocking value for a circular economy through 3D printing: a research agenda. Technol. Forecast. Soc. Change 115, 75e84. https://doi.org/10.1016/j.techfore.2016.09.021.

[15] Hienerth, C., Hippel, E. von, Berg Jensen, M., 2014. User community vs. producer innovation development efficiency: a first empirical study. Res. Policy 43, p190e201. https://doi.org/10.1016/j.respol.2013.07.010.

[16] Petrick, I.J., Simpson, T.W., 2013. 3D printing disrupts manufacturing: how econo- mies of one create new rules of competition. Res. Manag. 56, p12e16. https://doi.org/10.5437/08956308X5606193.

[17] Hart, K.R., Frketic, J.B., Brown, J.R., 2018. Recycling meal-ready-to-eat (MRE) pouches into polymer filament for material extrusion additive manufacturing. Addit. Manuf. 21, p536e543. https://doi.org/10.1016/j.addma.2018.04.011.

[18] Milios, L., 2018. Advancing to a Circular Economy: three essential ingredients for a comprehensive policy mix. Sustain. Sci. 13, p861e878. https://doi.org/10.1007/s11625-017-0502-9.

[19] Morseletto, P., 2020. Targets for a circular economy. Resour. Conserv. Recycl. 153, 104553. https://doi.org/10.1016/j.resconrec.2019.104553.

[20] Rosa, P., Sassanelli, C., Terzi, S., 2019. Towards Circular Business Models: a systematic literature review on classification frameworks and archetypes. J. Clean. Prod. 236, 117696. https://doi.org/10.1016/j.jclepro.2019.117696.

[21] Commision, European, 2015.Summary for policymakers. In: IntergovernmentalPanel on Climate Change. Clim. Chang. 2013 - Phys. Sci. Basis. Cambridge Uni- versity Press, Cambridge, pp. 1e30. https://doi.org/10.1017/CBO9781107415324.004.

[22] Intergovernmental Panel on Climate Change (Ed.). (n.d.). Summary for Policymakers. Climate Change 2013 - The Physical Science Basis, 1–30. https://doi.org/10.1017/cbo9781107415324.004.

[23] Ragaert, K., Delva, L., Van Geem, K., 2017. Mechanical and chemical recycling of solid plastic waste. Waste Manag. 69, 24e58. https://doi.org/10.1016/j.wasman.2017.07.044.

[24] Al-Salem, S., Lettieri, P., Baeyens, J., 2009. Recycling and recoveryroutesofplastic solid waste (PSW): a review. Waste Manag. 29, 2625e2643. https://doi.org/10.1016/j.wasman.2009.06.004.

[25] Hopewell, J., Dvorak, R., Kosior, E., 2009. Plastics recycling: challenges and oppor- tunities. Philos. Trans. R. Soc. B Biol. Sci. 364, 2115e2126.https://doi.org/10.1098/rstb.2008.0311.

[26] Signoret,C.,Caro-Bretelle,A.-S.,Lopez-Cuesta,J.-M.,Ienny, P.,Perrin,D.,2019.MIR spectral characterization of plastic to enable discrimination in an industrial recycling context: I. Specific case of styrenic polymers. Waste Manag. 95, 513e525.https://doi.org/10.1016/j.wasman.2019.05.050.

[27] Curtzwiler, G.W., Schweitzer, M., Li, Y.,Jiang, S., Vorst, K.L., 2019. Mixed post- consumer recycled polyolefins as a property tuning material for virgin poly- propylene. J. Clean. Prod.239,117978. https://doi.org/10.1016/j.jclepro.2019.117978.

[28] Horvath, B., Mallinguh, E., Fogarassy, C., 2018. Designing business solutions for plastic waste management to enhance circular transitions in Kenya. Sustain- ability 10, 1664. https://doi.org/10.3390/su10051664.

[29] Iacovidou, E., Velenturf, A.P., Purnell, P., 2019. Quality of resources: a typologyfor supporting transitions towards resource efficiency using the single-use plastic bottle as an example. Sci. Total Environ. 647, 441e448.https://doi.org/10.1016/j.scitotenv.2018.07.344.

[30] Ragaert, K., Delva,L., Van Geem, K., 2017. Mechanical and chemical recycling of solid plastic waste. Waste Manag. 69, 24e58. https://doi.org/10.1016/j.wasman.2017.07.044.

[31] Brogan Rylands, Tillmann Böhme, Robert Gorkin Joshua, Fan Thomas Birtchnell, (2016). "The adoption process and impact of Additive Manufacturing on manufacturing

systems", Journal of Manufacturing Technology Management , Vol. 27 Iss 7 pp. http://dx.doi.org/10.1108/JMTM-12-2015-0117.

[32] ASTM52900, 2015. Standard terminology for additive manufacturing egeneral principles eterminology. ASTMInt.i1e9.https://doi.org/10.1520/F2792-12A.2.

[33] Bourell, D., Kruth, J.P., Leu, M., Levy, G., Rosen, D., Beese, A.M., Clare, A., 2017. Ma- terials for additive manufacturing. CIRP Ann 66, 659e681. https://doi.org/10.1016/j.cirp.2017.05.009.

[34] Ligon, S.C., Liska, R., Stampfl, J., Gurr, M., Mülhaupt, R., 2017. Polymers for 3D printing and customized additive manufacturing. Chem. Rev. 117, 10212e10290. https://doi.org/10.1021/acs.chemrev.7b00074.

[35] Ligon, S.C., Liska, R., Stampfl, J., Gurr, M., Mülhaupt, R., 2017. Polymers for 3D printing and customized additive manufacturing. Chem. Rev. 117, 10212e10290. https://doi.org/10.1021/acs.chemrev.7b00074.

[36] Gonza´lez-Henríquez,C.M.,Sarabia-Vallejos, M.A., Rodriguez-Hernandez, J., 2019.Polymers for additive manufacturing and 4D-printing: Materials, methodolo- gies, and biomedical applications. Prog. Polym. Sci. 94, 57e116. https://doi.org/10.1016/j.progpolymsci.2019.03.001.

[37] Herzberger, J., Sirrine, J.M., Williams, C.B., Long, T.E., 2019. Polymer design for 3Dprinting elastomers: recent advances in structure, properties, and printing.Prog. Polym. Sci. 97, 101144.https://doi.org/10.1016/ j.progpolymsci.2019.101144.

[38] Turner, B.N., Gold, S.A., 2015. A review of melt extrusion additive manufacturing processes: II. Materials, dimensional accuracy, and surface roughness. Rapid Prototyp. J. 21, 250e261. https://doi.org/10.1108/RPJ-02-2013-0017.

[39] CruzSanchez,F.A.,Boudaoud,H.,Hoppe,S.,Camargo,M., 2017.Polymerrecyclingin an open-source additive manufacturing context: mechanical issues. Addit. Manuf. 17, 87e105.https://doi.org/10.1016/j.addma.2017.05.013.

[40] Hebda, M., McIlroy, C., Whiteside, B., Caton-Rose, F., Coates, P., 2019. A method for predicting geometric characteristics of polymer deposition during fused-fila- ment-fabrication. Addit. Manuf. 27, 99e108. https://doi.org/10.1016/j.addma.2019.02.013.

[41] Dizon, J.R.C., Espera, A.H., Chen, Q., Advincula, R.C., 2018. Mechanical character- ization of 3D-printed polymers. Addit. Manuf. 20, 44e67. https://doi.org/10.1016/j.addma.2017.12.002.

[42] Jasiuk, I., Abueidda, D.W., Kozuch, C., Pang, S., Su, F.Y., McKittrick, J., 2018. An overview on additive manufacturing of polymers. JOM 70, 275e283. https://doi.org/10.1007/s11837-017-2730-y.

[43] Tanikella, N.G., Wittbrodt, B., Pearce, J.M., 2017. Tensile strength of commercial polymer materials for fused filament fabrication 3D printing. Addit. Manuf. 15, 40e47. https://doi.org/10.1016/j.addma.2017.03.005.

[44] Safai,L.,Cuellar,J.S.,Smit,G.,Zadpoor,A.A.,2019.Areviewo fthefatiguebehaviorof 3D printed polymers. Addit. Manuf. 28, 87e97. https://doi.org/10.1016/j.addma.2019.03.023.

[45] Yadollahi, A., Shamsaei, N., 2017. Additive manufacturing of fatigue resistant ma- terials: challenges and opportunities. Int. J. Fatig. 98, 14e31. https://doi.org/10.1016/j.ijfatigue.2017.01.001.

[46] Phan, T.T.P., Phan, T.Q., Sherif El-Gizawy, A., 2019. Development of a combinedanalytical and experimental approach for the determination of the cohesive strength between material extrusion layers using the true area of contact. Addit. Manuf. 30, 100832.https://doi.org/10.1016/j.addma.2019.100832.

[47] Turner, B.N., Gold, S.A., 2015. A review of melt extrusion additive manufacturing processes: II. Materials, dimensional accuracy, and surface roughness. Rapid Prototyp. J. 21, 250e261. https://doi.org/10.1108/RPJ-02-2013-0017.

[48] Stansbury,J.W.,Idacavage,M.J.,2016.3Dprintingwithpolym ers:challengesamong expanding options and opportunities. Dent. Mater. 32, 54e64. https://doi.org/10.1016/j.dental.2015.09.018.

[49] Ligon, S.C., Liska, R., Stampfl, J., Gurr, M., Mülhaupt, R., 2017. Polymers for 3D printing and customized additive manufacturing. Chem. Rev. 117, 10212e10290. https://doi.org/10.1021/acs.chemrev.7b00074.

[50] Torrado,A.R.,Shemelya,C.M.,English,J.D.,Lin,Y.,Wicker,R .B.,Roberson,D.a.,2015. Characterizing the effect of additives to ABS on the mechanical property anisotropy of specimens fabricated by material extrusion 3D printing. Addit. Manuf. 6, 16e29.https://doi.org/10.1016/j.addma.2015.02.001.

[51] Ko,Y.S.,Herrmann,D.,Tolar,O.,Elspass,W.J.,Br€andli,C.,20 19.Improvingthefila- ment weld-strength of fused filament fabrication products through improved inter diffusion. Addit. Manuf. 29, 100815. https://doi.org/10.1016/j.addma.2019.100815.

[52] Gonza´lez-Henríquez,C.M.,Sarabia-Vallejos, M.A., Rodriguez-Hernandez, J.,2019. Polymers for additive manufacturing and 4D-printing: Materials, methodolo- gies, and biomedical applications. Prog. Polym. Sci. 94, 57e116. https://doi.org/10.1016/j.progpolymsci.2019.03.001.

[53] Guo, N., Leu, M.C., 2013. Additive manufacturing: technology, applications and research needs. Front. Mech. Eng. 8, 215e243. https://doi.org/10.1007/s11465-013-0248-8.

[54] Vaezi, M., Chianrabutra, S., Mellor, B., Yang, S., 2013. Multiple material additive manufacturing e Part 1: a review. Virtual Phys. Prototyp. 8, 19e50. https://doi.org/10.1080/17452759.2013.778175.

[55] Wong, K.V., Hernandez, A., 2012. A review of additive manufacturing. ISRN Mech.Eng. 2012, 1e10. https://doi.org/10.5402/2012/208760.

[56] Mellor, S., Hao, L., Zhang, D., 2014. Additive manufacturing: o framework for implementation. Int. J. Prod. Econ. 149, 194e201. https://doi.org/10.1016/j.ijpe.2013.07.008.

[57] Peng, T., Kellens, K., Tang, R., Chen, C., Chen, G., 2018.

Sustainability of additive manufacturing: an overview on its energy demand and environmental impact. Addit. Manuf. 21, 694e704. https://doi.org/10.1016/j.addma.2018.04.022.

[58] Baumers,M.,Tuck,C.,Bourell,D.L.,Sreenivasan,R.,Hague,R.,2011.Sustainabilityof additive manufacturing: measuring the energy consumption of the lasersin- tering process. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. 225, 2228e2239. https://doi.org/10.1177/0954405411406044.

[59] Bourhis,F.L.,Kerbrat,O.,Hascoet, J.-Y.,Mognol, P., 2013.Sustainablemanufacturing: evaluation and modeling of environmental impacts in additive manufacturing. Int. J. Adv. Manuf. Technol. 69, 1927e1939. https://doi.org/10.1007/s00170-013-5151-2.

[60] Yoon, H.-S., Lee, J.-Y., Kim, H.-S., Kim, M.-S., Kim, E.-S., Shin, Y.-J., Chu, W.-S., Ahn, S.H., 2014. A comparison of energy consumption in bulk forming, subtractive, and additive processes: review and case study. Int. J. Precis. Eng. Manuf. Technol. 1, 261e279. https://doi.org/10.1007/s40684-014-0033-0.

[61] Singh, R., Kumar, R., Singh, I., 2019c. Investigations on 3D printed thermosetting and ceramic-reinforced recycled thermoplastic-based functional prototypes.J. Thermoplast. Compos. Mater. 089270571986462. ISSN: 08927057. https:// doi.org/10.1177/0892705719864623.

[62] Chong,S.,Pan,G.-T.,Khalid, M.,Yang, T.C.,Hung,S.T., Huang,C.-M.,2017.Physical characterization and preassessment of recycled high-density polyethylene as3D printing. Material. J. Polym. Environ. 25, 136e145. https://doi.org/10.1007/s10924-016-0793-4.

[63] Siddaway,A.P.,Wood,A.M.,Hedges,L.V.,2019.Howtodoasystematicreview:a best practice guide for conducting and reporting narrative reviews, meta- analyses, and meta-syntheses. Annu. Rev. Psychol. 70, 747e770. https://doi.org/10.1146/annurev-psych-010418-102803.

[64] Unruh G. Circular economy, 3D printing, and the biospererules. Calif Manage Rev, 2018, 60:95-111. http://dx.doi.org/10.1177/0008125618759684.

[65] Garmulewicz A, Holweg M, Veldhuis H, YangA. Disruptivetechnology as an enabler of the circular economy: whatpotential does 3D printing hold? Calif Manage Rev, 2018, 60:112-32, http://dx.doi.org/10.1177/0008125617752695.

[66] Clemon LM, Zohdi TI. On the tolerable limits of granulatedrecycled material additives to maintain structural integrity.Constr Build Mater, 2018, 167:846-52. http://dx.doi.org/10.1016/J.CONBUILDMAT.2018.02.099.

[67] Santander P, Cruz F, Boudaoud H, Camargo M. 3D-printingbased distributed plastic recycling: a conceptual model for closed-loop supply chain design. In: 2018 IEEE int conf engtechnol innov. 2018. p. 1-8. http://dx.dolorg/10.1109/ICE.2018.8436296.

[68] Sauerwein M, Doubrovski EL. Local and recyclable materialsfor additive manufacturing: 3D printing with mussel shells.Mater Today Commun, 2018;15:214-7. http://dx.doi.org/10.1016/j.mtcomm.2018.02.028.

[69] Minetola P, Eyers D. Energy and cost assessment of 3Dprinted mobile case covers. Proc CIRP, 2018, 69:130-5, http://dx.doi.org/10.1016/j.procir.2017.11.065.

[70] Saboori A, Aversa A, Marchese G, Biamino S, Lombardi M, Fino P. Application of directed energy deposition-based additive manufacturing in repair. Appl Sci, 2019, 9:3316. http://dx.doi.org/10.3390/app9163316.

[71] Sauerwein M, Doubrovski E, Balkenende R, Bakker C. Exploring the potential of additive manufacturing for product design in a circular economy. J Clean Prod, 2019;226:1138-49. http://dx.doi.org/10.1016/j.jclepro.2019.04.108.

[72] Nascimento DLM, Alencastro V, Quelhas OLG, Caiado RGG, Garza-Reyes JA, Rocha-Lona L, et al. Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context. J Manuf Technol Manag, 2019, 30:607-27, http://dx.doi.org/10.1108/JMTM-03-2018-0071.