AMERICAN JOURNAL OF INNOVATION IN SCIENCE AND ENGINEERING (AJISE)

ISSN: 2158-7205 (ONLINE)

VOLUME 2 ISSUE 2(2023)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Innovation in Science and Engineering (AJISE)

Volume 2 Issue 2, Year 2023
ISSN: 2158-7205 (Online)
DOI: https://doi.org/10.54536/ajise.v2i2.1279
https://journals.e-palli.com/home/index.php/ajise

An Overview for the Potentials of Additive Manufacturing: Polymers Recycling Project in Egypt

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Article Information

Received: February 07, 2023
Accepted: March 18, 2023
Published: May 08, 2023

Keywords

Additive Manufacturing, Egypt Vision 2030, Polymers Waste, Recycling Products Sustainability

ABSTRACT

Additive manufacturing is a star-rising technology around the globe. It satisfies key needs in different fields of interest on a global scale. For both ongoing industrial revolutions, it is considered an enabler as well as for achieving certain Sustainable Development Goals. Regarding the manufacturing sector, the technology serves well for different delicate fields like aerospace, automotive and medicine. Polymers are amongst the wide range of materials that are utilized in additive manufacturing. They provide indispensable mechanical properties in different fields as they possess light weight with high strength and toughness. The existence of polymers in the form of waste is massive, especially after the outbreak of COVID-19. The calls for sustainable development are global. Exploitation of polymer wastes as a feedstock material for additive manufacturing can be considered an opportunity to be seized by Egyptian manufacturers. Such that producing new products, reducing wastes and costs. These piles of waste may now be viewed as wealth. Under the umbrella of the current reforms and developments taking place in the country this can be called upon to be a national project. The paper presents an overview for the opportunity of establishing such a national recycling project in Egypt that depends on 3d printing.

INTRODUCTION

Around the globe, there are several major fields of keen interest are currently taking place. Sustainability, Industry 4.0 and Industry 5.0 have all emerged simultaneously with no notable time gaps, and countries worldwide are making their efforts towards adopting them all in parallel. The Egyptian political perspective after the revolution on June 30th, 2013 has dramatically changed. It has created several pathways to locate Egypt on the global track of development. The Egyptian strategy "Egypt Vision 2030" is a national representation of the United Nations Sustainable Development Goals (Amin, 2021). This strategy represents how seriously Egypt beats the grand, rapid and complicated changes taking place around the world.

Several initiatives have been called upon to support the implementation of the strategy. As "Digital Egypt" initiative, that drafts new developmental conditions to facilitate Industry 4.0 adoption in Egypt (Moghaieb, 2019). This initiative was raised by the Egyptian Ministry of Communication. Aiming to transform the entire ecosystem of the Egyptian society alongside all the existing government services to be completely digitized. "Decent Life" is another initiative, which can be considered as the Egyptian context for the Japanese movement "Society 5.0" to adopt Industry 5.0. The main goal of "Decent Life" is human-centered, as it aims to enhance the daily living conditions of Egyptian citizens, especially in the countryside (Amin, 2021).

Given this plenitude of strategies aiming towards Egypt's development, there are many local and global challenges that should be well recognized. Climate change, water scarcity, and COVID-19 pandemic all are examples of global challenges. Although waste management concern is a local challenge, it is significant and should be considered. Egypt is a populous country at approximately 100 million inhabitants generating an estimated amount of about 1.2 Kg of a daily solid waste/person/day. Therefore, resulting in massive amounts of wastes roaming through the Egyptian streets (Development, 2021). The corona virus pandemic has magnified the waste problem, especially that of polymeric material (Yee Van Fan, 2021). Polymeric waste piles are accumulating. Proper waste management and recycling projects are among the Egyptian goals to achieve its 2030 vision (Development, 2021).

This paper aims to provide an outline for using additive manufacturing technology to promote the call for national polymeric waste recycling project headed for Egypt 2030 vision goals. Furthermore, the current project output "recycled polymers products" are considered one of the pathways leading the world towards sustainability.

Additive Manufacturing and Global Trends

Additive Manufacturing- A Review

Additive manufacturing is the process of building up products layers from a certain material rather than cutting from it. It is used to be called rapid prototyping, free fabrication and 3d printing. The technique was developed initially to test prototypes and validate the authenticity of designs. The term additive-manufacturing is the official term used in the ASTM International Standards (Mahesh Mani, 2014). The process of production starts with a computer aided design for the product. Then it passes through a printer software that slices the design into several layers. Afterward, the machine starts building

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the layers incrementally to finally obtain the 3d physical product (Heinrich, 2021).

Additive Manufacturing as a technology includes several techniques. Those techniques do utilize wide range of materials. Exclusive attention is being directed towards those techniques associated with plastics. In order to help solve the plastic waste problem. Polymers dependent additive manufacturing has been used in the production of various application parts. From medical implants, optical products, architectural parts, sports equipment, smart textiles, soft robotics to custom tools for aerospace industry. They all benefit the high ability of customization and complex shapes production that additive manufacturing provides.

Additive Manufacturing Polymer Dependent Methods in Brief:

- Stereolithography Apparatus, is a vat photopolymerization technology, in which a vat of the polymer resin is cured using an ultraviolet light source. The principle depends on a computerized building stage on which the light illuminates the pattern to be printed (Md. Sarower Tareq, 2021), (Ferry P. W. Melchels, 2010).

- Selective Laser Sintering, which depends on using an infra-red laser beam to appropriately heat powdery substances. The powder used is a pre-polymer thermoplastic. With the help of a roller, the powder is spread over the surface of a built cylinder. Then a piston moves downward for a distance equal to one object layer such that the powder layer is accommodated. The fabrication chamber is entirely sealed and its temperature is maintained at (the thermoplastic glass transition temperature) just below the melting temperature (Mazzoli, 2013), (Ian Gibson, 1997).

- Poly Jet Printing and Multi Jet Fusion, are polymer-based additive manufacturing techniques for producing prototypes and finished products. Poly Jet Printing is similar to Stereolithography. While Multi Jet Fusion is greatly comparable to Selective Laser Sintering.

- Fused Deposition Modeling, is the revolutionary digital form of conventional extrusion and injection molding (Md. Sarower Tareq, 2021). This is the most popular polymer-based additive manufacturing technology. Its principle is based on the availability of uninterrupted feed of the polymer filament into the liquefying chamber. The liquefying chamber transforms the filament from the solid state into a semi-liquid state ready for deposition through the extrusion nozzle over the building platform (Ankita Jaisingh Sheoran, 2020).

The process of additive manufacturing generally faces a set of provocations that require improvements. Processing conditions affecting the structure and properties of the product are under investigations for further enhancement (Arit Dasa, 2020). Also, size limitations of the produced part is another issue. As larger parts are unsuitable for the technology due to amplified processing time (K.Satish Prakasha, 2018).

Additive Manufacturing and Industrial Revolutions

Additive Manufacturing and Industry 4.0

Industry 4.0 is the 4th industrial revolution. It firstly appeared in 2014 by the German government (Xun Xu, 2021). It is named the Digital Revolution, as it aims to digitizing the entire manufacturing sector. This digitization constitutes the integration of the physical along with digital technologies (Rojko, 2017). Cyber-Physical Production Systems represent its core. Smart factories concept is considered a target for Industry 4.0. These smart factories depend on remote decision-making and self-managed operations, as well as mass customization (Marina Crnjac, 2017). Additive manufacturing is a technology with strong capabilities that promote Industry 4.0 adoption (Ugur M Dilberoglu, 2017). It can handle a wide range of materials through the process. It has the merit of producing intricate, sophisticated and highly customized/personalized products. It also works with computer-aided designs with minimal human intervention (Javeed, 2019). It is typically a programmable machine that can be self-organized/optimized.

Additive Manufacturing and Industry 5.0

Industry 5.0 is also called "Society" according to the Japanese government. It is a value-driven revolution, rather than a technological one (Yuqian Lu, 2022). Industry 5.0 according to the European Commission is driven by 3 main values: Sustainability, Human Centricity and Resilience (Maija Breque, 2021). Industry 5.0 is not initiated to replace Industry 4.0 but to complement it. It is supposed to value and appreciate the human role. Human centricity in Industry 5.0 is not limited to the fear of unemployment that is going to spread due to digitization brought by Industry 4.0. It is a much wider concept that cares for personnel health and opinions as well (Yuqian Lu, 2022).

It is also meant to promote resilience measures and encourage sustainability efforts. Industry 5.0 is an approach that maintains the engine of prosperity through the transition to digital green manufacturing. Additive manufacturing is a customized technology that promotes human centricity. The technology values customers' personal requirements and delights (Javeed, 2019). The resilience of manufacturing allows fast response to any changes in the demand (Bardia Naghshineh, 2022). Additive manufacturing can stand disruptions in orders with minimal production disturbance. Additive manufacturing has higher impacts on achieving sustainability performances than subtractive methods (Sam Solaimani, 2021).

Additive Manufacturing and Sustainability

Profound problems regarding the environment have been intensively discussed since late 1980's. Calamities in terms of climate change, scarcity of water and sparse resources are alarming (Hossam A. Kishawy, 2018).

Greenhouse gasses and water pollution are spreading diseases. So, the criterion for evaluating an organization's success is no longer limited to economic means. The

criterion has widened to include the environment as well as the social impacts of the business (Correia, 2019). A sustainable enterprise nowadays should address environmentally harmless activities as well as emphasizing labor working conditions. Along with the economic growth, these are now called the triple bottom lines of sustainability which should be maintained to claim an enterprise is successful. By 2015, the United Nations issued a set of 17 goals known as Sustainable Development Goals. These are globally obligatory on developing and developed countries to be achieved by 2030 (Nations, 2017).

Additive manufacturing technology to be used as a core for a business, then it has to be assessed with the three new lines of business success, or what is known as the Triple Bottom Lines (TBL) of sustainability (Correia, 2019), results are shown in table 1:

Table 1: Additive Manufacturing against Sustainability Triple Bottom Lines

Triple Bottom Lines	Gains	Inadequacies
Environmental Line	-Fewer waste -Higher material utilization -High possibilities of recycling	-Higher energy intensity
Social Line	-Enhanced customer satisfaction -Potential benefits on workers' health	-Undetermined effect on unemployment
Economic Line	-Short lead times -Less assembly -On-demand manufacturing	-long time - Costs/part -limited dimensions

Additive manufacturing is acclaimed to enhance sustainable practices. Environmentally, it is meant to eliminate resource demands and minimize energy consumption. Along with decreased carbon footprint related to the process. Since it uses no tooling system as well as no environmentally damaging lubricants. Socially, it may be argued to decrease human involvement such that increasing unemployment.

On the other hand, it is a computer aided manufacturing method that values designers and increases their capacity and welcomes their significant influence. New business models can be built based on additive manufacturing, economically speaking (Muthu, 2016). Additive manufacturing is anticipated to reduce the effects of transportation, eliminate inventory and supply issues. Over the near future, centralized additive manufacturing is viewed as an improved business approach (Danfang Chen, 2015), (Carla Gonclaves Machado, 2019)

Additive Manufacturing and COVID-19

The virus was initiated in Wuhan city of China and shortly was declared a pandemic. Corona virus is a respiratory novel virus that causes severe acute respiratory disease that may lead to death. Scientists and epidemiologists are still studying this 120nm in diameter pathogen (Rigoberto Advincula, 2020). The unprecedented events caused by the virus from its novelty to its vast spread among people have led to certain containment actions. One of these actions included mainly the usage of personal protective equipment as precautionary measures. These equipment constituents were face shields, surgical masks and latex gloves. Along with frequent hand sanitization (Kuan Shiong Khoo, 2021). The circumstances that occurred with the virus spread worldwide resulted in curfew inside countries and isolation for some parts of cities. This has slowed down trade on all economic levels creating an urgent demand for the equipment entailed to cope with the virus. Thus, encouraging local resourcing for shortages that occurred in these goods. Additive manufacturing technology stepped in to meet these demands (Rigoberto Advincula, 2020). Previous researches related to that concluded that the usage of additive manufacturing exceeded the expectations in fulfilling this decentralized supply chain (Novak JI, 2020; P., 2020).

Additive Manufacturing in Egypt

Since 2014 and after changing the Egyptian regimen, Egypt has started the journey of revitalization. By the issuing of the Egyptian Strategy for Development "Egypt Vision 2030" in 2016, Egypt is aiming to be placed among the top 30 countries worldwide regarding the economic and scientific and innovation statuses (Chen, 2018). Since then, Egypt has been committed to implement reforms in these sectors in line with the health, educational and housing sectors. Despite the several successes earned because of the reforms, other pressing challenges are yet to be managed. One of them is the identification of innovative development mechanisms while considering the availability of limited resources (Amin, 2021).

From this point further, additive manufacturing can be considered an innovative mechanism that can recycle wastes and produce broadly new products (K. DePalma, 2020). Consequently, overcoming the limited resources problem regarding raw materials. Additionally, there is an ongoing awareness promotion for green manufacturing called "Go Green". This call was held just prior to the climate conference held in Sharm Elshiekh city (COP 27) November, 2022. The call aimed at establishing new idea for green smart manufacturing projects. To identify the applicability of such a proposal the additive manufacturing situation in Egypt is to be studied in the following sections.

Additive Manufacturing and Education in Egypt

All levels of education from primary to university are

under the spot of reform these days in Egypt. Study plans and curriculum updates are carefully managed. Enhancement for universities to join the digital era is taking place by leaps and bounds (Ashour, 2020).

Additive manufacturing is being adhered to where possible, especially for the mechanical departments. Several graduation projects are about executing 3d printers by the students themselves under the proper guidance of the staff (Ashraf Elsafty, 2020). For example, at Pharos University in Alexandria (PUA), which is a private university, an additive manufacturing project is accomplished this year. The project is an open-source recycling technique, which integrates an extruder above the nozzle directly. Figure 1 refers to the 3D printer presented by the senior students as their graduation project in Pharos University 2021. Such that, it recycles and manufactures at the same time. The American University in Egypt offers around the year courses regarding additive manufacturing. The Egyptian ministry of higher education started in 2020 to establish a new generation of universities to deal with the global market requirements. That includes international and national universities (Alamein International University-Galala University-King Salman International University etc.…) which all include advanced manufacturing laboratories. As, the public universities have their own labs that include 3d printers that are built in the fulfillment of the student's graduation project bachelor's degree. Even in post graduate's researches additive manufacturing is becoming of great concern. For example, through the outbreak of the coronavirus pandemic Egyptian researchers have put their efforts to utilize the process for facing the situation. Additive manufacturing was proposed by researchers to manufacture face shields with and without filters to support the growing demand during the pandemic (May, 2021; Mohamed K. Ahmed, 2020).

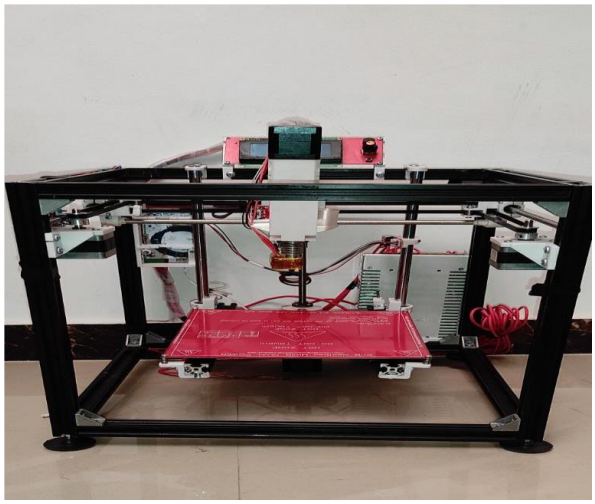

Figure 1: 3D-printer with integrated Direct Filament Extruder made at the PUA as a graduation project

Additive Manufacturing Markets in Egypt

There is a growing market for 3d printers in Egypt. Despite the dominancy of the engineering sector in both industry and education regarding the additive manufacturing technology, but recently other sectors such as medical and art are strongly taking parts. Dentistry applications are a very large market for the usage of additive manufacturing and are growing widely in Egypt. According to the Journal of the American Chamber of Commerce in Egypt (Noureldin, 2019),the pace of the commercial usage of the technology in customized accessories production is at its maximum. A cost drop by 51 % occurred in the costs of the machines/materials assisted its spread (Mehrshad Mehrpouya, 2019). Finally, all the in the Egyptian market refer to a massive growing in 3D printers' utilizations.

Municipal Solid Wastes in Egypt and Opportunities for Recycling

On local basis, an approximate daily amount of 1.2 kg/person/day of solid wastes is produced. Regionally, Egypt is considered chief in polymeric waste generation in the African continent. Egypt owns 18.4% of the total continent's polymeric wastes available (Otobong Donald Akan, 2021). This massive amount of solid waste exists with a collection efficiency of 40% and a recycling efficiency of no more than 2.5% (Development, 2021). The available wastes offer an adequate feedstock for 3d printers in the Egyptian market. However, it is the quality of the final product that raise concerns here. As to use wastes as feedstock either being chemically/mechanically recycled or not prior to the manufacturing stage might lower the grade of the finally produced part.

The proposed project suggests utilization of polymeric wastes from the general medical waste portion. The steps will follow a typical mechanical recycling steps assisted with some chemical methods to improve the wastes quality and abate thermal/mechanical degradation effects. To be finally introduced as high quality filaments to the 3D printers to manufacture new added value products.

RESULTS AND DISCUSSION

The status of the proposed project can be considered promising. Feasibly speaking, materials and machines are both available for affordable prices. The required experiences to start the business can be easily provided. The developmental track Egypt is riding on now opens horizons for newly suggested projects to be nationally adopted. On the other hand, there are obstacles associated with the process. Product quality which is influenced by the materials or the processing conditions. Material concerns do rise due to poor waste management methods. That they do not guarantee sorting. Such that mixed wastes used as feedstock with/without prior recycling would negatively impact the properties of the produced part. Recycling of sorted wastes before being fed in the additive manufacturing process has its own complications. As recycling processes in themselves might degrade the produced feedstock quality. The additive manufacturing technology has its own spectrum of challenges. From build orientation, voids formation

to processing time. However, there are great positive chances for the project success. Availability of a massive market that appreciates the indispensability of plastic products. The encouragements to foster sustainability practices. Which mainly preserve resources, eliminate wastes and decrease CO_2 emissions. Although, several adversaries for the project do exist; extremely low price imported products as well as the interest of investors to invest in recycling projects. But, hopefully an event like the "Climate of the Planet, COP 27" conference, held in Sharm Elshiekh during November 11th to 22nd, 2022 will definitely encourage recycling activities through sustainable means. A SWOT analysis presented in figure 2 demonstrates the potentials of additive manufacturing in Egypt. This analysis helps the current project in being assessed carefully to enhance its opportunities of success.

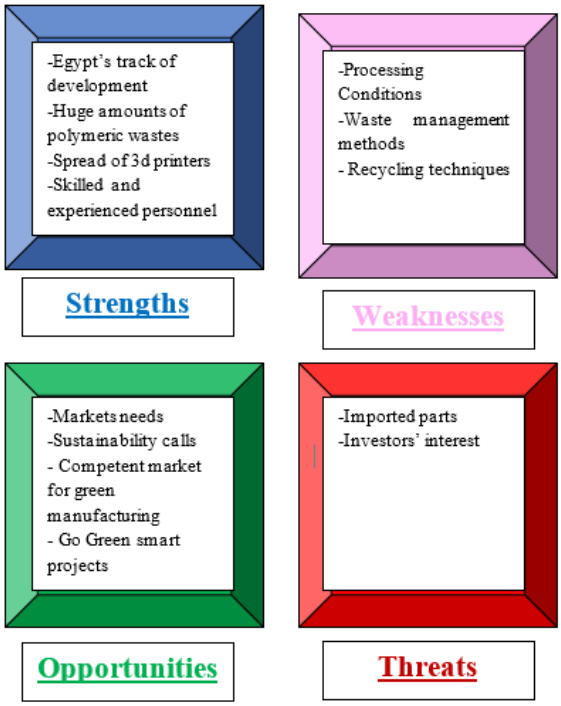

Figure 2: SWOT analysis for the potentials of additive manufacturing in Egypt

CONCLUSION

The additive manufacturing future for recycling practices in Egypt can be considered fortunate. Polymeric Wastes availability with the widespread acknowledgment of the process among people, increase the adoption possibility of the recycling business. Egypt is a dense country with a multi-level skilled population. There are low-skilled, semi-skilled and highly skilled employees in all fields. This allows such a recycling business to find all kinds of needed human resources to begin. The current project can be deployed as a national project under the umbrella of the Egyptian Sustainable Development Strategy. The "Go Green" call for smart green manufacturing processes can be a supportive initiative for the project. Such that, providing licenses and funds for startups utilizing the idea. Egypt's government presents all the support for such projects towards achieving its 2030 vision on the national aspect and for a sustainable world as a global aspect.

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