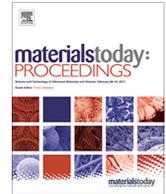




Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Emergence of additive manufacturing in global scale during the crisis of 2019-nCoV (novel corona virus)

Vijay Tambrallimath*, R. Keshavamurthy, Abhinandan Badari, Lohith Ramesh, Gagan Raj

Dayananda Sagar College of Engineering, Bangalore, India

ARTICLE INFO

Article history:

Received 16 November 2020

Received in revised form 16 November 2020

Accepted 26 December 2020

Available online xxxx

Keywords:

Additive manufacturing

COVID-19

Manufacturing

Medical kit

Corona virus

ABSTRACT

The global pandemic COVID-19 has emerged as a bane for the human race. The emergence of this disease was initially noted in Wuhan, China and slowly spreading to large number of countries. The greater number of positive cases and increasing mortality rate clubbed with no prescribed medication to cure has led to greater impact on global society and has badly hit the manufacturing sector. Additive Manufacturing (AM) is considered to be primary source of manufacturing in meeting the supply chain towards medical devices and protection kits. This paper discusses the response of global AM community in development of essential products in the desired time span for greater cure.

© 2021 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Mechanical, Electronics and Computer Engineering 2020: Materials Science.

1. Introduction

The emergence of new epidemic disease named as 2019-nCoV (novel corona virus) has reportedly seen its advancement to world through its origin from Hubei Province of China from the city of Wuhan during December 2019 [1]. The initial identification of this disease relates to severe pneumonia symptoms and the reported patients had a history of visit to Hunan seafood and live animal market in the city of Wuhan. The identified samples of patients from Hunan seafood market after testing had the similarity index greater than 90% of bat corona virus and greater than 70% homology to SARS-CoV (Severe Acute Respiratory Syndrome – Corona Virus) that had emerged in 2002–2003 in Guangdong Province of China with its origin from bat mammals and transferred to humans through intermediary palm civet cats [2,3]. Hence 2019-nCoV is also known as SARS-CoV-2 (Severe Acute Respiratory Syndrome Corona Virus 2). The electron microscopy analysis of this novel corona virus depicts its structure to be spherical in nature with diameter ranging from 60 to 140 nm and having tentacle like projections [4]. The global impact of this virus spread has seen an exponential upsurge in the number of people being affected. As on April 6, 2020 the global corona virus cases stands to 16,82,160 with total deaths of 1,01,975 and the total recovered cases to be 3,72,093 [5]. The effect of control of disease by reducing

the mortality rate and in the same time upholding the economy of the country is impossible. Certain key factors like social distancing, quarantine and isolation of the infected community at larger scale would reduce the impact of spread. The primary decision of any government agency is to reduce the rate of mortality and in-turn restructures the economic goals in meeting the needs of individuals [6].

The analysis of this 2019-nCoV disease spread to global community has an ill effect on manufacturing sector with both market distribution and supply chain. The increased number of cases reported has led to incremental requirement of hospital treatments that are working to the fullest of their capacity. Impact of these admissions to hospitals has seen a upsurge requirement of certain equipments for healthcare workers. Ventilators, face masks and face shields along with testing kits and diagnostic tools has seen great shortage in global scale, which acts as necessity for health workers to treat the epidemic cases [7]. The impact of this on global manufacturing and precisely on India has seen an unprecedented degradation. The dependency of India on electronic goods and raw materials on China market has given a strong blow. The Indian pharmaceuticals are 70% dependent on China for Active Pharmaceutical Ingredients (API). Tourism and aviation are yet other sectors that have had a huge blow on their smooth functioning [8]. Major automotive manufacturers in India like Maruti, Hyundai, Honda, Suzuki, TVS & Tata Motors had been in-line with nationwide lockdown and have stopped the manufacturing which would lead to revenue loss of 13,000–15,000 crores [9].

* Corresponding author.

E-mail address: vijay.tambrallimath@gmail.com (V. Tambrallimath).

<https://doi.org/10.1016/j.matpr.2020.12.999>

2214-7853/© 2021 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Mechanical, Electronics and Computer Engineering 2020: Materials Science.

Throughout the history the spread of pandemics, disease and war has led to embracement of technology, the movement from conventional system to advanced and innovative technology. Amid all these concerns the government has urged all the manufacturing sectors to help in production of parts that help in mitigation of this virus at the earliest without greater spread. The world of Additive Manufacturing (AM) has emerged to this need and has given an unprecedented support in development of required parts and necessity equipments. The advancement of Additive manufacturing has seen an usage increment in industrial space since 2018. The process of AM is a versatile method in meeting the specified demands of variety of industries. It provides most suitable and fastest results to meet the demand. The norm of the time in evolution of digital storage of parts is more suitable than physical storages [10]. This paper effectively discusses the various parts developed by the process of AM during this crisis and also the emergence of this technology to greater impact.

2. Emergence of additive manufacturing

Additive Manufacturing (AM) is the process of development of parts by addition of material layer wise. The process of AM involves the development of CAD model and conversion the same to STL file and using this file in slicing software in which the optimal parameters of build would be stated along with layer thickness. According to ISO/ASTM52900-15 the classification of AM is done into seven categories viz, binder jetting, direct energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat polymerization [11]. Emergence of AM was initially used in development of prototypes in manufacturing industry, with advent of time the impact of this utilization has seen large utilization in medical field, education, design and many more. The development of new organs, custom fit mask, operation practice and dentistry application has seen large use through AM [12].

In the scenario of world effected with COVID 19, with total lockdown on major manufacturing countries, increased number of positive COVID 19 cases has led to larger requirement of large amount of personal protection equipments (PPE) for healthcare workers, ventilators and certain essential parts for treatment of affected persons would not be met with conventional dependency of manufacturing system. Additive Manufacturing, has responded in positive affirmation towards manufacture of essential parts. Global communities of AM have come forward in lending the required help for development of the above mentioned equipments [13]. Among many active participants, world's largest steel producer ArcelorMittal has pledged in support of development of prototype of ventilator using AM. The requirement of large number of ventilators during this time is of utmost important and this prototyped model would be extensively tested and if found successful would be developed at rapid rate [14]. Towards the better preparedness of the country to fight the COVID epidemic the government of United Kingdom (UK) has urged the manufacturing companies to develop as much as possible ventilators for the treatment of positive COVID people. The present number of ventilators present with UK government stands to 5,900.

With this call from the UK government large numbers of AM companies have pledged their support. One of the ISO 13,485 certified company, 3 T Additive Manufacturing from Berkshire, has quoted its facility to be well suited for development of metal and polymer devices using various materials required for medical industry. The advent of this AM technology consumes less time for production of parts and its delivery towards usage. The involvement of cost in development of support structures and other post processing can be nullified using laser sintering technology. In the similar lines British engineering and metal additive manufac-

turing firm Renishaw is yet another manufacturer that has rose to the necessary demand and are working in development of ventilators in response to the call of UK government.

Shrewsbury-based product design company, Quigley Design, is one among many UK companies that have had firsthand experience in design and development of medical devices. The company has made an appeal to all manufacturers to consider the design, manufacturing ability, reliability, safety and its use by trained and untrained staff [15]. In the verge of expanding positive cases of COVID19 and large number of deaths in recent times, Italy faced the nightmare with this pandemic. The reanimation machine, one of the medical devices that enable resuscitation of heart-lung, needed a replacement valve for its effective usage. The acquiring of these valves in short time through its place of manufacturing was not feasible. The best option was aroused with development of this valve using Fused Deposition Modeling (FDM) according to the requirement. Isinnova, a startup Italian company, developed the required part with assistance from a well know 3D printing company FabLab in Milan. The developed part using the process of FDM is shown in Fig. 1. The successful development and approval for its usage larger quantities were developed by another local company Lonati SpA, using polymer laser powder bed fusion process as shown in Fig. 2. The material used for this process was polyamide based material [16].

The initial impact of this COVID 19 virus was noted in China. The necessity of the people of China to contain its spread by being in isolation was a tough task as the beds in hospital were at brim. Winsun a 3D printing company developed Additively Manufactured houses for isolating the positive case people in Xianning. The house which was AM is shown in Fig. 3. Each house was built using extrusion process by robotic arm using quick hardening concrete and was built in approximately 2 h. Each house had a carpet area of 10sq.m and height of 2.8 m [17]. Additive Manufacturing research and application center of Hunan Vanguard Group Co., Ltd, China, have developed a spectral frame for medical usage using the process of AM. In an effort to enhance the safety of health workers the company started developing the frame with their 50 3D printing machines. The work was carried out in Changsha city. The process of development of frame is shown in Fig. 4 [18]

Materialise, a global AM service provider has made a study on most common contact points for humans in daily activities and has designed a door handle that can be operated in hands free manner. Fig. 5 shows the hands free design developed by the company. Companies like Airflow3D, California and BCN3D, Barcelona



Fig. 1. Ventilator valve alongside valve built using FDM.



Fig. 2. Valves built used powder bed fusion.



Fig. 5. Hands free door handle developed by Materialise.



Fig. 3. Houses developed for isolation in Xianning, China.

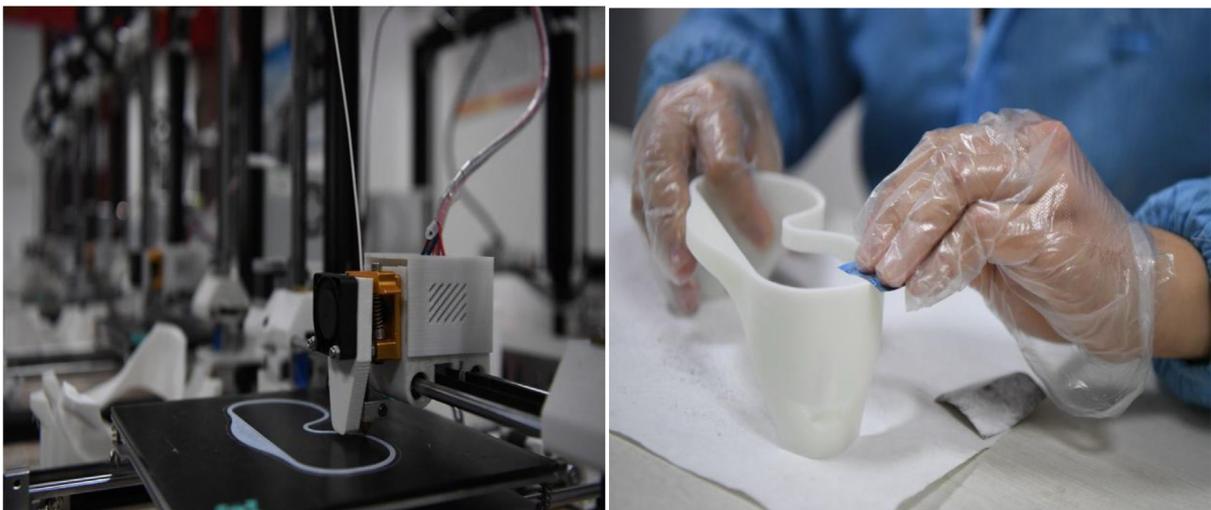


Fig. 4. Spectacle frame being developed by Vanguard Group Co., Ltd using FDM.



Fig. 6. Full face shields developed by Stratasys.

have supported the global community for through lending their AM process for development of validated designs for medical help.

Giant automobile manufacturers like Volkswagen have come up in their manufacturing facility to develop medical devices and ventilators for the greater cause. The manufacturing facility has almost 125 industrial grade 3D printers. Stratasys, an industry with foremost experience in AM has developed face shields to be used by medical workers. Fig. 6 shows the full face mask developed by Stratasys. Boston based AM company, Formlabs are efficiently working on producing 3D printed test swabs for conducting COVID-19 tests. They aim at producing 75,000–1,50,000 test swabs on daily basis that would provide the hospitals with sufficient kits for testing. Fig. 7 shows the test swabs developed by AM [19].

3. Challenges

The responses of global Additive Manufacturing companies are appreciably at this juncture of time, however, there emerges the fundamental criteria of CAD design sharing for the process

of manufacturing to start at global scale. various government bodies has urged for development of medical equipments and safety kits at faster rate, yet the necessity to develop these require stringent guidelines for manufacturing, towards its validation and the environment hygiene to be maintained during the print.

The necessity actions have to be moved at a greater speed in coordinating the necessary parameters to be followed by the developers. This kind of necessary developments will lead in ensuring the usage of the developed medical part for required purpose. Also, the product needs to developed with only approved materials and designs, along with greater reliability and quality [20].

4. Future of additive manufacturing

The utilization of AM during COVID-19 has seen as an important unit of manufacturing that has enables the supply chain management to the greater extent. With this advent the utilization of AM has a greater scope to provide medical supplies at greater speed, accurate strength and enhanced flexibility. The dependency of certain parts on manufacturing a product will be greatly reduced and enables the development of required part at the remote location. Time to market parts will be greatly enhanced as the necessity to wait for global supplier is nullified. The ability of one's own economy and policies of warranty of parts can be feasibly altered with in-house development.

The scope of the manufacturers would be in identification of parts imported and working on them in development of better part according to need. The overall scenario of the process of AM will greatly enable and change the manufacturing industry for good cause.

5. Conclusion

The advent of COVID-19 epidemic has made to rethink the human and nature relations in the broader perspective. The dependency of economy, globally, plays a very important role in manufacturing sector and its supply chain. The planet has also seen the dearth of required medical equipments for better cause and safety. Additive Manufacturing has played a major role in meeting the required necessary devices in curing the positive cases of COVID-19 and also in protecting the health workers.

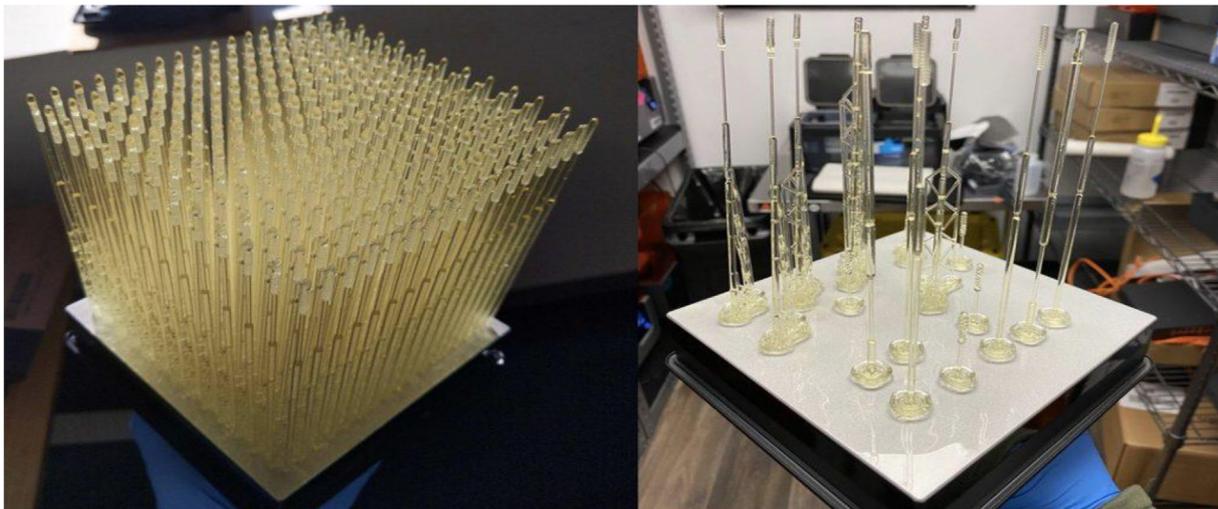


Fig. 7. Test swabs built by Formlabs for COVID-19 testing.

CRedit authorship contribution statement

Vijay Tambrallimath: Conceptualization, Methodology, Validation, Writing - review & editing. **R. Keshavamurthy:** Conceptualization, Methodology, Validation, Writing - review & editing. **Abhinandan Badari:** Conceptualization, Methodology, Validation, Writing - review & editing. **Lohith Ramesh:** Conceptualization, Methodology, Validation, Writing - review & editing. **Gagan Raj:** Conceptualization, Methodology, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Wang C, Horby PW, Hayden FG, Gao GF. A novel coronavirus outbreak of global health concern. *Lancet*. 2020. [https://doi.org/10.1016/S0140-6736\(20\)30185-9](https://doi.org/10.1016/S0140-6736(20)30185-9).
- [2] Chan-Yeung M, Xu RH. SARS: epidemiology. *Respirology*. 2003;8:S9-14.
- [3] Xinhua. China's CDC detects a large number of new coronaviruses in the South China seafood market in Wuhan. Available at: https://www.xinhuanet.com/2020-01/27/c_1125504355.htm. Accessed 6 April, 2020.
- [4] D.D. Richman, R.J. Whitley, F.G. Hayden, *Clinical Virology*, 4th ed., ASM Press, Washington, 2016.
- [5] Corona virus outbreak, available at <https://www.worldometers.info/coronavirus/>. Accessed on 11 April, 2020
- [6] WHO. Coronavirus disease 2019 (COVID19) situation report—44. March 4, 2020. https://www.who.int/docs/defaultsource/coronaviruse/situationreports/20200304sitrep44covid19.pdf?sfvrsn=783b4c9d_2 Accessed 7 April, 2020.
- [7] <https://www.metal-am.com/the-global-additive-manufacturing-community-responds-to-coronavirus/> Accessed 7 april, 2020.
- [8] COVID 19 and its impact on Indian economy. <https://bfseletsonline.com/covid-19-and-its-impact-on-indian-economy/> accessed on 7 April 2020
- [9] Corona virus pandemic <https://auto.ndtv.com/news/indian-automobile-sector-could-bear-revenue-loss-of-around-rs-15-000-crores-every-day-2199256> Accessed on 7 April, 2020
- [10] Coronavirus and 3D printing. <https://www.immensalabs.com/coronavirus-3d-printing/> Accessed on 10 April, 2020
- [11] R.Keshavamurthy, Vijay Tambrallimath, Prabhakar.K. and Sekhar N. Additive Manufacturing Processes and their Applications for Green Technology. Handbook of Research on Green Engineering Techniques for Modern Manufacturing. Editors: Dr.Paulo Davim, Dr.S.T.Kumaran, Prof.Taw Jo Ko, Dr. S.Arvind Raj, M. Uthayakumar, IGI Global, USA, November 2018. Doi: 10.4018/978-1-5225-5445-5. 2019
- [12] Lalit Kumar , Abid Haleem, Qamar Tanveer, Mohd. Javaid, Mohd Shuaib and Vineet Kumar. Rapid Manufacturing: Classification and Recent Development. International Journal of Advanced Engineering Research and Science. Vol-4, Issue-3, Mar- 2017. ISSN: 2349-6495(P) | 2456-1908(O)
- [13] Response of 3D printing companies during Coronavirus crisis. <https://www.tctmagazine.com/3d-printing-news/3d-printing-companies-respond-coronavirus-crisis/> Accessed on 10 April, 2020
- [14] D printed ventilator. <https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/arcelormittal-to-develop-a-d-printed-ventilator-prototype-in-the-wake-of-the-covid-19-pandemic/articleshow/74911864.cms?from=mdr>. Accessed 10 April, 2020
- [15] Manufacturers and 3D printers call. <https://www.tctmagazine.com/3d-printing-news/3d-printing-uk-government-covid-19-fight/>. Accessed on 10 April, 2020
- [16] D printing crowd sourcing. <https://www.compositesworld.com/blog/post/d-printing-crowdsourcing-to-help-hospitals-experiencing-supply-shortages-linked-to-covid-19>. Accessed 10 April, 2020
- [17] Winsun 3D prints isolation wards. <https://www.3dnatives.com/en/winsun-coronavirus-260220205/> Accessed 10 April, 2020
- [18] Robot, 3D printing, drone, 5G deployed in fight against epidemic. http://www.xinhuanet.com/english/2020-02/12/c_138777328.htm Accessed 10 April, 2020
- [19] <https://3dprintingindustry.com/news/3d-printing-community-responds-to-covid-19-and-coronavirus-resources-169143/> Accessed 11 April, 2020
- [20] Additive Manufacturing steps up in the fight against COVID-19. <https://www.pesmedia.com/3d-printing-coronavirus-300320/>. Accessed on 10 April, 2020