website: www.ijoetr.com

International Journal of Emerging Trends in Research

Significance of Hybrid Manufacturing and its Technologies in the field of Manufacturing and Design Industry

Alina Khan[1], Aryaman Bahl[2], Abid Haleem[1], Shashi Bahl[3*], Mohd Javaid[1]

[1]*Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India*
[2]*Centre for Computational Natural Sciences and Bioinformatics, International Institute of Information Technology, Hyderabad (Telangana), India*
[3]*Department of Mechanical Engineering, I.K. Gujral Punjab Technical University, Kapurthala (Punjab), India*

* Corresponding author. E-mail: shashi.bahl@ptu.ac.in

Abstract

Additive manufacturing (AM) has become a significant part of today's world's manufacturing and design industry. With the increase in demand for upgrading the technology to create complex and customized products with flexibility in the machinery, now the industry needs the usage of such technologies that can do better than the conventional one and needs less power, high productivity, better surface finish, and many more advantages. Due to these demands, Hybrid Manufacturing (HM) has come into existence as a turning point for the manufacturing industry. This paper strives to define HM with the help of the definition of researchers, a table based on different hybrids and work done by the different researchers in the last decades, defining and comparing major processes of HM, namely Laser metal deposition (LMD), Metal powder, Sheet lamination and Power bed fusion (PBF) in the form of a table, followed by a discussion on limitations and future scope.

Keywords: additive manufacturing; hybrid manufacturing; customized products; laser metal deposition

1. Introduction

As the world is moving towards advanced technologies, the needs of the manufacturing and design industries are expanding day by day. These new manufacturing requirements are to be taken by industry along with their limitations of lack of fast production, mass production in some specific domain of manufacturing or other, more time consumption, less output and many more. So, to overcome these types of problems in the manufacturing and design industry, a technique called hybrid manufacturing was introduced, which started in the early 1980s in Japan and then started growing in multiple technologies under the name of 3D Printing. It first started with Stereolithography under Additive manufacturing. Hybrid Manufacturing is effective and productive by combining two technologies with the same main objective and decreasing the cons of both technologies as much as possible.

Hybrid manufacturing came into existence for its multiple benefits to the industry, such as it is an efficient and productive way as it improves surface quality, reduces tool wear, etc. When the word hybrid came about in the manufacturing and design industry, it opened up a field where an insufficient number of hybrids have already been made, and researchers are still studying many more. Since then, multiple combinations of techniques have been found, whereas the definition of hybrid in manufacturing is still unclear. Many researchers have given the definition, but it cannot be described entirely with only one definition; it is because the scope is increasing day by day, so new combinations are getting added, making it quite hard to define newly discovered technology with the previous definition.

2. Objectives of the Paper

The primary objective of this paper is to study major HM techniques, their comparison, and their contribution to the field of manufacturing by studying some combinations with the help of a table. Limitations and future scope of HM and finally what things conventional manufacturing or designing industry lack due to which we required to introduce the HM. This is a review-based paper in which the papers related to hybrid manufacturing are identified from Science direct, Sci-hub, and Google scholar and based on various resources used by the author from the internet.

3. Overview of Hybrid Manufacturing

Hybrid manufacturing (HM) is a valuable asset to the manufacturing industry. Basically, one talks about additive manufacturing (AM) and subtractive manufacturing (SM) while illustrating HM [1]. Conventionally, SM is the technique that has always been used in previous decades, but it has some detriments in the case of welding processes, as it is of lower efficiency and produces more waste (arc welding), which increases the overall cost of the project, also welded joints fatigue strength is less than the members joined. While in operations like CNC turning and milling, one can achieve more acceptable tolerance, it lacks flexibility in complex geometries. Every technology has its own negatives, so to reduce these detriments, HM is used as a technology where the combination of conventional and the AM is used to bridge the gap between the two technology and come up with the best in them. As per the open definition, a hybrid manufacturing process combines two or more established manufacturing processes into a new combined set-up whereby the advantages of each discrete process can be exploited synergistically [2]. However, narrow definition says that hybrid processes comprise simultaneous acting of different (chemical, physical, controlled) processing principles on the same processing zone [3].

Table 1: Previous research on hybrids

S. No.	Technologies Used	Work done	References

1	Mechanical machining and Laser cutting	Capable of producing micro metallic components	[4]
2	Laser Cladding and mechanical machining	Performed drilling, milling, and grinding to machine laser clad parts in a single station by using a five-axis CNC machine	[5]
3	Arc welding and mechanical machining	Used face milling to machine each slice built by inert metal gas (MIG) & Metal active gas (MAG)	[6]
4	Injection molding and milling	When the molding of the part is done, multi-axis machinery improves surface accuracy	[7]
5	Turning and rolling	Operations of turning and cold rolling were done within a single machine by integrating a cold rolling on a turning machine that enables gears to be turned and rolled in series, which indicates the capability to reduce production cost and time	[8]

Hybrid manufacturing can be classified based on these five combinations: subtractive, transformative, additive, joining and dividing technologies [9]. Now the reason these names refer to these technologies is because joining means two or more work pieces joined together to make a new workpiece, while dividing means the opposite of the joining process. In subtractive material is removed from the surface of the workpiece. On the other hand, in additive technology, the material is added to the surface of the workpiece layer by layer. In transformative, one workpiece is used to create another workpiece. However, in this paper, we will discuss mainly the combination of subtractive and additive manufacturing.

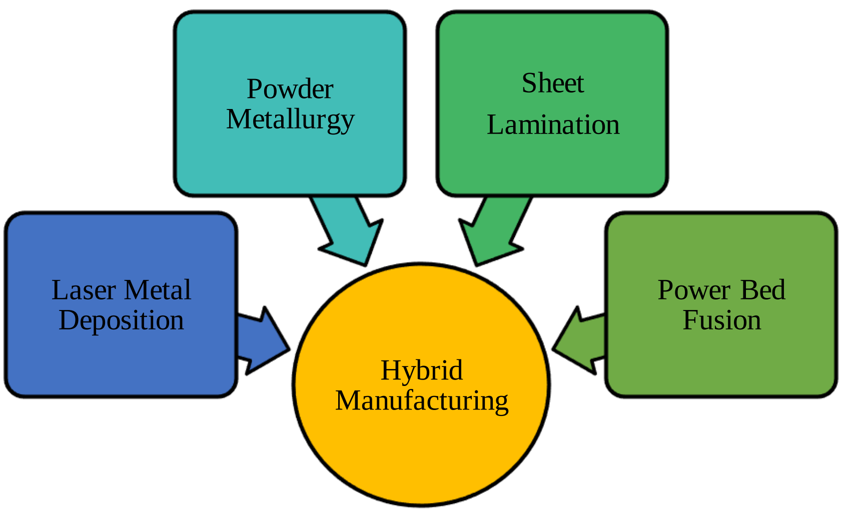

Figure 1: Classification of Hybrid Manufacturing

Hybrid manufacturing can be divided into four categories: Laser metal deposition (LMD), Powder metallurgy, Sheet lamination and Power bed fusion (PBF) [10]. Laser metal deposition is also known as direct energy deposition (DED) or direct metal deposition (DMD). In this process, a welded pool is made by the laser on the component's surface, and a nozzle is used to add the metal powder automatically. The formation of welded beads occurs, resulting in structures on the entire component [11]. The second technology is powder metallurgy; this process involves many manufacturing technologies of AM like gas atomisation and water atomisation where it is being used [12]. The ideal materials for the manufacture of clutch buttons and brake pads are copper and bronze powders because they are well suited for sintering and highly resistant to corrosion sources. Various parameters generally give the characteristics of these powders. Some examples include: shape and contour, which are described based on morphology, particle size and size distribution, are specified by granulometry, level of element purity is determined by chemical composition.

Sheet lamination can be divided into ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). UAM requires removal of unbound material and additional CNC machining, while LOM uses a cross-hatching method for the removal post built during the printing process [13]. Power bed fusion (PBF) processes are used extensively in numerous industries, such as the medical and aerospace sectors. In this process, a powder bed layer is diffused selectively using an energy source, electron, or laser beam for manufacturing 3D objects. Some processes which make use of laser beam (PBF-LB) are (SLS (Selective laser sintering) and SLM (selective laser melting) [14]. Electron beam (PBF-EB) is used by EBM (Electron beam melting). Here post-processing is also needed for better results. Each process has its benefits, detriments and applications as discussed in Table 2.

Table 2: Range of parameters for Phase 1 experiments

S. No.	Parameter	Laser Metal Deposition	Powder metallurgy	Sheet Lamination	Powder Bed Fusion
1	Other names	Direct energy deposition (DED) or Direct metal deposition (DMD)	--------	LOM/SDL/LLM	-------
2	Invention	In 1997	Late 19th century	1991 by a company called Helisy	1994 by Ralf Larson
3	Usable for which type of material	Metals	Metal parts	Thermoplastics such as PVC, Paper composites	Polymer, metal, ceramic
4	Principle-based on:	AM	AM	AM	AM
5	Industrial Use	Aviation and Aerospace industry, Petrochemicals and Medical Technology	Oxygen getters in food technology, Nickel cobalt superalloy in gas turbine discs, brakes, and clutches	Form /fit testing, less detailed parts, rapid tooling	Medical sector (Orthopedics), Military and command aircraft
6	Hybrid with technology	Laser welding or laser cutting	AM Surface coating, metal	Laminated Object Manufacturing (LOM) and	-----

			injection molding	Ultrasonic AM (UAM).	
7	Benefits	Higher build rates, geometry changes can be made, a simple change in materials.	Eliminates wastes in comparison to traditional machining, Versatile (in making of metal and alloy components)	UAM: Can bond different metals, requires less energy as metal is not melted during the process LOM: readily available A4 sheets, inexpensive	Improved production development, fully customized parts on a batch-to-batch basis, good resolution, suitable for visual models and prototypes
8	Further divided into the following technology	------------	Major AM powders are Gas Atomisation, Induction Melted Bar Atomisation (EIGA), Plasma Rotating Electrode Atomisation (PREP) and Plasma Atomised Wire (PAW)	LOM (Laminated object manufacturing) and UAM (Ultrasonic additive manufacturing)	Power bed fusion laser beam (PBF-LB) and Power bed fusion electron beam (PBF-EB)
9	Based on	Powder-based	Powder-based	Solid based	Powder-based
10	Detriments	Not all metals bond together or form intermetallic, causing them to break apart. Capital cost is too high in comparison to other processes. Not robust	High raw material cost The limited size of a product is generally 2-20 Kg. Low quality of mechanical properties of parts	LOM: Produce smoke or fumes Fire hazards Not ideal for complex geometries It is not used to create functional prototypes	Relatively slow and long print time Post-processing is needed Weak structural properties High power usage
11	Applications	Turbine blade repair, corroded tool repairing, self-lubricating surface	Cutting tools and discs, machinery parts, bearings and	For full-colour printing, paper processes such as LOM and SDL are employed. In	Tire moulds, seat belt brackets, brake caliper, medical applications

	production, sintered tool repairing	bushes, magnets.	HM, metal-based materials are employed to create ceramic or composite fiber parts. LOM is for visual modeling and aesthetics.	(jaw reconstruction, knee replacement), In aerospace applications (Injector head, rocket engine combustion chamber)

4. Limitations

In this era of technology, every technique or process has its own demerits that cannot be entirely eliminated but can only be reduced. Hybrid manufacturing has various advantages, but at the same time has some limitations that put a stop to different expectations of advancing in hybrid technology [15]. The first significant challenge is the implementation cost. Setting up an entirely new hybrid manufacturing system costs a lot and needs skilled labour to deal with the work. So, not all shops can invest this much capital in starting the hybrid form of manufacturing. Secondly, mass production on time is also a major challenge to complete the goal of mass production on a timely basis, whether the supplier would be able to meet the demand or not. Thirdly, operating the machine in the best way to manufacture a specific product is also a big challenge. Furthermore, it estimates when the material needs to be added, when the material is to be subtracted, and whether the software runs according to the new material added. Fourth, maintaining the machine after working on it with a new material that might have heat or distort the part or surface of the machine is also considered as a very gig challenge. Lastly, the reusability of expensive powder after collecting is the most appropriate practice to collect the leftover from the last operation.

Ezugwu *et al*. [16] investigated the effects of different cooling pressures in high-pressure cooling-assisted mechanical machining and concluded that a higher cooling pressure does not always imply a longer tool life. Sørby and Tønnessen [17] concluded that high-pressure rake face cooling is likely to have a negative impact on other regions of the workpiece surface. High frequency and amplitude vibration mechanisms are likely to degrade machined items' surface quality and dimensional accuracy in ultrasonic-assisted machining processes. Furthermore, combining HM with AM has its own set of drawbacks, including a long production time, a poor surface polish, and a high cost when compared to components created with traditional methods.

5. Major Contribution and Future Scope

This paper has presented and discussed the different hybrid manufacturing techniques based on AM. Table 1 presented the previous research on hybrids found in the last two decades. Table 2 discussed about the similarities, dissimilarities, and comparisons of HM's four majorly distributed processes. Lastly, some challenges of HM are discussed. As this is a review-based paper, this is a brief of various researchers, combinations of HM processes, and challenges faced till now.

HM has vast scope in coming years due to its increasing hybrids, which are benefiting the manufacturing industry day by day and making the life of humans more manageable and creating models which were only in theory but now have become a reality with the customizing nature and solution to complex geometries of the models and providing flexibility. Still, researchers are working on upgrading the current processes and searching the new possible ways of manufacturing with the help of HM. HM has helped make many operations easier by combining the conventional and AM benefits, including reemphasizing, specific, better surface finish and high productivity, low material wastage, geometrical freedom, and material options, and reducing their negatives to a maximum extent. In the coming years, many manufacturers will turn towards the HM as the process becomes more and more reliable and affordable to the industry. The hybrid additive and transformative combo are still in their early stages. Demonstrating the links between constituent processes and their associated control systems is critical. It will have a massive impact on the future development of hybrid processes [18].

6. Conclusion

Hybrid manufacturing provides an excellent capability to strengthen the manufacturing process with the help of new product properties and sustainable production; with this, economic targets can also be achieved. An effort to decrease the time to market decreases the manufacturing process chain and cuts the cost of production. As the mode of producing products with HM increased, hybrid additive processes have been proposed to fabricate multi-material parts. Introducing a technology that is still developing by researchers demands a lot of domain knowledge, and also, many innovative technologies have not yet been established in many companies. With these viewpoints, the challenge is to train the staff for complex hybrid machinery and handle the parameters of material deposition. These challenges are supposed to be solved in the coming future in the industry with more advanced research and developed combinations of technologies.

References

[1] Nagel JKS, Liou FW. Hybrid Manufacturing System Design and Development. In: Aziz FA, editor. Manuf. Syst., Rijeka: IntechOpen; 2012, p. 223–46. https://doi.org/10.5772/35597.

[2] Zhu Z, Dhokia VG, Nassehi A, Newman ST. A review of hybrid manufacturing processes – state of the art and future perspectives. Int J Comput Integr Manuf 2013;26:596–615. https://doi.org/10.1080/0951192X.2012.749530.

[3] Pragana JPM, Rosenthal S, Bragança IMF, Silva CMA, Tekkaya AE, Martins PAF. Hybrid Additive Manufacturing of Collector Coins. J Manuf Mater Process 2020;4. https://doi.org/10.3390/jmmp4040115.

[4] Quintana I, Dobrev T, Aranzabe A, Lalev G, Dimov S. Investigation of amorphous and crystalline Ni alloys response to machining with micro-second and pico-second lasers. Appl Surf Sci 2009;255:6641–6. https://doi.org/10.1016/j.apsusc.2009.02.061.

[5] Hur J, Lee K, Zhu-hu, Kim J. Hybrid rapid prototyping system using machining and deposition. Comput Des 2002;34:741–54. https://doi.org/10.1016/S0010-4485(01)00203-2.

[6] Karunakaran KP, Sreenathbabu A, Pushpa V. Hybrid layered manufacturing: Direct rapid metal tool-making process. Proc Inst Mech Eng Part B J Eng Manuf 2004;218:1657–65. https://doi.org/10.1177/095440540421801202.

[7] Kelkar A, Koc B. Geometric planning and analysis for hybrid re-configurable molding and machining process. Rapid Prototyp J 2008;14:23–34. https://doi.org/10.1108/13552540810841535.

[8] Axinte DA, Gindy N. Turning assisted with deep cold rolling—a cost efficient hybrid process for workpiece surface quality enhancement. Proc Inst Mech Eng Part B J Eng Manuf 2004;218:807–11. https://doi.org/10.1177/095440540421800713.

[9] Nassehi A, Newman S, Dhokia V, Zhu Z, Asrai RI. Using formal methods to model hybrid manufacturing processes. In: ElMaraghy HA, editor. Enabling Manuf. Compet. Econ. Sustain., Berlin, Heidelberg: Springer, Berlin, Heidelberg; 2011, p. 52–6. https://doi.org/10.1007/978-3-642-23860-4_8.

[10] Engineering Product Design. Hybrid Manufacturing n.d. https://engineeringproductdesign.com/hybrid-manufacturing/ (accessed April 2, 2022).

[11] Graf B, Marko A, Petrat T, Gumenyuk A, Rethmeier M. 3D laser metal deposition: process steps for additive manufacturing. Weld World 2018;62:877–83. https://doi.org/10.1007/s40194-018-0590-x.

[12] Altuntaş O, Güral A, Tekeli S. Microstructure engineering for superior wear and impact toughness strength of hypereutectoid powder metallurgy steel. Powder Metall 2022;65:101–11. https://doi.org/10.1080/00325899.2021.1954280.

[13] Zhang X, Liou F. Chapter 1 - Introduction to additive manufacturing. In: Pou J, Riveiro A, Davim JPBT-AM, editors. Handbooks Adv. Manuf., Elsevier; 2021, p. 1–31. https://doi.org/10.1016/B978-0-12-818411-0.00009-4.

[14] Gan X, Fei G, Wang J, Wang Z, Lavorgna M, Xia H. Powder quality and electrical conductivity of selective laser sintered polymer composite components. In: Friedrich K, Walter R, Soutis C, Advani SG, Fiedler IHBBT-S and P of AMPC, editors. Woodhead Publ. Ser. Compos. Sci. Eng., Woodhead Publishing; 2020, p. 149–85. https://doi.org/10.1016/B978-0-12-819535-2.00006-5.

[15] Mein S. Understanding the Benefits and Challenges for Hybrid Manufacturing. Fire Trace Int 2020. https://www.firetrace.com/fire-protection-blog/hybrid-benefits (accessed April 2, 2022).

[16] Ezugwu EO, Bonney J, Fadare DA, Sales WF. Machining of nickel-base, Inconel 718, alloy with ceramic tools under finishing conditions with various coolant supply pressures. J Mater

Process Technol 2005;162–163:609–14. https://doi.org/10.1016/j.jmatprotec.2005.02.144.

[17] Sørby K, Tønnessen K. High-pressure cooling of face-grooving operations in Ti6Al4V. Proc Inst Mech Eng Part B J Eng Manuf 2006;220:1621–7. https://doi.org/10.1243/09544054JEM474.

[18] Nau B, Roderburg A, Klocke F. Ramp-up of hybrid manufacturing technologies. CIRP J Manuf Sci Technol 2011;4:313–6. https://doi.org/10.1016/j.cirpj.2011.04.003.