IOSR Journal Of Humanities And Social Science (IOSR-JHSS)
Volume 29, Issue 8, Series10 (August, 2024) 07-21
e-ISSN: 2279-0837, p-ISSN: 2279-0845.
www.iosrjournals.org

Applicability of Hybrid Metal Manufacturing (HMM), Characteristics, Steel Types, and Mechanical Properties: Systematic Literature Review

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Abstract:
Background: *Additive manufacturing (AM) is one of the pillars of Industry 4.0, where automation to create smart factories is the main target. Process hybridization is one of the main strategies for implementing a more flexible, efficient system and interconnected manufacturing environment. Currently, there are different researches focused on hybridization of metal AM and subtractive manufacturing (SM), this technology is called hybrid metal manufacturing (HMM).*
Materials and Methods: *Many of these techniques consist of integrating Directed Energy Deposition (DED) and Powder Bed Fusion (PBF) additive processes with subtractive computer numerical control (CNC) machining within a multi-axis machine tool. In this context, the present article is a systematic literature review (SLR), prepared with the help of the Parsifal tool, having Scopus and Web of Science as search bases. The objective was to investigate the scientific literature to verify the applications of HMM in the metal mechanical sector, evaluate its characteristics, identify the main types of steel used in the process, and investigate its mechanical properties and the results obtained.*
Results*: Recent advances in HMM methods allow the manufacturing of parts with complex geometries while achieving comparable or higher quality than those manufactured by conventional methods. Current HMM technologies are capable of processing a wider selection of metals, including materials used in steel molding such as H13 and P20. In the injection molding industry, mold makers are implementing metal AM technologies in mold manufacturing. The main challenge currently faced by mold makers is to print steel molds with mechanical properties comparable to those manufactured conventionally*.
Conclusion: *Finally, the review summarizes the current status of the HMM application and future perspectives in mold making.*
Key Word*: HMM; Application and Characteristics; Steel Types and Mechanical Properties.*

Date of Submission: 14-08-2024 Date of Acceptance: 31-08-2024

I. Introduction

Hybrid manufacturing (HM) is a designation used for processes that combine different technologies as a way to overcome their limitations and benefit from their intrinsic advantages. Manufacturing industries require efficient processes that provide a reduction in the manufacturing costs and time needed to gain competitiveness while meeting quality standards. Thus, hybrid manufacturing systems are becoming an industrial solution for the manufacturing and repair of overly complex parts aimed at various industries [1].

The combination of AM and CNC machining is an example of a hybrid process that is of particular interest because, in general, AM systems have an advantage when producing complex geometries from difficult-to-process materials, however, compared to finishing in the subtractive process, the resulting surface quality and dimensional accuracy are generally significantly inferior [2]. However, the full integration of both processes is a complex task that still has to overcome many difficulties, as both laser-based additive processes and machining processes need to overcome challenges to improve their performance and the quality of the manufactured parts [1].

Additive manufacturing is an emerging area and in need of further studies, so a better understanding of the main trends will contribute to the dissemination of knowledge about the technology and its consolidation [3]. In this context, this article aims to verify the applications of hybrid additive manufacturing of metals in the metal mechanical sector, to evaluate its characteristics, to identify the main types of steels used in the process, to investigate their mechanical properties, and the results obtained.

The method adopted was the use of the Parsifal tool to systematically review the scientific literature, through bibliometric searches performed in the Scopus and Web of Science databases, the keywords were "Hybrid

Additive Manufacturing" and "Metal Additive Manufacturing", and the period was delimited from 2018 to the current year 2022 due to recent publications on the advances of this technology. It is hoped that the results obtained can make an important contribution to the field of research that addresses the methodology of applying HMM to assist companies in adopting this technology.

II. Material And Methods

Hybrid Metal Manufacturing (HMM)

Additive manufacturing has the potential to provide several sustainability benefits. These benefits include the generation of less waste during production; the ability to optimize geometries and create lightweight components that reduce material consumption and in-use energy consumption through the ability to create parts on demand, layer by layer[4].

The combination of additive and subtractive processes on a single hybrid machine is especially suitable for manufacturing low-machinability materials, such as heat-resistant alloy steels and high-hardness materials, which were widely used in various industries [1].

A powder-based additive-subtractive manufacturing system using laser deposition and CNC milling is called hybrid manufacturing, a laser beam creates a melt pool on a surface as the powder is injected into the melt pool. The deposition follows prescribed scanning paths to create the desired part geometry. Milling operations machine the part within dimensional tolerance [5].

Developing workstations for hybrid processes includes challenges associated with hardware and software integration. These workstations must include a tool magazine with AM heads, and milling and measuring tools, among others [6].

Laser metal deposition is widely recognized as an additive manufacturing technique used for refurbishment and repair applications, along with structural and geometric restoration [7].

HMM Applications and Features

The combination of both technologies AM and CNC machining, on a single machine, is therefore advantageous, as it allows ready-to-use products to be built with an all-in-one hybrid machine, which maximizes the strengths of each technology. In this way, complex components that are originally not possible to machine due to accessibility constraints are now accessible [1].

Some examples of the application of PBF processes for the production of functional parts are dental and bone implants, airfoils, or turbine blades with embedded cooling channels, thus being able to service the aerospace, energy, and medical industries, among others [1].

Figure 1 illustrates the application of MHAM in which the substrate part (a) can be fabricated by traditional subtractive manufacturing, and the top part (b) with an internal metal AM cooling channel system [8].

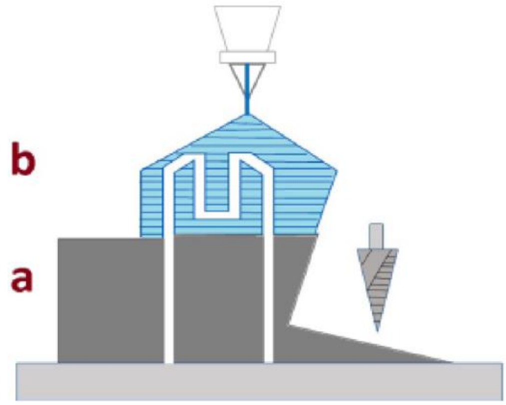

Figure 1 - Illustration of hybrid metal additive manufacturing.

Laser melting (SLM), electron beam melting (EBM), and DED processes have been widely applied in academic research and systems developed for industrial applications [9]. One of the main applications of MHAM is in the maintenance and repair of existing components [10].

The integration of AM and SM includes computer-aided design (CAD), manufacturing (CAM), inspection (CAI), and engineering (CAE). All these tools must be combined synergistically to obtain an efficient hybrid process, which mainly depends on efficient tool path strategies and 5-axis hybrid additive manufacturing adds versatility to traditional 2.5-axis-based AM systems and enables the ability to produce parts without support structures [6,11].

Usually, AM parts need some post-processing, for example, machining, heat treatment, or surface treatment. Hybrid AM, as an integration of AM processes with some post-processing technologies, aims to combine their capabilities synergistically and thus produce functional components with complex geometries, mechanical properties, and enhanced surface integrity [12].

Figure 2 shows the advantages of hybrid AM as a combination of additive and CNC machining processes.

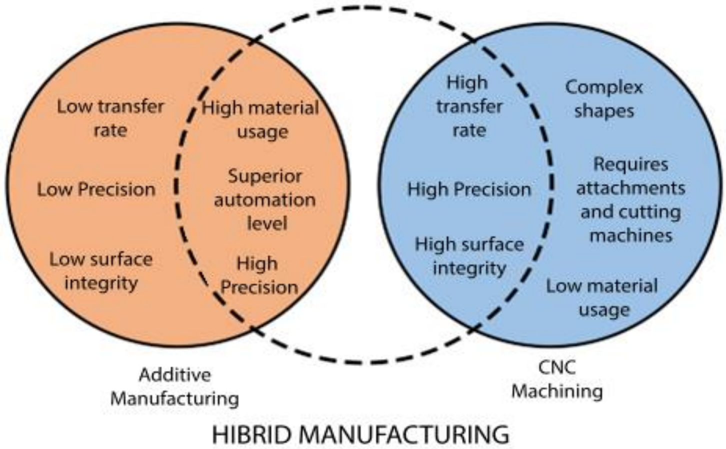

Figure 2 - Advantages of hybrid AM.

Steel Types and Mechanical Properties

Currently, various types of stainless steel, tool steel, cobalt-chromium alloys, titanium and its alloys, aluminum alloys, nickel alloys, and some precious metals such as pure silver and gold have been successfully processed by MA 13, the materials, for example, Ti-6Al-4V and Inconel 718 are the two alloys commonly used in critical applications such as aircraft structures and gas turbines. Ti-6Al-4V is the most widely used commercial titanium alloy, characterized by its high strength-to-weight ratio and excellent corrosion resistance. This material has been rigorously studied for Directed Energy Deposition processing [14].

Powder Bed Fusion (PFB) has the greatest potential for tooling in hot working and injection molding. A greater number of powdered metals are being designed for different tooling applications with lower raw material and processing costs, as well as, further productivity improvement, improved surface roughness, and guaranteed quality are some of the researched goals 15. Porosity and surface discontinuity in metallic AM in its built-up condition is a detrimental factor that affects its performance under cyclic loading, i.e., fatigue and abrasion wear. Several studies in the literature have investigated the effect of surface conditions on the fatigue and abrasion wear behavior of AM materials [16].

A comprehensive study of the inhomogeneity of the microstructure was performed in different areas and orientations. For example: within the melt pool structure, along with the build direction, and across the plane parallel to the deposited layers. This inhomogeneity of the microstructure is considered one of the main causes that can result in an anisotropic material [17]. The AM process parameters need to be optimized to produce tools capable of increasing the wear and deformation resistance of the workpiece. It is important to avoid porosities in the fabricated part to obtain a dense layer through process parameter control [18].

Developments in process parameters have focused on improving surface properties without changing the mass of the material. This led to the laser metal deposition technique being categorized under AM 19 [19].

Method

The methodology used in the execution of this article was the systematic literature review (SLR) which, according to Sampaio, Mancini [20], as well as other types of review studies, the SLR is a form of research that is used as a data source the literature on a given topic. This type of research makes available a summary of the evidence related to a specific intervention strategy by applying explicit and systematized methods of searching, critically appraising, and synthesizing the selected information.

The fundamental idea of an SLR is that it is replicable, meaning that another researcher can replicate the process and arrive at the same body of evidence and the same conclusion. A systematic review includes an exhaustive search of designated databases [21].

Systematic Literature Review (SLR)

Researchers must develop a research protocol that includes the following items: how to find studies, criteria for inclusion and exclusion of articles, the definition of results of interest, verification of the accuracy of results, determination of quality, search, and analysis of the statistics used, as illustrated in Figure 3 [20].

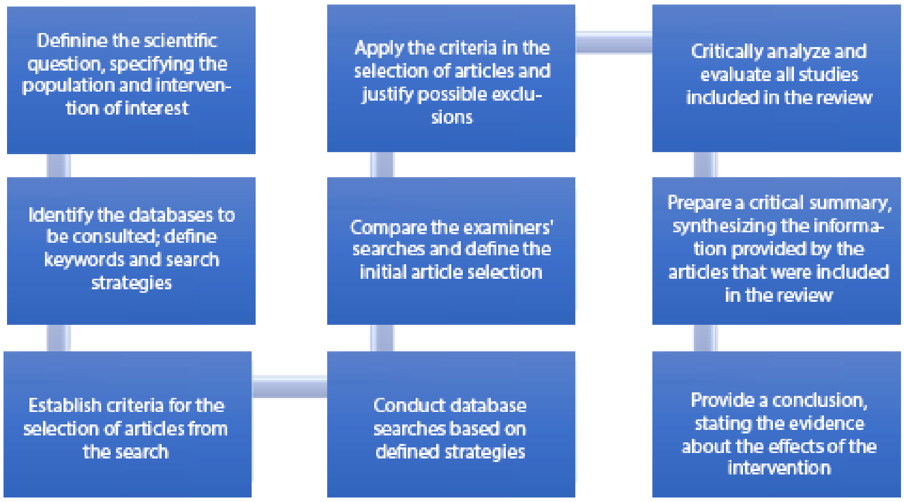

Figure 3 - Overview of the SLR research protocol.

For data collection, following the guidelines of the SLR method, a systematic review protocol was developed with the aid of Parsifal, a web-based tool developed to support researchers in the task of conducting systematic literature reviews. During the planning phase, this tool facilitates the development of research questions, allows the selection of search bases and stores inclusion and exclusion criteria, provides a mechanism for specifying quality assessment criteria and generating search strings, and keeps track of all data collected, making the SLR protocol easy to replicate.
Parsifal is divided into the following protocols:

- Analysis
- Planning
- Driving
- Statement

III. Result

Analysis

Given the above, the SLR protocol was used to identify the applications of hybrid additive manufacturing of metals, through existing research, addressing its characteristics, the types of steels used, and their mechanical properties, thus contributing to future studies about this approach. The data analysis was descriptive.

Planning

The first step was planning. In this step, the real need for a systematic review was verified, an evaluation protocol was developed, and the following research questions were defined:

What are the applications of this technology in the metal-mechanic sector?
What are the main characteristics of the additive manufacturing process in steel?
What types of atomized steels are available for additive manufacturing?
What are the main mechanical properties of this steel?
What were the results obtained with the application of additive manufacturing in steel?

Table 1 defines the terms used in the PICRC for the separation of the keywords used to create the search string.

Table 1 - Terms used in the PICOC.

Population	Papers published in academic journals and periodicals or presented at conferences
Intervention	Additive manufacturing in steel
Comparison	Steels used, application, characteristics and mechanical properties
Outcome	Overview of the application of atomized steel in additive manufacturing
Context	Academics, Scientific articles, Case studies

The keywords suggested by the protocol used to search the databases were "Additive Manufacturing", "Hybrid Additive Manufacturing" and "Metal Additive Manufacturing", the string automatically generated by Parsifal was: "Additive Manufacturing" OR "Hybrid Additive Manufacturing" OR "Metal Additive Manufacturing".

Regarding the databases, the databases available on the Capes Periodical Portal were used for this research due to their wide variety and the filter criteria as described in Table 2.

Table 2 - Databases and filter criteria

Data base	CAPES journals portal (Web of Sciense and Scopus)
Type of documents	Conference and Review Articles
Search field	Article Title, Abstract, Keywords
Research areas	Materials science; Engineering materials; Metallurgy and metallurgical engineering
Limit results	Year: 2018 to 2023 Document type : Articles Language : English

The inclusion and exclusion criteria observed in the selection of articles to be analyzed are described in Table 3.

Table 3 - Selection Criteria

Selection Criteria	
Inclusion	Exclusion
About Application	Paper discusses another type of material
About Characteristics	Document discusses the AM welding process
Addresses steel types	Duplicate documents
Mechanical Properties	Documents outside the areas of Engineering, Metal Mechanics
	Documents outside the scope of AM metal
	Studies prior to 2018
	Only citations
	Non-academic work

As a first step in checking the quality of the researched articles, questions were defined according to Table 4.

Table 4 - Qualifying questions

Q1	Does the article have one of these words in the title or abstract: Hybrid Additive Manufacturing, AM, Steel, Metal Additive Manufacturing, AM Metal, Mechanical properties?
Q2	Is the author of this article among the 10 most relevant on the topic?
Q3	Does the article presents the application of additive manufacturing of steel in the manufacturing of parts?
Q4	Does the article presents the main characteristics of the additive manufacturing process in steel?
Q5	Does the article presents types of atomized steels available for additive manufacturing?
Q6	Does the article presents the mechanical properties of this steel?

Q7	Does this article presents the results obtained with the application of additive manufacturing in steel?
Q8	Does this article presents the application of additive manufacturing in the fields of Mechanical Engineering and Metalworking?

To assess the quality of the studies, a set of answers to the above questions was defined, and scores were assigned as shown in Table 5.

Table 5 - Answers and evaluation score

Description	Weight
Yes	1,0
Partially	0,5
No	0,0
Maximum score	8,0
Cutoff score	5,0

Driving

In this second step, the database search was performed in July 2022 and returned a total of 722 documents, proportionally divided between the WoS and Scopus databases as illustrated in the graph in Figure 4.

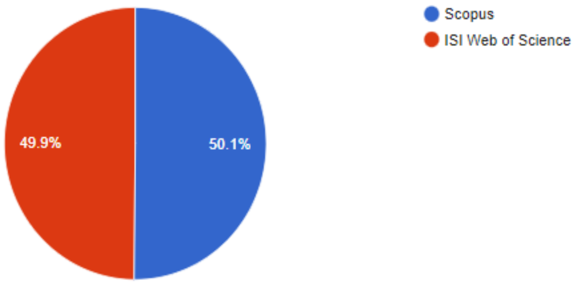

Figure 4 - Graph of the proportionality of the search results

Through a bibliometric analysis, it was possible to evaluate the number of publications per year in the period 2018 to 2022. In Figure 5 it is possible to verify an ascending curve starting in 2020. Although the year 2022 is still in effect, it is observed that the growth of research related to the theme of HMM in the first quarter, this fact contributed to and justified the interest in the execution of this SLR including this period.

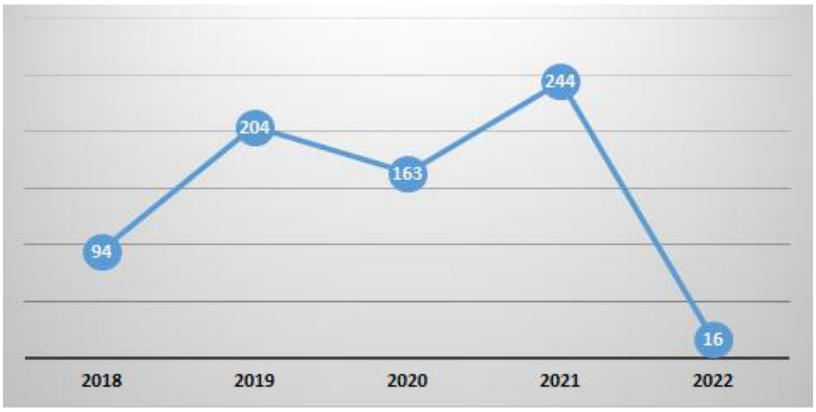

Figure 5 - Number of publications in the period 2018 – 2022

In this bibliometric analysis, it was also verified the ten countries with the largest number of publications shown in Figure 6.

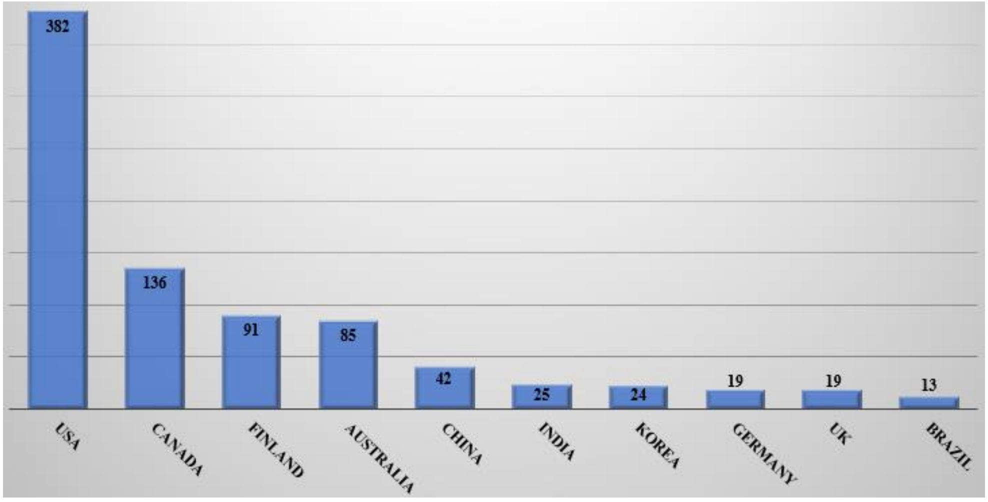

Figure 6 - Chart with the 10 countries with the most publications

Bibliometry was used to survey the authors according to the number of publications, citations, and the h-index. The ten most relevant authors were identified using the h-index as a criterion, as shown in Table 6.

Table 6 - Most relevant authors according to h-index

	Author	No. Publications	Index h	Citations
1	Kumar S. A.	65	16	753
2	Popov V.V.	16	16	818
3	Yadollahi A.	43	14	3914
4	Ahn D. G.	29	12	456
5	Cortina M.	20	11	1255
6	Davila J. L.	17	8	328
7	Afkhami S.	20	7	259
8	Jackson M.	8	4	100
9	Basinger K.	7	3	38
10	Sefene E. M.	14	2	43

After collecting the data, the articles selected in the searches were imported into Parsifal to be analyzed. A search for duplicate articles was performed and 190 documents were separated, returning 532 documents.

The next step was the primary evaluation of the articles, applying the inclusion and exclusion selection criteria, done by reading the titles, abstracts, and keywords to segregate the articles outside the scope of the research. In this step, 268 articles were accepted.

Finally, the introduction, results and discussions, and final considerations of the articles were read, applying the questions for qualification and separating them by inclusion criteria. In this last step, 34 articles were qualified.

Statement

In the context by which HMM was addressed in the studies analyzed in this SLR, an evaluation from the results obtained allowed the identification of 4 main aspects in the qualified articles:

1 - Recent developments in HMM have increased the interest of researchers and the publication of papers, as can be seen in the evolution of the timeline in Figure 7.

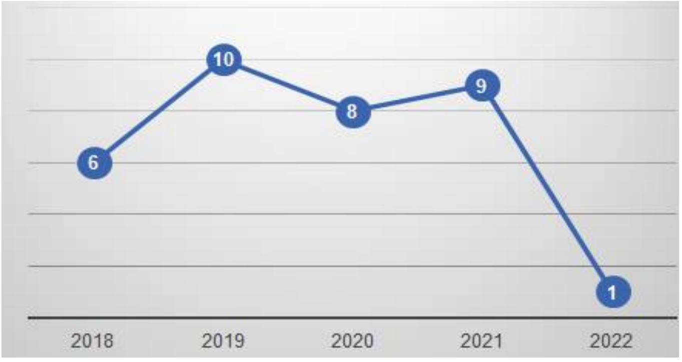

Figure 7 - Number of publications on the timeline

2 - HMM is becoming a globally important topic of interest in research and publications, the USA is one of the leading countries in the number of publications as shown in Figure 8.

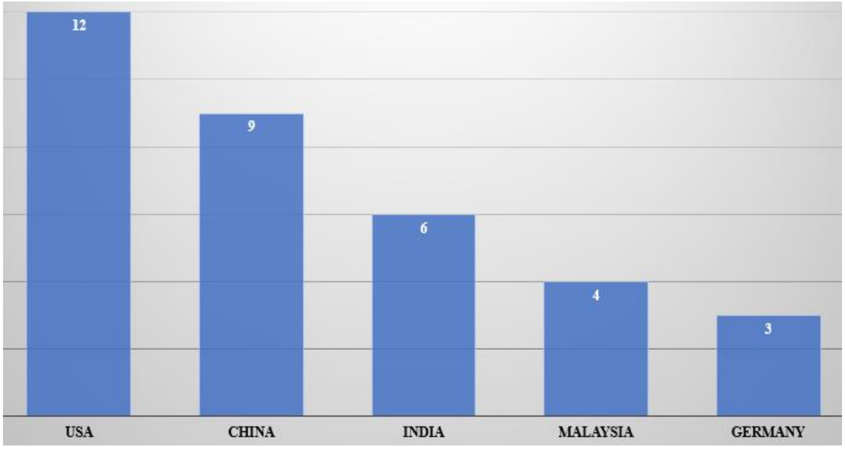

Figure 8 - Number of publications by countries

3 - Figure 9 shows that the field of mechanical properties is among the most researched and addressed in the articles that were carefully selected in this SLR.

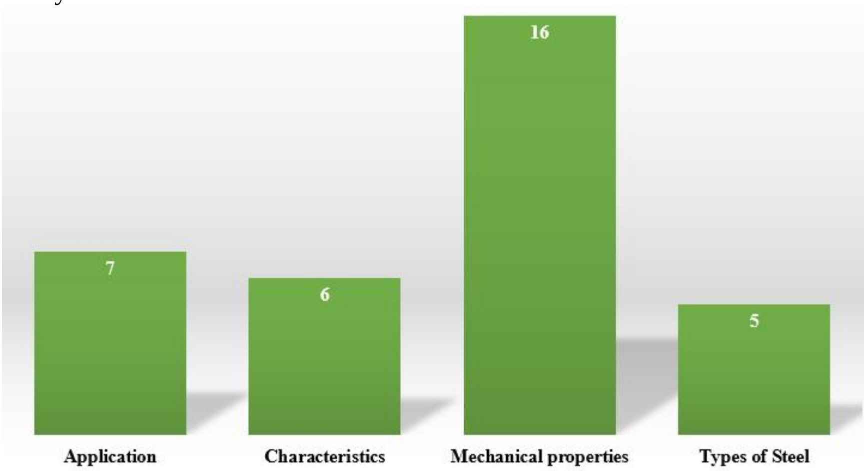

Figure 9 - Evaluation of the selection of inclusion criteria

4 - Graphically represented in Figure 10 is the score assigned to the quality issues according to their relevance to this SLR.

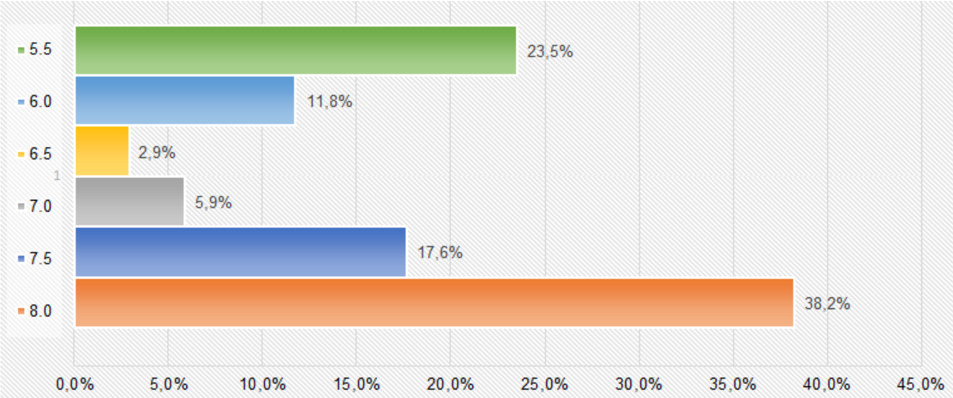

Figure 10 - Graph of the question score attribution

IV. Discussion

DED processes have several advantageous characteristics in their application, as described in Table 7, such as relatively lower heat input, less distortion, lower dilution rate, excellent metal alloying, excellent mechanical performance, relatively higher precision geometry, suitability for full automation and control of thermal accuracy, in terms of repair, restoration, and remanufacturing of products [9].

Table 7 - Characteristics of DED applications

Application	Purpose	
Repair, restoration and remanufacturing	Repair of damaged parts Restoration and remanufacturing of parts to the desired shapes and properties	Reduction of lead time, cost and GHG emissions Recycling of used materials and parts Production of discontinued parts Improved properties and functionality
Porous coating	Metal foams Porous structures in biomedical materials	Metal foam manufacturing Improved biocompatibility BTF improvement
Tailor-made materials and structures	Functionally graded materials and structures (FGM&S) Multilayer coating of heterogeneous materials Hardfacing	Control of material properties Improved wear and corrosion resistance as well as service life Reduction in material cost
Thermal management	Molding and forming tools with conformal cooling channels (CCCs) Mold thermal management Heat sink (cooling fin)	Control of temperature distributions Even and fast cooling characteristics Reduced cooling cycle time Product quality improvement

Most of the research papers and systems developed related to the HMM process have been focused on combining DED with machining processes, as shown in Figure 11 [9].

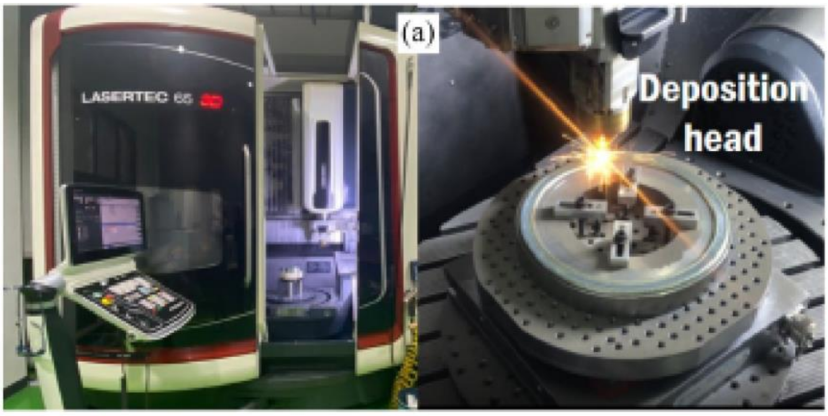

Figure 11 - Hybrid metal additive manufacturing

The characteristics and the improvement that can be obtained in the surface finish of additively manufactured components by post-processing through machining operations are demonstrated in Figure 12. Different approaches to seamlessly and synergistically combine the capabilities of powder-based laser AM technologies with post-processing machining processes have been implemented [12].

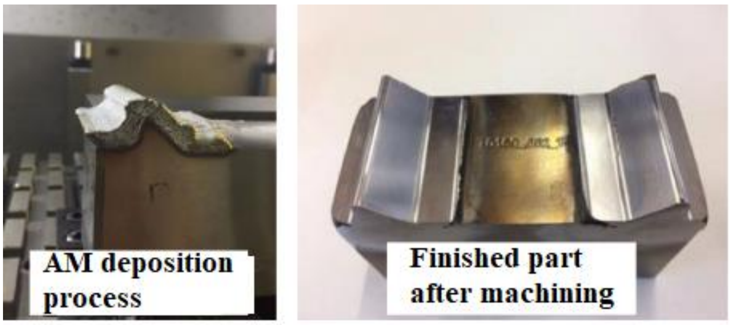

Figure 12 - Hybrid metal additive manufacturing

In Table 8 a summary of hybrid AM solutions is presented and the different process combinations are analyzed and discussed, their main advantages and limitations are highlighted [12].

Table 8 - Summary of the characteristics of the hybrid AM

Hybrid Manufacturing	Additive Manufacturing Technology	Post processing	Advantages	Limitations and challenges
AM + machining	LPBF	Machining	Complex geometries and good surface finish	Need parts inspections, software integration, parameter optimization, oxidation (out of AM chamber). Undercuts cannot be machined.
	DLD	Machining	Productivity gains and good surface finish	
AM + heat treatment	LPBF	Laser remelting	Improved microstructure, reduced residual and surface stresses, improved roughness and surface properties	Need parameter optimization.
	DLD	Laser remelting	Smooth surfaces and isotropic topographies	Need parameter optimization.
AM + surface treatment	LPBF	Laser polishing	Reduced surface roughness	Process optimization is necessary to avoid oxidation
	DLD	Laser polishing	Reduced surface roughness	Results are highly dependent on laser energy

DLD	Peening	Refined microstructure and beneficial compressive residual stresses	Integration of processes on the same machine.

Given the enormous potential in the application of metallic AM, qualification and certification are critical to ensure successful adoption by various industries and accelerate the progress of standardization.

The first qualification principle standard (ISO/ASTM 52942:2020), a total of seven standards is proposed and under development, as described in Table 9, which covers the industrial fields of AM, machine operations for specific processes, and the applications [22].

Table 9 - Summary of published ISO/ASTM AM standards related to AM metal (ASTM International 2020; ISO 2020)

Topic	Code	Published active ISO/AM standards Simplified title with reflection on default scope
Terminology	ISO/ASTM 52900:2015	General principles – Terminology
	ISO/ASTM 52921:2013	Coordinate testing systems and methodologies
General principle	ISO 17296-2:2015	General Principles – Part 2: Overview of Process and Raw Material Categories
	ISO 17296-3:2014	General principles – Part 3: Main characteristics and corresponding test methods
	ISO/ASTM 52950:2021	General Principles – Part 4: Data Processing Overview
	ISO/ASTM 52901:2017	General Principles – Requirements for Purchased AM Parts
Materials and processes	F2924-14	Ti6Al4V with PBF
	F3001-14	Ti6Al4V ELI (Extra Low Interstitial) with PBF
	F3049-14	Guide to characterizing properties of metallic powders used for AM processes
	F3055-14a	Nickel alloy (UNS N07718) with PBF
	F3056-14	Nickel alloy (UNS N06625) with PBF
	F3184-16	Stainless steel alloy (UNS S31603) with PBF
	F3187-16	Metal DED guide
	F3213-17	Standard specification for Co28Cr6Mo via PBF
	F3301-18a	Standard specification for post-process thermal metallic parts made via PBF
	F3302-18	Standard specification for titanium alloys via PBF
	F3318-18	Specification for AlSi10Mg with PBF-LB
	ISO/ASTM 52930:2021	Deployment/Operation and Performance Qualification (IQ/OQ/PQ) of laser beam PBF equipment for production manufacturing
	ISO/ASTM 52904-19	Practice for metallic PBF process to meet critical applications
	ISO/ASTM 52907:2020	Methods for characterizing metallic powders
Project	F3413-19	Design guide – DED
	ISO/ASTM 52910-18	Design – Requirements, guidelines and recommendations
	ISO/ASTM 52911-1-19	Design – Part 1: PBF based on metal laser
Test methods	F2971-13	Standard practice for reporting data for test samples prepared by AM
	F3122-14	Guide for evaluating the mechanical properties of metallic AM materials
	ISO/ASTM 52902-19	Test artifacts - Evaluation of geometric capability of AM systems
Qualification principle	ISO/ASTM 52942:2020	Skilled machine operators of laser metal PBF machines and equipment used in aerospace applications
Data	ISO/ASTM 52915:2020	Specification for AMF File Format (AMF) version 1.2

AM metal can be categorized into subcategories whose relative and typical attributes in terms of process speed, precision, and build volume are listed in Table 10 [23].

Table 10 - Attributes of various AM metal shape systems

Process		Material shape	Power/heat source	Speed	Precision	Size
Powder bed	Laser powder bed fusion	Powder	Laser	Average	High	Average
	Electron beam powder layer melting	Powder	Electron beam	Average	High	Average
Deposition	Directed energy deposition	Powder	Laser	Average	Average	High
	Cold spray	Powder	Kinetic energy	High	Average	High
	Electron beam melting	Wire	Electron beam	High	Low	High
Consolidation	Metal injection molding	Powder	Binder / Matrix	High	Average	Low
	Binder jet	Powder	Post-consolidation			
			Binder	Average	Average	Average
			Post-consolidation			

Table 10 also includes other near-liquid form manufacturing techniques, such as metal injection molding (MIM), a powder sintering and consolidation process.

In AM metal various types of stainless steel, tool steel (H13 and P20), cobalt-chromium alloys, titanium and its alloys, aluminum alloys, nickel alloys, and some precious metals such as pure silver and gold have been successfully processed.

Although a variety of steels exist, the fatigue characteristics of few of them have been studied so far. Table 11 summarizes a list of steels investigated in fatigue studies and their typical characteristics [13].

Table 11 - Steels investigated for the evaluation of fatigue characteristics of AM materials.

Steel name according to:				Description
Commercial	EOS	UNS	Others	
316L	316L	S31673	ENI.4401	A ductile austenitic stainless steel with high corrosion resistance and a wide range of applications in the automotive, aerospace, food and chemical industries
18Ni-300	MS1	K93120	ENI. 2709	A hardenable maraging steel with good machinability and thermal conductivity. This steel uses martensitic microstructure and age hardening to gain its mechanical properties. It is usually used as tool steel for die making and aerospace industry.
15-5 PH	PH1	S15500	-	A precipitation-hardened martensitic steel with high strength, high hardness and excellent corrosion resistance. It is used to manufacture heavy machine parts and functional prototypes.
630	17-4 PH	S17400	17Cr-4Ni; AISI630; ENI.4542	A precipitation-hardened martensitic steel with good corrosion resistance. It is generally used for medical instruments and other corrosion resistance parts with good mechanical characteristics.
300M	-	K44220	4340M	A modified version of AISI 4340 steel with higher silicon, vanadium, carbon and molybdenum contents. It is generally used in the aerospace industry due to its high strength, good fracture toughness and ductility.
H-13	-	T20813	DIN 1.2344	A tempered and tempered carbon hot work tool steel. It is often used in injection molding and hot extrusion.
Marlok* C1650	-	-	-	A precipitation hardened maraging tool steel. It is often used in aluminum smelting due to its superior thermal and mechanical properties.

Due to the complexity of the AM metal process, system manufacturers have developed sets of optimized processing conditions for some existing powdered metals. Table 12 defines the specific machine models and manufacturers for one or more types of powdered metals for AM [15].

Table 12 - Configuration of machine models and manufacturers

Manufacturer	Model	Al	Co	Cu	Fe	Ni	Ti	W
3D Systems	DMP Factory 500 PrinterModule	By request				Nickel alloys	By Request	
	DMP Factory/Flex 350	AlSi7Mg0.6, AlSi10Mg	CoCrF75	-	Maraging Steel, 17-4PH, 316L	Ni625, Ni718	Ti Gr1, Ti Gr5, Ti Gr23	-
	DMP Flex 100	-	CoCr	-	17-4PH, 316L	-	-	-
	ProX DMP 300	AlSi12	CoCr	-	Maraging Steel, 17-4PH	-	-	-
	ProX DMP 200	AlSi12	CoCr	-	Maraging Steel, 17-4PH, 316L	-	-	-
Additive Industries	MetalFAB1	AlSi10Mg, ScalmAlloy©	-	-	Tool steel 1.2709, 316L	IN718	Ti6Al4V	-
Concept Laser	X Line 2000R	AlSi10Mg	Balanced Productivity	-	-	Nickel 718	Ti6AL4V, Grade 23	-
	M Line Factory	A205	CoCrMo	-	-	Nickel 718CL	-	-
	M2 Multilaser	AlSi10Mg, AlSi7Mg	CoCrMo	-	Maraging M300, 17-4PH, 316L	Nickel 625, Nickel 718	Ti6AL4V, Grade 23	-
EOS	EOS M 400-4	AlSi10Mg	-	-	MS1, 316L	HX, IN718	Ti64, Ti64ELI	
	EOS M 400	AlSi10Mg	-	-	MS1, 316L	IN718	Ti64	
	EOS M 300-4	AlSi10Mg	-	-	MS1, 316L	IN718		
	EOS M 290	AlSi10Mg	MP1	-	MS1, CX, PH1, 17-4PH, 316L	HX, IN625, IN718	Ti64, Ti64ELI, TiCP Grade 2	
	EOS M 100	-	SP2	-	316L	-	Ti64	W1
SLMSolutions	SLM®NXG XII 600	ALSi10Mg (No limitation)	No limitation			IN718 (Unlimited)	No limitation	
	SLM®800	AlSi10Mg, AlSi7Mg0.6, AlSi9Cu3	CoCr28Mo6, SLM® MediDent	CuSn10, CuNi2SiCr	Maraging 1.2709, 316L (1.4404), 15-5PH (1.4545), 17-4PH (1.4542), Invar 36®	HX, IN625, IN718, IN939	Ti6Al4V ELI (Grade 23), TA15, e Ti(Grade 2)	-
	SLM®500							
	SLM®280							
	SLM®125							
Renishaw	RenAM 500Q/S	AlSi10Mg	CoCr	-	Maraging M300, 316L	IN625, IN718	Ti6Al4ELI	-
	RenAM 500E							
	RenAM 500M							
	AM 400							
	AM 250							
Trumpf	TruPrint 1000	Yes to all except W+ precious metal alloys + amorphous metals						
	TruPrint 2000	Yes to all except Cu andW+ amorphous metals						
	TruPrint 3000	Yes to all except Co, Cu and W						
	TruPrint 5000	Yes to all except Co, Cu and W						

Powder metal options have been growing since 1995. However, the number of options is still minimal compared to the number of materials available in conventional manufacturing.

Laser metal deposition is widely recognized as an additive manufacturing technique used for refurbishment and repair applications along with structural and geometric restoration; however, mechanical properties need to be considered to ensure the final quality of the process.

In this regard, the high incident laser energy and a constant path length scanning strategy exhibit good mechanical properties. In contrast, martensitic and homogeneous microstructures are obtained at low incident energy, as can be seen in Table 13 [7].

Table 13 - Type of steel, laser power, and its mechanical properties

Substrate Material	Used material	Laser Power (W)	Process	Mechanical properties
Titânio	Ti6Al4V	600	DLMD	-
Ti6Al4V	Ti6Al4V	1500	DLMD	20% hardness increase
MetoClad e Ti6Al4V	MetcoClad718 e Ti6Al4V	550	Laser coating	-
Ti-6Al-2.5Mo-1.5Cr-0.5Fe-0.3Si	TiNi-Ti composite coating	400	Laser coating	Wear resistance has improved about 70% of the substrate, and hardness has also been significantly improved.
Ti6Al4V	Ti6Al4V with 0.4% traces of boron	1600	Laser coating	30% hardness increase
Ti6Al4V	Ti6Al4V	700	Laser metal deposition	Improved hardness and fatigue strength in the coating
Ti6Al4V	Ti6Al4V	210-1100	Laser coating	High hardness achieved

There is an effect of residual stress, surface finish, and microstructure defects that occur in the mechanical properties of material during the laser metal deposition technique that need to be considered in the scanning strategy and parameters during the process.

V. Conclusion

This article aimed to identify the applications of hybrid additive manufacturing of metals, its characteristics, the types of steels, and their mechanical properties, from a systematic review of the literature identified 722 articles published in the last five years, reached through specific protocols 268 articles being selected 34 articles as research objects of this article.

From a variety of studies, it was inferred that:

- AM metal's hybrid process combining DED and subtractive manufacturing can overcome the disadvantages of additional post-processing by multitasking in an integrated system;
- Developing workstations for hybrid processes include challenges associated with hardware and software integration;
- . Different powdered metals are being designed for various tooling applications with lower raw material and processing costs, among them H13 and P20;
- Experimental results indicate that reducing the surface roughness of AM materials will improve their fatigue and abrasion wear resistance.

Due to practical constraints, this article cannot provide a comprehensive review of HMM, as there is currently limited research work, and its application is still under development.

It is hoped that this research will contribute to a deeper understanding of HMM and its applications, however, there are still some knowledge gaps in the field of study.

In this sense, future research is suggested for:

- Development of new HMM processes and systems;
- Software development for HMM systems (including programs for path generation);
- Machine tool retrofit;
- Thermomechanical analyses to estimate deposition and strategies.

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