A Literature Review on Wire Arc Additive Manufacturing of ER4043 And ER4047 Aluminium Alloys

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Abstract- Wire arc additive manufacturing (WAAM) is a fusion manufacturing process in which the heat energy of an electric arc is employed for melting the electrodes and depositing material layers for wall formation or for simultaneously cladding two materials in order to form a composite structure. Wire and arc additive manufacturing (WAAM) process is a group of additive manufacturing (AM) techniques that use an electric arc as a heat source and a metal wire as a feedstock for the fabrication of 3D metallic components in a layer-based manufacturing process.This directed energy deposition-arc method is advantageous and efficient as it produces large parts with structural integrity due to the high deposition rates, reduced wastage of raw material, and low consumption of energy in comparison with the conventional joining processes. These features have resulted in a constant and continuous increase in interest in this modern manufacturing technique which demands further studies to promote new industrial applications. The high demand for WAAM in aerospace, automobile, nuclear, moulds, and dies industries demonstrates compatibility and reflects comprehensiveness. This paper presents the literature reports regarding the WAAM applications, methods employed, optimization and process limitations and metallurgical behavior of materials will be analyzed and discussed in this paper.

Keywords- AM, Wire and arc additive manufacturing (WAAM), Cold Metal Transfer.

I. INTRODUCTION

In recent decades, additive manufacturing techniques (AM), also referred to as 3D printing or rapid prototyping, have attracted the attention of various industries such as aerospace, automotive, and construction. AM is the process of manufacturing 3-D pieces by adding layer-upon-layer of material. The various advantages of AM compared to conventional manufacturing (CM) processes can be discussed in three aspects. First, AM makes it possible to build complex components that are difficult to manufacture by the CM processes. Second, the AM processes improve the buy-to-fly ratio by reducing the amount of waste material, which reduces the final price of the parts. Third, the AM process can have a significant impact on reducing energy consumption and protecting the environment by reducing both the production time and the weight of parts produced due to new designs or material modifications [3-5]. Wire and Arc Additive Manufacturing (WAAM) refers to a specific group of AM techniques that use an electric arc as the heat source and a metal wire as the feedstock. The WAAM technique uses arc welding processes and more specifically automated arc welding. The three welding methods commonly used in the WAAM technique are Gas Tungsten Arc Welding (GTAW), Plasma Arc Welding (PAW), and Gas Metal Arc Welding (GMAW). Therefore, WAAM technique is divided into three groups, namely GTAW-based WAAM, PAW-based WAAM, and GMAW-based WAAM. The main advantage of WAAM over other AM techniques is that its deposition rate is higher, hence WAAM is used to produce large near-net-shape components. Another advantage of WAAM is its lower capital costs compared to other methods.

Despite the increasing consumption of aluminum and its alloys in various industries due to its unique properties, such as high strength-to-weight ratio, high ductility, and high durability, most of the research and productions in the WAAM field have focused on the stainless steels, nickel and titanium alloys. The main reason is the gas pores and the coarse dendritic structure formation during the WAAM process, which leads to a severe loss of the mechanical properties of the aluminum alloy components.

1.1 ADDITIVE MANUFACTURING

Additive manufacturing (AM) is also known as 3D printing. It is a transformational approach to industrial production that uses a computer-controlled process to generate three-dimensional objects through the process of adding materials layer-by-layer. Additive manufacturing (sometimes referred to as rapid prototyping or 3D printing) is a method of manufacture where layers of a material are built up to create a solid object. While there are many different 3D printing technologies this article will focus on the general process from design to the final part. Whether the final part is a quick prototype or a final functional part, the general process does not change.

Additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object, with material being added together (such as plastics, liquids or powder grains being fused together), typically layer by layer.3D printable models may be created with a computer-aided design (CAD) package, via a 3D scanner, or by a plain digital camera and photogrammetry software. 3D printed models created with CAD result in relatively fewer errors than other methods. Errors in 3D printable models can be identified and corrected before printing. The manual modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

CAD models can be saved in the stereo lithography file format (STL), a de facto CAD file format for additive manufacturing that stores data based on triangulations of the surface of CAD models. STL is not tailored for additive manufacturing because it generates large file sizes of topology optimized parts and lattice structures due to the large number of surfaces involved. A newer CAD file format, the Additive Manufacturing File format (AMF) was introduced in 2011 to solve this problem. It stores information using curved triangulations.

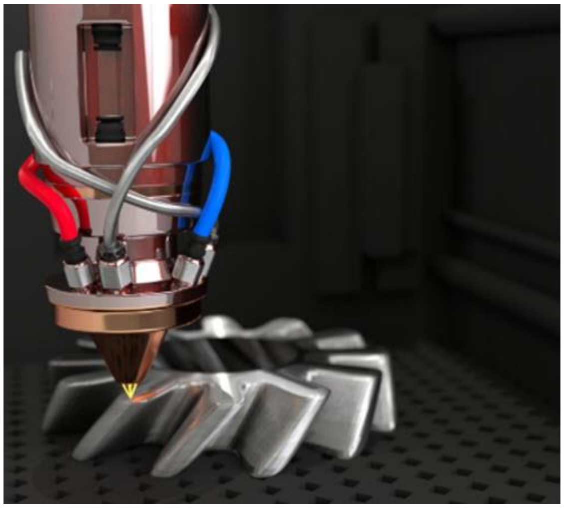

Figure 1.1 Additive Manufacturing

1.2 ADDITIVE MANUFACTURING TECHNOLOGIES

- **Sintering** is where the material is heated, but not to the point of being liquefied, in order to create a multifaceted, high-resolution object. Selective laser sintering uses a laser on thermoplastic powder in order to get the molecules to adhere together. Direct metal laser sintering does the same thing as selective laser sintering except uses a metal powder as the material.

- **Stereo lithography** uses a process known as photo polymerization. This process involves a UV laser that is directed into a vat of photopolymer resin in order to build torque-resistant ceramic parts that are able to withstand extreme temperatures

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- **Melting** is where the additional manufacturing technology such as direct laser sintering, completely melts the material. A laser or electron beam can be used to melt the layers of powder.

1.3 WORKING OF ADDITIVE MANUFACTURING PROCESS

Additive manufacturing works by using a computer-aided design (CAD) or 3D object scanner that directs hardware to place material, layer-by-layer to create precise geometric shapes. This is different than traditional manufacturing methods that use milling, machining, shaping, carving or various other methods to remove excess material.

1.3.1BINDER JETTING

Binder jetting uses a 3D printer style head that lays down and moves on the x, y, and z axes in order to alternate layers of powdered material. The powdered particles are bound together using droplets from the liquid binder which are propelled out of the printer head. When finished, the part is cured in an oven to get rid of any excess binding agents.

1.3.2DIRECTED ENERGY DEPOSITION

Directed energy deposition uses an electron beam gun or a laser that is mounted on a multi-axis arm. Material (powder or wire form) is deposited from the nozzle onto the surface of the object. Then, the laser melts the material. Additional material is added layer-by-layer and hardens creating the new piece. This additive manufacturing technique can be used with a wide range of material including polymer, metal, and ceramic.

1.3.3MATERIAL EXTRUSION

This is the most recognized additive manufacturing processes. During material extrusion spooled polymers are pushed through a heated nozzle mounted on a moveable arm. This continuous stream of heated polymers is deposited layer-by-layer. The layers stay formed together through temperature control or chemical bonding agents to create the 3D object.

1.3.4 POWDER BED FUSION

The power bed fusion additive manufacturing process uses the following printing techniques: direct metal laser sintering (DMLS), direct metal laser melting (DMLM), selective heat sintering (SHS), electron beam melting (EBM), and selective laser sintering (SLS). Powder bed fusion works by using either a laser, thermal print head, or electron beam to melt and fuse thin layers of material powder together in a three-dimensional space

1.3.5SHEET LAMINATION

- **Ultrasonic additive manufacturing (UAM)** uses sheets or ribbons of metal and binds them together through the use of ultrasonic welding. Additional CNC machining and removal of excess metal is frequently needed during the welding process. This process requires little energy and is a low-temperature process and can be used with different metals such as stainless steel, copper, steel, titanium and aluminum.

- **Laminated object manufacturing (LOM**) also uses a layer-by-layer approach but uses paper as material and adhesive instead of welding. Each layer of material is bonded with glue on top of the prior one until the component is finished. This process is frequently used for visual and aesthetic models and should not be used for structural purposes.

1.3.6 VAT POLYMERIZATION

Vat photo polymerization uses a vat of liquid photopolymer resin to construct an object layer-by-layer. The process involves mirrors precisely directing the ultraviolet (UV) light where to go. When the photopolymer molecules are exposed to certain wavelengths of light, they rapidly bind together to create a solid form. This additive manufacturing process is fast and extremely accurate.

1.3.7WIRE ARC ADDITIVE MANUFACTURING

This additive manufacturing process uses an arc welding process to 3D print objects. This process is controlled by a robotic arm that follows a predetermined path. The object is built upon a base plate and the object can be cut when finished. This process can work with a wide range of metals such as stainless steel, nickel-based alloys, titanium alloys, and aluminum alloys as long as they are in wire form.

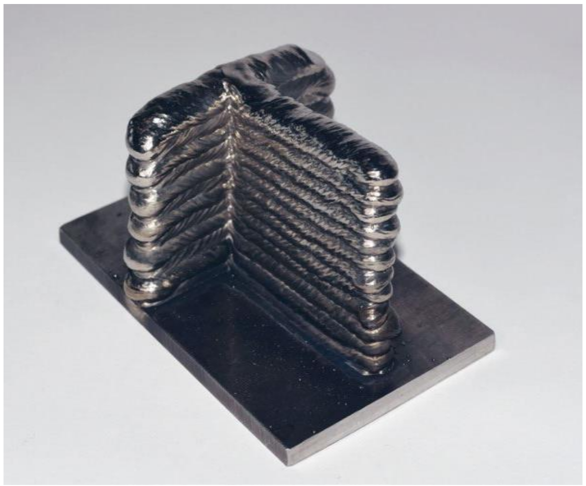

Figure 1.2 Wire Arc Additive Manufacturing

1.4 ADVANTAGES OF ADDITIVE MANUFACTURING

- **Accelerated prototyping**. AM expedites product development by enabling the creation of many varying prototypes that can be produced faster and cheaper in comparison to lengthy traditional methods. Several prototypes can be printed before committing to a production run, leaving less room for error in the whole process. In AM, any changes to the original specification are made digitally, reducing the modification costs to achieve the desired result.

Traditional design modifications are generally more expensive to undertake.

- **Customisation.**AM manufacturing offers design innovation and creative freedom without the cost and time constraints of traditional manufacturing. The ability to easily alter original specifications means that AM offers greater opportunity for businesses to provide customised designs to their clients. With the ease to digitally adjust design, product customisation becomes a simple proposition. Short production runs are then easily tailored to specific needs.
- **Energy savings**. In conventional manufacturing, machinery and equipment often require auxiliary tools that have greater energy needs. AM uses fewer resources, having less need for ancillary equipment, and thereby reducing manufacturing waste material. AM reduces the number of raw materials needed to manufacture a product. As such, there is lower energy consumption associated with raw material extraction, and AM has fewer energy needs overall.
- **Environment benefits.**The environmental benefits of additive manufacturing are an advantage to businesses seeking to improve manufacturing sustainability. AM offers many positive environmental benefits in comparison to traditional manufacturing. The most notable of which are waste reduction and energy savings. The processes of additive manufacturing, compared to traditional manufacturing, are more efficient and significantly reduce the environmental impact of waste products. AM offers greater material efficiency because it only uses what is needed to create a product.
- **Inventory stock reduction.**AM can reduce inventory, eliminating the need to hold surplus inventory stock and associated carrying costs. With additive manufacturing, components are printed on demand, meaning there is no over-production, no unsold finished goods, and a reduction in inventory stock.
- **Manufacturing and assembly.**A significant benefit of additive manufacturing is the ability to combine existing multi-part assemblies into a single part. Instead of creating individual parts and assembling them at a later point, additive manufacturing can combine manufacturing and assembly into a single process. Effectively consolidating manufacture and assembly into one.
- **Material waste reduction.**In conventional manufacturing processes, material is typically removed from a larger piece of work; think timber milling or cutting shapes from sheets of steel. In contrast AM starts from scratch, adding material to create a component or part. By using only the substance necessary to create that part, AM ensures minimal waste. AM also reduces the need for tooling, therefore limiting the amount of material needed to produce components.

1.5 DISADVANTAGES OF ADDITIVE MANUFACTURING

- **Cost of entry.**With additive manufacturing, the cost of entry is still prohibitive to many organisations and, in particular, smaller businesses. The capital costs to purchase necessary equipment can be substantial and many manufacturers have already invested significant capital into the plant and equipment for their traditional operations. Making the switch is not necessarily an easy proposition and certainly not an inexpensive one.
- **Production costs.**Production costs are high. Materials for AM are frequently required in the form of exceptionally fine or small particles that can considerably increase the raw material cost of a project. Additionally, the inferior surface quality often associated with AM means there is an added cost to undertake any surface finishes and the post-processing required to meet quality specifications and standards.
- **Additional materials.** Currently there is a limit to the types of materials that can be processed within AM specifications and these are typically pre-alloy materials in a base powder. The mechanical properties of a finished product are entirely dependent upon the characteristics of the powder used in the process. All the materials and traits required in an AM component have to be included early in the mix. It is, therefore, impossible to successfully introduce additional materials and properties later in the process.
- **It's slow.**As mentioned, additive manufacturing technology has been around since the eighties, yet even in 2021, AM is still considered a niche process. That is largely because AM still has slow build rates and doesn't provide an efficient way to scaleoperations to produce a high volume of parts. Depending on the final product sought, additive manufacturing may take up to 3 hours to produce a shape that a traditional process could create in seconds. It is virtually impossible to realise economies of scale.
- **Post-processing.**A certain level of post-processing is required in additive manufacturing because surface finishes and dimensional accuracy can be of a lower

quality compared to other manufacturing methods. The layering and multiple interfaces of additive manufacturing can cause defects in the product, whereby post-processing is needed to rectify any quality issues.

1.6 APPLICATION OF ADDITIVE MANUFACTURING

AEROSPACE

Additive manufacturing's ability to convert raw materials into complex 3D forms without the need for complex tools makes it advantageous to the aerospace industries. AM enables complex designs, materials to be mixed, and energy efficiency in order to produce lightweight parts enabling designers to save time and experience significant cost savings. AM is used in the aerospace industry to create hinges, brackets, interior components, and lightweight fuselage and airframe designs in order to improve fuel efficiency. It can also be found in turbine blades.

AUTOMOTIVE

Additive manufacturing has enabled the automotive industry to create lighter, stronger, and safer products. They are able to develop more robust designs and use rapid prototyping to experience reduced lead times and a reduction in costs. One way the automotive industry uses AM is to create accurate models that enable the designer's intentions to be clearly communicated to show the overall form of a concept. Further, AM enables full testing and validation of prototype performance. AM can be found in various finished products for a vehicle such as in battery covers, air condition ducts, and front bumpers.

MEDICAL

In the medical industry, additive manufacturing has helped solve medical issues resulting in a huge benefit to humanity. AM plays a major role in product development in the healthcare industry. It helps reduce the cost of production, development, cycle time, and enables rapid product development. AM also makes operations faster, cost-efficient, and more accurate than manual processes. A few items that AM is used to create are dental prosthetics such as crowns, repair bone defects through customized implants, and custom fit masks.

ENERGY

Additive manufacturing's innovation in producing efficient, on-demand, lightweight components has driven success in the energy sector. Centring on AM's capability to quickly create tailored components and environmentally friendly materials that can withstand extreme conditions.

II. LITERATURE REVIEW

Zhi-qiang Liuetal.[1],the influence of process parameters on additive manufacturing of thin-walled parts and scanning paths on additive-manufactured thick-walled parts was investigated. The microstructure and mechanical properties of the manufactured parts were studied.

Ali et al. [2],presents investigations on the additive manufacturing of hot work steel with the energy-reduced gas metal arc welding (GMAW) process, which is a cold metal transfer (CMT) process. The paper analyses the influence of arc energy and the thermal field on the resulting mechanical properties and microstructure of the material.

Chen Shen [3], present thesis work, an innovative wire-arc additive manufacturing process is used to fabricate iron aluminide alloy in-situ, through separate feeding of pure of Fe and Al wires into a molten pool that is generated by the gas tungsten arc welding process. This new manufacturing process possesses revolutionary time and cost saving in comparison to traditional methods.

K. S. Derekar[4],presents growing market demands of aluminium products, mainly high-strength alloys in automobile and aerospace, could be satisfactorily fulfilled using WAAM as an economical next-generation option. GMAW based CMT variants have been widely applied and studied as a competent technique for WAAM of aluminium. The elimination of porosity, a prominent issue highly debated in aluminium welding, was appreciably tackled by the application of interlayer rolling and the CMT-PADV technique. Study of weld pool behaviour and weld metal solidification characteristics of heat treatable and non-heat-treatable aluminium alloys for thin and thick structures through metallurgical viewpoint can prove to be an important constructive field of study.

Arturo etal.[5],thispaperpresentselaborated using a 3D print device equipped with a Cold Metal Transfer welding source. Two sets of process parameters leading to different average powers were compared in order to establish the relations between the powers and energies produced and the geometrical characteristics of the deposits. The effects of the travel speed and layer superposition on the transfer mechanisms as well as on the geometrical characteristics of the deposits were discussed for both sets of parameters.

Finally, the formed microstructures were analysed and the porosity defects were quantified.

Babu et al. [6], fusion-based metal additive manufacturing induces spatial and temporal variations of melt pool, thermal gradient, liquid-solid interface velocity, and thermal gyrations. These variations always lead to spatial microstructural and mechanical heterogeneities within a given geometry and processing conditions for wide range of nickel-based super alloys. However, with innovative beam scanning strategies, site-specific microstructure control can be achieved during AM. This hypothesis was conclusively proven using well-designed E-PBF melting experiments with alloy 718 powders, by coupling heat transfer models, solidification maps and in situ IR imaging. Approaches to control the solid-state transformation in the same alloy using in situ heat treatment were also explored**.**

Gianni et al [7], results revealed that both techniques allowed sound components to be manufactured and no significant differences were observed in terms of their microstructural and mechanical properties, while CMT was also found to provide a relevant energy saving. This allows the selection of the best technology taking into account not only the geometrical characteristic of the part but also the environmental impact associated to each technique.

Zhen Chen[8], In this graphene nanoplatelets (GNPs) reinforced K418 nickel-based super alloy composites were successfully fabricated by laser powder bed fusion (L-PBF). Plasma-assisted ball milling (P-milling) was used to prepare K418 composite powder with homogenous dispersion of GNPs on the surface. The effects of the addition of GNPs on microstructure and phase composition of L-PBF-processed GNPs/K418 samples were studied by comparing with their counterparts without GNPs fabricated under the same conditions. The microstructures of as-built K418 and GNPs/K418 composite sample were characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and Raman spectroscopy.

Sirisha et al [9], it includes wastage of material, time and cost. This processes generally involve high residual stresses and distortions due to the excessive heat input and high deposition rate. The improvements of surface quality and mechanical properties are critical factors in Wire-Arc Additive Manufacturing. In the present work, the effect of process conditions, on various parameters for Wire-Arc Additive manufactured aluminium alloy components based on Taguchi design of experiments were studied.

Guangjie et al [10], this paper conclude from this project is that all challenges needs to be considered, more or less, when building a torque arm with WAAM. However, most of them such as the "starts and stops" and "cross of paths", were solved with the automatic slicing in Simplify3D. To verify the "Voids in solid layer" point, further investigation of the torque arm needs to be done. However, according to the information found in previous works, this should be solved by the overlapping beads.

Mehdi [11], control of heat input during welding has a great influence on the weld seam geometry, as well as the mechanical and metallurgical properties of the welding joint. The amount of residual stresses and distortion in the welded work piece is directly related to the amount of weld heat input. Gas metal arc welding (GMAW) provides an abundant amount of heat input and, despite modified and controlled metal transfer modes and optimization of feeding techniques, such as synergic control, precision in setting the GMAW parameters is essential to achieve optimal heat input.

Jianglong et al [12], conclude that there may be higher requirements for the qualities and properties of wires for WAAM than for welding. External surface qualities, micro hardness, composition and microstructures of five ER4043 aluminium wires were investigated in the present research. The results indicate that the internal and external properties of the wires exert great influence on the performance of the WAAM parts.

Quanquan et al [13], results obtained in this research reveal a novel path to eliminating microcracks during the LPBF of Hastelloy X by the addition of titanium carbide nanoparticles. Various factors of this setup were investigated, including hot cracking elimination mechanism, microstructure evolution, and mechanical properties.

Amberlee et al [14],the relationship between microstructure and properties is not widely assessed in parts produced by additive manufacturing, particularly for aluminum. These relationships can be used by engineers to develop new materials, additive processes, and additively manufactured parts for a variety of applications. Thus, the tensile, compressive, and microstructural properties of common aluminum weld filler alloys (ER1100, ER4043 , ER4943, ER4047, and ER5356) were evaluated following gas metal arcweld (GMAW) – based metal 3-D printing to identify optimal alloy systems for this type of additive manufacturing.

Heard et al [15], The 4047 Al alloy can be considered as a near eutectic binary alloy. The resulting microstructure upon solidification should consist of the primary a-Al solidification phase followed by the solidification of the Al–Si eutectic phase. The properties of Al–Si alloys are strongly influenced by microstructural features, such as the morphology of the primary a-Al phase, the size, morphology and distribution of the second phase silicon particles, porosity content, dendrite arm spacing (DAS), eutectic morphology and grain structure.

Orgar et al [16], study addresses wire arc additive manufacturing of AA5183 aluminium alloy using conventional gas metal arc welding deposition on 20mm thick AA6082-T6 plate as support material. Microscopic examination demonstrates that the process is feasible, but can be further optimized to reduce gas porosity and hot cracking. Hardness measurements confirmed relative high hardness.

Luo et al [17], In this study, pulsed arc and non-pulsed arc were used in WAAM process of aluminium alloys. Arc information in manufacturing was used to identify the droplet transfer in projected transfer mode. A calculation method was proposed to analyze the arc pulse effect on the droplet transfer. As a result, it was found that the pulsed arc can achieve higher droplet transfer frequency and the size of the droplet in the pulsed arc is smaller than that in the non-pulsed arc.

Maximilian et al [18], the investigations show the that mechanical properties like tensile strength and material hardness can be adapted throughout the energy input per unit length significantly. Additive manufacturing processes enable both cost and time savings in the context of component manufacturing. Thereby, wire arc additive manufacturing (WAAM) is particularly suitable for the production of large volume parts due to deposition rates in the range of kilograms per hour.

III. CONCLUSION

From the above literature Review we conclude that, WAAM is a manufacturing method with lots of opportunities even though it needs to be further developed. The current design of the torque arm was possible to manufacture, though with a noticeable amount of material off set due to lack of time. With more tests and refinements, a more near net shape print would be possible to achieve. Some more advanced features in the design could also be achieved.

REFERENCES

[1] Zhi-qiang Liu, Pei-lei Zhang, Shao-wei Li, Di Wu, and Zhi-shui Yu, "Wire and arc additive manufacturing of 4043 Al-alloy using a CMT method"-International Journal of Minerals, Metallurgy and Materials Accepted manuscript, https://doi.org/10.1007/s12613-019- 930-6 © University of Science and Technology Beijing and Springer-Verlag GmbH Germany, part of Springer Nature 2019.

[2] Y. Ali, P. Henckell, J. Hildebrand, J. Reimann, J.P. Bergmann, S. Barnikol-Oettler, "Wire arc additive manufacturing of hot work tool steel with CMT process"-Technische Universität Ilmenau, Department of Production Technology, Germany, Journal of Materials Processing Tech. 269 (2019) 109–116.

[3] Chen ShenYoshihiko, "Application of wire-arc additive manufacturing (WAAM) process in in-situ fabrication of iron aluminide structures"-University of Wollongong Thesis Collection 1954-2016.

[4] K. S. Derekar (2018): A review of wire arc additive manufacturing and advances in wire arc additive manufacturing of aluminium, Materials Science and Technology, DOI:10.1080/02670836.2018.

[5] Arturo Gomez Ortega, Luis Corona Galvan, Mehdi Salem, Kamel Moussaoui, Stéphane Segonds, et al.. Characterisation of 4043 aluminium alloy deposits obtained by wire and arc additive manufacturing using a Cold Metal Transfer process. Science and Technology of Welding and Joining, Maney Publishing, 2019, 24 (6), pp.538-547. 10.1080/13621718.2018.

[6] S.S. BABU, N. RAGHAVAN, J. RAPLEE, S.J. FOSTER, C. FREDERICK, M. HAINES, R. DINWIDDIE, M.K. KIRKA, A. PLOTKOWSKI, Y. LEE, AND R.R. DEHOFF, "Additive Manufacturing of Nickel Superalloys: Opportunities for Innovation and Challenges Related to Qualification" The Minerals, Metals & Materials Society and ASM International 2018.

[7] Gianni Campatelli, Davide Campanella, Antonio Barcellona, Livan Fratini, Niccolò Grossi, Giuseppe Ingarao, "Microstructural, mechanical and energy demand characterization of alternative WAAM techniques for Al-alloy parts production" CIRP Journal of Manufacturing Science and Technology (2019).

[8] Z. Chen, P. Wei, S. Zhang, B. Lu, L. Zhang, X. Yang, K. Huang, Y. Huang, X. Li, Q. Zhao, Graphene reinforced nickel-based superalloy composites fabricated by additive manufacturing, Materials Science & Engineering A (2019), doi: https://doi.org/10.1016/ j.msea.2019.138484.

[9] A. Sirisha Bhadrakali, K.L. Narayana, T. Ram Prabhu, " Optimization Of Process Parameters For ER-4043 Aluminum Deposited By Wire Arc Additive Manufacturing" European Journal of Molecular & Clinical Medicine ISSN 2515-8260 Volume 07, Issue 08, 2020.

[10] Mattias Karlsson, Axel Magnusson, "Wire and Arc Additive Manufacturing, Pre printing strategy for torque arm"- Luleå University of Technology Department of Engineering Sciences and Mathematics.

[11] Mehdi Gharagozloo, “Development of Parameters of GMAW-P for the Wire and Arc Additive Manufacturing (WAAM) of Aluminum Alloys”- thesis presented to école de technologie supérieure in partial fulfillment for a master’s degree with thesis in aerospace engineering m.a.sc. montreal, september 14, 2020.

[12] Jianglong Gu, Jialuo Ding, Baoqiang Cong, Jing Bai, Huimin Gu, Stewart W. Williams and Yuchun Zhai, “The Influence of Wire properties on the Quality and Performance of Wire+Arc Additive Manufactured Aluminium Parts”- Advanced Materials Research Vol 1081 (2015) pp 210-214.

[13] Han Q, Gu Y, Setchi R, Lacan F, Johnston R, Evans SL, Yang S, Additive manufacturing of high-strength crack-free Ni-based Hastelloy X superalloy, Additive Manufacturing (2019), doi: https://doi.org/10.1016/j.addma.2019.100919.

[14] AmberleeS.Haselhuhn, MichaelW.Buhr, BasWijnen, PaulG.Sanders, Joshua M.Pearce, “Structure-property relationships of common aluminum weld alloys utilized as feedstock for GMAW-based 3-D metal printing” - Materials Science&EngineeringA673(2016)511–523.

[15] D W Heard, S Brophy & M Brochu (2012) Solid freeform fabrication of Al–Si components via the CSC-MIG process, Canadian Metallurgical Quarterly, 51:3, 302-312, DOI: 10.1179/1879139512Y.0000000023.

[16] A. Horgar, H. Fostervoll, B. Nyhus, X. Ren, M. Eriksson, O.M. Akselsen, “Additive manufacturing using WAAM with AA5183 wire” - Journal of Materials Processing Tech. 259 (2018) 68–74.

[17] Luo Y, Li J, Xu J, Zhu L, Han J, Zhang C, “Influence of pulsed arc on the metal droplet deposited by projected transfer mode in wire-arc additive manufacturing” - Journal of Materials Processing Tech. (2010), https://doi.org/10.1016/j.jmatprotec.2018.04.047.

[18] Maximilian Gierth, Philipp Henckell, Yarop Ali, Jonas Scholl and Jean Pierre Bergmann, “Wire Arc Additive Manufacturing (WAAM) ofAluminum Alloy AlMg5Mn with Energy-ReducedGas Metal ArcWelding (GMAW)” - Production Technology Group, Technische Universität Ilmenau, D-98693(2020) Ilmenau, Germany.