Naser Alshallal. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 13, Issue 11, November 2023, pp 236-246

RESEARCH ARTICLE OPEN ACCESS

Effects of aluminum casting process indicators on the mechanical properties of metal mold castings and a study of the variables that affect the weld joints of aluminum alloys

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ABSTRACT
Engineering structures utilize aluminum alloys with varied properties. The American National Standards Institute (ANSI) uses a numerical method to classify alloy systems. In contrast, the German Standards Institute (DIN) and the International Organization for Standardization (ISO) use names to designate the principal alloying components. The properties of an alloy, such as its tensile strength, density, ductility, formability, workability, weldability, and corrosion resistance, must be considered when deciding which metal is best for a given use. Due to their economic relevance and potential to boost efficiency and expand utilization in varied industrial sectors, aluminum ingots retain substantial importance as the primary ingots are now being strengthened, finally stabilizing their properties. Existing methods for designing metal plumbing molds rely heavily on a trial-and-error technique, which is susceptible to human mistakes, especially during decision-making. Consequently, this study intends to explore the impact of aluminum casting process indicators on the mechanical properties of metal molds and analyze the variables that influence these qualities. This paper will look specifically at the welding joints seen in aluminum alloys. According to previous studies, aluminum alloys naturally include high strength and flexibility, a favorable blend of corrosion resistance, and outstanding corrosion resistance. A permanent welding process was used when welding and annealing the aluminum alloy. Welding aluminum alloys using traditional methods is a substantial challenge.

Keywords - *Aluminum, casting process, weld joints, aluminum alloys*

Date of Submission: 15-11-2023 Date of acceptance: 30-11-2023

I. Introduction

The market for reinforced aluminum alloys has had a notable surge recently, primarily attributed to their efficacy and unique qualities that align well with significant advancements in the industrial sector. Aluminum, classified as a non-ferrous material, finds extensive application in engineering owing to its favorable corrosion resistance characteristics and lower density than ferrous metals. Casting technology is widely utilized in the production of numerous metal components. The Hypoeutectic Al-Si foundry is a frequently employed material in manufacturing engine blocks, with the gravity casting process being the predominant technique for its production (Timelli, 2016). Aluminum molds are made using several techniques, including pressure casting. Pressure and temperature parameters are manipulated to improve mechanical properties. This leads to an improvement in porosity as well. The casting process plays a role in the casting's final mechanical properties. For instance, castings made in a metal mold have more excellent ductility than those made in a sand mold (Mae, 2008). Common types of sand used in casting include chromite, quartz, and alumina. This contributes to its ability to form a desirable mechanical and fine structure in A356 cast aluminum alloy (Sun, 2012). The mechanical characteristics of A356 aluminum are subject to the influence of pattern types. A356 aluminum is utilized as a consumable pattern housing, exhibiting superior tensile strength, elongation, and toughness compared to lost foam casting (Wenming, 2012).

Additionally, the application of high pressure during the casting process resulted in a decrease in the porosity of the A356 alloy cylinder blocks. According to Dao (2012), the mechanical characteristics of AlSi9Mg exhibited an upward trend as the pressure was increased during the semi-solid casting process. The compression casting

(Suresh, 2013). The availability of the material under four unique heat treatment regimes for both sand and cold castings enhances its potential applications. The utilization of this alloy is also suitable for the production of relatively thin castings. Additionally, this alloy's casting procedure does not present any complications associated with hot rupture (Kabir, 2014).

The material has favorable characteristics regarding wear resistance, strength, and machinability. In the context of designing die-cast automobile components, it is imperative to possess a comprehensive understanding of the phenomenon of hardening and its consequential impact on mechanical properties (Zeren, 2006). The process of strengthening cast aluminum alloys commences with segregating the primary alpha phase from the molten state. Following nucleation, the temperature decline drives the growth of the first phase in the form of solid crystals exhibiting a dendritic morphology. The impact of varying cooling rates during solidification is widely acknowledged as a significant factor that can result in variations in cast structures' amount and morphological features. Consequently, these variations can contribute to distinct mechanical properties. Superior tensile and stress properties are observed in fine microstructured castings, particularly in aluminum cast alloys. Research on the impact of solidification microstructure on tensile properties reveals a negative correlation between solidification dendrite arm spacing (SDAS) values and both tensile strength and elasticity (Kabir, 2014). Due to the perceived significance of Structural Design and Analysis Software (SDAS), numerous automakers have incorporated SDAS values into the engineering data of their aluminum castings. The achievement of manufacturing castings with improved features is facilitated by implementing more stringent control measures over Solidification Defects and Segregation (SDAS) (Pavlović-Krstić, 2009).

2.2 Casting processes

Because casting requires significantly higher temperatures to generate molten metal than agglomeration techniques, it is believed that wrought metal came before casting in primordial times. By melting down an alloy and pouring it into a mold, shape casting allows the metal to be molded into a form that is both useful and close to the desired final form. Therefore, shape castings can be utilized without completely finishing or machining, making internal and surface integration crucial. Even though many operations can be automated with the help of contemporary engineering approaches, form casting remains mainly a batch process. Hence, this stands in stark opposition to the method offers several advantages over alternative processes for producing aluminum ingots. The process above exhibits enhanced mechanical characteristics characterized by diminished porosity as well as the refinement of iron-rich and alpha (Al) mineral dendrites with varying iron concentrations of Al5Cu0.6Mn-xFe in comparison to gravity die casting (Lin, 2014; Suprianto et al., 2016).

The use of cast aluminum alloys in automotive structural applications is experiencing a notable surge owing to the imperative requirement for weight reduction (Timelli, 2016). Various factors, including the dimensions, configuration, and arrangement of microstructural characteristics inside the casting, influence the longevity of a cast aluminum component. This holds particular significance in areas that encounter substantial mechanical stresses. The response of aluminum alloys to static and dynamic loads is subject to the influence of several factors. These factors encompass grain size, secondary dendrite arm spacing (SDAS), phase distribution, the presence of secondary phases or intermetallic compounds, the morphology of silicon particles (including size, shape, and distribution), and defects such as porosity. Fundamentally, the existence of more sophisticated microstructure features, as evidenced by reduced secondary dendrite arm spacing (SDAS) measurements, is correlated with enhanced mechanical capabilities. A range of parameters influences the mechanical properties of Al-Si alloys. However, one particular structural feature, referred to as SDAS, has attracted considerable attention from researchers in recent times(Pavlovic-Krstic, 2010).

II. Literature review

2.1 Aluminum alloys

For several decades, the automotive industry has been predominantly reliant on aluminum and aluminum alloy castings (Mallick, 2010). Approximately 66% of aluminum castings are utilized within the automotive sector, exhibiting a consistent upward trend while displacing iron castings. Although aluminum castings are more expensive than iron castings, there exists a continuous market demand for reducing vehicle weight and improving fuel efficiency. This serves as the impetus for the substitution of iron components with aluminum. The LM25 aluminum alloy is widely utilized in several industries, including but not limited to food, chemical, marine, electrical, and automotive. The principal use of this technology within the automotive industry pertains to manufacturing cylinder blocks, heads, and various other castings for engines and vehicle bodies of 2A70 aluminum alloy and Inconel 6000 nickel alloy were investigated by Zheng et al. (2017), who also investigated the impacts of dive depth. The dive depth was set at being between 0 and 0.5 mm. Joint strength was found to be significantly affected by the depth of immersion. The exemplary structures and mechanical properties of the HSLA steel and AA5052-H13 aluminum alloy junction were significantly impacted by tool displacement, as discovered by Ramachandran et al. (2015). The impact of tool displacement on the UTS of AISI 304 and AA5052 FSW joints was investigated by Naghibi et al. (2016). The results indicate that an offset of 2 mm yields the highest UTS.

The effect of tool compensation on material flow was also studied by Kar et al. (2019) for aluminum and titanium FSW, and they discovered that increasing tool displacement increased material flow. In addition, the FSW method was optimized for AA6061 and AA7075 aluminum alloys by Tamjidi et al. (2017) through research into the impact of travel speed, rotation speed, and tool displacement. They determined that the mechanical properties might be enhanced by using AA7075 for compensation. Savin et al. (2016) conducted a statistical analysis on the impact of various parameters on the FSW of AA6061-T6. They determined that the most critical factors influencing UTS and joint stiffness were the pin's form, rotational speed, travel speed, and tilt angle. Periyasami et al. [24] also investigated parameter effects on FSW for AA6061 and AA7075-T651. According to the findings, the UTS of the joint is most affected by the tool displacement, the tilt angle, and the pin diameter.

On the other hand, Dirazkola et al. (2019) evaluated the effect of rotating speed, travel speed, diving depth, and angle of inclination on the UTS of heterogeneous FSW of AA5754 and Polymethyl methacrylate (PMMA). They determined the ideal values for the above parameters. Single-factor tests were utilized in those articles, which means that both variables were held constant. The researchers opted to apply AI to lessen the possibility of empty co-production and wasted resources due to the high expenses and time commitment of beta testing. This explains why they took various AI-related approaches (Kumar, 2019). The initial phase involves optimizing the FSW process parameters for identical and dissimilar joints.

Couplings are numerous aluminum alloy joints commonly utilized in the automotive industry. However, CCD and ANOVA are frequently employed to optimize FSW process parameters. Finally, the maximum final tensile strength was discovered following FSW for dissimilar aluminum connections (Ghiasvand, 2022). It is important to continuous casting of steel, commonly called the continuous casting of aluminum and its alloys, which emerged during the twentieth century. Semi-continuous production is accomplished by utilizing direct current (DC) casting techniques in aluminum production. To date, "jumbo" plates have been the largest ingots manufactured. 2,700 mm x 610 mm (Grealy, 2001) bars measuring 1,050 mm (42 inches) in diameter and 7 meters long, weighing 20 tons. What is produced at the end of both processes can be further worked on in a rolling, forming, or extruding operation. For this reason, casting engineers now have access to a tool, thanks to the advancements in simulation and modeling of casting processes during the past half-century (Benedyk, 2017).

In the 15 years after the first Advanced Casting, Welding Modeling Procedures and Conferences on Advanced Hardening (MCWASP), the field of hardening and casting has advanced tremendously (Cockcroft & Maijer, 2009). Surface free flow, heat and fluid movement, and thermal pressure are only a few physical phenomena modeled as computing and processing capacity grow (Olofsson, 2020). However, one of the biggest remaining problems in making the molding process a genuinely successful and valuable tool for manufacturing organizations is applying these computed results in actual casting process windows and performance requirements (Yasuda, 2015). Preventing casting defects, including porosity, thermal fractures, and aggregate separation, account for a large portion of present-day modeling applications (Mark & Laurens, 2021). Several suggestions for better casting practice were arrived at by formulating the stress accumulation during casting, heat and fluid movement, and the solidification process to study the effect of all casting agents (Smith & Jolly, 2007).

2.3 Aluminum casting process and mechanical properties

Further investigation is warranted to examine the impact of tool displacement, tilt angle, and dive depth on the friction stir welding (FSW) process. Kumar et al. (2020) investigated the impact of the tilt angle on the mechanical properties of friction stir welding (FSW) of AISI 316L. The maximum UTS value was discovered to be attained with a score of 1.5 out of the three chosen grades (0, 1.5, and 3). The inclination angle impacts the maximum temperature, the shear layer under the tool shoulder, and the stirring area. However, Rajendran et al. (2019) found that a perfect joint is attained at a tilt angle of 1 to 3 degrees while working with FSW of aluminum alloy AA2024. Mechanical properties and microstructure of FSW damage, cracks, big transverse knife marks, or other noticeable faults on the specimen. Defects and weft adhesions such as sticky sand, fins, burrs, and more must be eliminated (Ghiasvand, 2022).

2.3.2 Impact test

When an impact sample fails under a subsequent shock load, the energy absorbed by the material can be calculated using an impact tester. The national measurement department should regularly check the impact testing machine to ensure it is by GB/T3808-2002, "Inspection of Pendulum Impact Testing Machines." The three types of impacting samples are V-shaped impingement samples, U-shaped impact samples, and non-notch impact samples. Cylindrical, non-grooved impact samples made from die-cast blank test bars of 30 mm diameter are used for grey cast iron. The standard gauge measures 4.2" x 1.20". Must conform to GB6296-1986 "Impact test method for grey cast iron" in all respects, including casting technique for blank test strip, technical requirements of impact sample, technical standards of impact testing machine, and test circumstances and methods. Castings that have been annealed, machined, and heat-treated in the same furnace as the casting itself are called blank castings. The specimen's technical specifications, including its shape, size, and demand, are set by market forces. U-shaped impact yens (often used for metals and alloys cast with large sensitivity of the degree) or V-shaped impact samples (Suprianto et al., 2016) are used as the striking samples for other types of cast metals and alloys.

You can get U- or V-shaped impact samples by using a single test block (rod), a molded test block (rod), or a casting body. The supply and demand terminals will determine the sampling location and direction as well as the type, shape, size, and casting method of the single casting test block (rod) and the attached casting test block (rod), as well as the connection method and connection location of the attached casting test block (rod) and casting body. Casting criteria are agreed upon or determined to match. When castings need to be heated, both the single-cast test die (rod) and the associated test block must undergo heat treatment in the same furnace (Ghiasvand, 2022).

2.3.3 Hardness test

Casting hardness can be measured using the Brinell hardness (HB) or Rockwell hardness (HRC) systems. Tough and brittle castings are typically assessed using the Rockwell hardness method. In contrast, lower and brittle castings are typically measured using the Brinell hardness method. There is a specific conversion relationship remember that the final casting quality check is just the last inspection point to prevent unqualified castings from leaving the plant before beginning to evaluate their mechanical qualities. Strengthening quality control and management throughout the entire production process of castings, stabilizing the production process, organizing civilized production, adopting as advanced production technology and equipment as possible, and being equipped with sufficient effective inspection methods for process quality and quality control are all essential to ensuring the quality of castings produced by an enterprise. Timelli (2016) describes the final cast.

Traditional methods of evaluating mechanical efficiency Conventional mechanical performance testing is performed at room temperature. Tensile strength, yield strength, elongation at break, area reduction, deflection, shock absorption (impact toughness), and material hardness are typical test items. A tensile testing machine determines the material's tensile strength, yield strength, elongation after fracture, and decrease in area. An impact testing machine evaluates a material's resistance to stress. Hardness is often tested using several hardness testers while bending and bending resistance are assessed with transverse bending test methods (Mark & Laurens, 2021).

2.3.1 Tensile test

Single-cast cylindrical test rods or connected die-cast test rods are used to create tensile samples of gray cast iron. The vertical cast dry sand mold has a diameter of 30 mm, and a single test rod is poured in the same batch as the casting. The parallel segment has a diameter of 20 mm 0.5 mm. When bending strength and deflection are used as acceptance criteria for the mechanical properties of the casting, a bending test may be carried out. The bending sample directly adopts the cast blank test strip with a diameter of 30 mm ± 1 mm. The test machine's bending test and technical requirements, calculation, and measurement data processing shall adhere to industry standards for shape, size, and surface quality of tensile test specimens, bending test specimens, cast blank test rods, tensile testing, and techniques (Lin, 2014).

Types of tensile specimens, cross-sections, and tensile testing techniques for metals and other cast alloys (such as measuring tensile specimen size, stabilization methods, test rates, performance measurement techniques, approximating and processing test findings, etc.). Surface requirements of GBT228, "Method of tensile testing of metallic materials at room temperature," must be met, including those for shape, gauge, length, size, and quality. There can be no signs of mechanical responsible for regularly performing standard compliance checks on hardness testers (Lin, 2014).

2.4 Weldability and Optimization of Process Variables for aluminum alloys

Simple in building, transportation, and advanced maritime and aeronautical applications like wing partitions, etc., aluminum alloys have seen widespread use in recent years. The combination of aluminum alloy's good and excellent wear resistance allows it to be both strong and flexible despite its lightweight nature. The welding method was used to anneal aluminum alloy permanently; incorporating aluminum alloys into the regular welding process is complex (Sathish, 2021).

The current standard for welding aluminum alloys of varying thicknesses is TIG welding. Compared to arc welding, TIG welding is more straightforward and efficient and yields higher-quality weld connections (i.e., fewer flaws). Mechanical strength research confirms that TIG welding increases the micrograin's strength. The TIG welding procedure has the added benefit of producing far higher-quality welds than alternative welding methods. Lightweight, very strong, highly malleable, and non-reactive are characteristics rarely found in the same material. It has the lowest specific gravity of any commercially available metal, is highly malleable, and will not rust thanks to a thin chromium coating on its surface. It is not a good conductor of electricity since it magnetizes only some metals (only some less magnetic ones) (Varshney & Kumar, 2021). Low heat input from the welding process keeps residual strains to a minimum, especially for friction welding. Measuring stress is done by observing the transverse force in the wench (also known as the transverse or transverse friction force; Mehdi & Mishra, 2020).

Dengkui et al. revealed that using distinct geometric shapes modifies the material's mechanical properties. Characterizing weld joints, including weld width, depth of penetration, and aspects of the reinforcing process, was found to be effective in this study. Alterations were made to the mechanical qualities, and increased strength was attained as a bonus. This research resulted in lower WZ and PMZ stiffness values, joint weakness, and mechanical characteristics (Denykui, 2018).

Welding parameters (current, welding speed, and welding duration) were optimized to reach a tensile strength of 130.27 MPa, as Aravind and Daniel Das proposed. For the most robust possible welds, the S/N ratio recommends the following (Aravind. & Daniel Das, 2020): What is more, Ramandeep et al. The welding current was found to increase the weld joint's rigidity. For their investigation, welding defects such as porosity between Rockwell hardness, Brinell hardness, and tensile strength for cast alloys with a homogeneous metal structure, such as cast steel. Look up "Conversion value of hardness and strength of copper alloys" (GB/T3771-1983) and "Hardness and strength conversion value of ferrous metals" (GB/T112-199) (Dao, 2012).

The Brinell hardness method uses a carbide ball set at a specified diameter to press it into the sample surface with the accompanying test force. Remove the test force after the allotted time has passed, then measure the indentation's diameter on the sample's surface and divide the result by the force used to make it. Distance is equal to the quotient of the surface area of a sphere. The HBW prefix is appropriate for materials with a Brinell hardness rating of less than or equal to 650. Materials, specimens, procedures, and outcomes The Brinell hardness tester must be calibrated per GBT231.1-2002, "Part One of the mineral Brinell hardness:" test method. Tensile specimens, impact specimens, castings, and hardness test blocks suit Brinell hardness testing. The testing area must be flat, smooth, and devoid of scales and other contaminants (Ghiasvand, 2022).

The Rockwell hardness scale can be used to measure several properties. Standardized measures include the HRA, HRB, and HRC. The indenter used to measure HRB is a steel ball with a hardness value of 130 c, while those used to measure HRA and HRC are diamond cones with a hardness value of 100 e. The main load for HRA is 490.3 N, with a corresponding measuring range of 60–85 HRA; for HRC, it is 1373 N, with a corresponding range of 20–67 HRC. All aspects of the Rockwell hardness tester, from the instruments used to the samples tested and the procedures followed in analyzing the results, must adhere to the standards outlined in GB/T 230.1-2004. Mineral Rockwell Hardness Part I: Testing Procedure (A, B, C, D, E, F, G, H, K, N, and T Scale). In all other respects, the Rockwell hardness tester is identical to the Brinell hardness tester (Suprianto et al., 2016), down to the specifications for the test surface, the kind of specimen, and the testing environment.

Shore hardness (HS) and Vickers hardness (HV) are further measures of mineral hardness alongside Brinell and Rockwell hardness. The GB/T4341-2001 "Method of Testing of Mineral Shore Hardness" specifies the standards to be used when measuring the shore hardness of minerals. The method used to determine hardness must be compliant with GB/T4341-2001. Compliance of metal Vickers with the GB/T4340.1-1999 "Vickers metal hardness tester part one: test method" standards The National Metrology Administration is and a substantial amount of heat. Although the AC TIG approach is smaller, the magnitude of the current utilized is significant (Mehdi & Mishra, 2019). According to Sun and Gong (2019), a comparison of the residual stresses in Tungsten Inert Gas (TIG) and Friction Stir Welding (FSW) techniques reveals that the longitudinal residual stress in the welded joint is greater than the transient residual stress for AA6061 and AA7075 materials. A thorough examination of comparative heat transfer and residual pressure investigations is required in the literature. Residual stresses and heat transfer at the origins and terminations of the joints influence the weld's quality. According to Sathish (2021), an investigation revealed that the tensile strength of joints in thin plate welding initially exhibited an upward trend with increased spindle rotation during stirrup welding. However, it subsequently decreased after reaching a particular threshold.

2.5 Effect of Welding Variables on Aluminum Alloy Weldments

The mechanical characteristics of cold-treated or heat-treated aluminum alloys are diminished in a localized region, referred to as the heat-affected zone, when welds are performed. The impact of heat input and heat removal rate on the size of the heat-affected zone during welding is widely acknowledged. The strength of welds is influenced by input and thermal removal rates, particularly in the case of heat-treated alloy plates that have not undergone post-weld reheating. The objective of the research outlined in this work is to examine the correlation between the factors influencing the rate of heat intake, the output force, and the magnitude of the heat-impacted area (Gurmeet, 2017).

A considerable body of research has been conducted to investigate the influence of various welding parameters on the tensile strength of welds and the size of the heat-affected zone in aluminum alloys. The conclusions above were reached from the findings of this investigation. Determining the influence of welding heat on both the strength and the heat-affected zone is contingent upon the El/Vt parameters. The variables E and I indicate the welding voltage and current, respectively. Similarly, the variable V is used to denote the welding speed, while the variable t represents the thickness of the material. The correlation between the size of the heat-affected zone and the modulus El/Vt can be estimated using equations 4 and 5 for 6061-T6 and 6063-T6 alloys and 6 and 7 for non-heat-treatable alloys. According to Sathish (2021), adherence to suggested techniques ensures that the heat-impacted affect the properties of welded samples, which affect the tensile strength (Ramandeep, 2019). In order to comprehend the metallic properties of the core material and the welded area, Gurmeet et al. conducted an empirical comparison analysis of TIG welding and the FSW method. TIG weld joint stiffness was also determined and compared to other weld joint stiffness in their research (Gurmeet, 2017).

Furthermore, aluminum alloy 2219 was TIG-welded by Ji Kun et al. (2014). It was evidence of the improved hardness and tensile qualities achieved through heat treatment after welding. They also concluded that post-weld heat treatment could attain maximum elongation and impact toughness. Tamar et al. (2011) also found that post-weld aging behavior improved the tensile strength of welded AA7075 joints. High-velocity impacts dissipate less energy in welded joints made of AA7075.

Adalarasan et al. (2014) recommended a TIG welding method with optimal process parameters, including 24 V, 180 A, welding speed of 110 mm/min, and gas flow at a rate of 12 L/min for welding 6061 aluminum alloy. They used ANOVA to assess the welding current's noteworthy contribution and considered it the primary variable under their control. Peak current (130, 150, and 170 A), core voltage (20, 25, 30 A), and gas pressure (4, 5, 6 kgf/cm2) were investigated as potential optimization parameters for TIG welding on AA6063 by Sethuraman et al. (2018). ANOVA and regression analysis were used to determine the impact of each independent variable. After investigating, Shanavas et al. (2017) determined that the optimal settings were 180 amperes, 100 mm/min of welding speed, and 11 L/m of buoyancy of the inert gas. They also determined that the achieved tensile strength was more significant than other joints. To our knowledge, no weldability experiments using the TIG technique have been conducted on aluminum alloy AA8006. 2219 aluminum is more challenging to weld than previously believed due to the increased susceptibility of joints to fatigue.

Researchers have developed many techniques for addressing these limitations, including AC TIG (All Current Treat All Weld), VPT (Validation of All Parameters), and plasma approaches. Nevertheless, the instability, inconsistency, and welding procedure cycle associated with the AC technique have yet to be resolved, rendering it a non-issue. To achieve a suitable welding junction, it is necessary to utilize a variable-polarity plasma welder. The process of joining large aluminum sheets through welding requires the utilization of high-penetration seams internal stresses and strains are produced within these fractions due to the heat gradients created within them. The low-cycle stress mechanism initiates these thermal cycles by setting the processes of crack initiation and growth in motion. Consider a cylinder head from a motor vehicle as an example of a part that is vulnerable to thermal cycles and, thus, the thermomechanical fatigue (TMF) phenomenon. Fatigue fractures in this particular component are induced by the cyclic beginning of shutdowns, which entail temperature fluctuations of up to 300 °C. In this application, aluminum alloys' mechanical response encompasses plastic deformation at low temperatures and significant viscosity at elevated temperatures. The alloys in question also experience an aging phenomenon, particularly when subjected to temperatures exceeding 150 °C. As a result, numerous stress mechanisms are activated during the thermomechanical cycle employed on the material, making the understanding of the entire fatigue process somewhat complex. Efforts will be made to improve the performance of these materials by modifying microstructural characteristics, such as the cooling rate, to reduce the distance between secondary and porous dendritic arms (Ratke, 2006).

Conversely, some authors assert that low SDAS values' beneficial impact is heightened during low cycles. In contrast, porosity, particularly its size, is significant during high cycles. The reduced size of the Small Scale Direct Air Staging (SDAS) system also leads to a decrease in the duration of the homogenization heat treatment process, as the distances over which heat propagation occurs are shorter. Due to the evident significance of SDAS, an increasing number of automotive firms have incorporated SDAS limitations into their technical standards, particularly for SDAS about the combustion chamber surface. This specific area of the cylinder heads experiences the highest thermal and mechanical stress levels. Typically, the prescribed standards for Specific Design and Analysis Specifications (SDAS) exhibit variability among different cylinder head models, such as those manufactured by BMW, Porsche, VW, Fiat, and others.

Furthermore, the SDAS (Secondary et al.) value exhibits a range of 20 to 40 µm and is quantified at a distance of 3-5 mm from the surface of the combustion chamber. It is essential to acknowledge that certain cylinder heads necessitate the fulfillment of additional rigors criteria, wherein the Solidification Defects Area Size (SDAS) at a distance of 4 mm from the combustion chamber's surface must not exceed 20 µm (Pavlovic, 2007). Achieving control over the solidification rate, and therefore the solidification defect size (SDAS) area is a maximum distance of 1.5 inches from the weld's center line.

The use of cast aluminum has experienced a notable rise, leading to increased demands for mechanical qualities (El-Sayed, 2015; Youssef & El-Sayed, 2016). The investigation of inclusions in Al castings, including their types, origins, and detrimental impacts, is crucial due to their significant influence on the mechanical properties of such castings. The flaw of the double oxide film is a crucial inclusion that has been documented to significantly impact the dependability and consistency of castings (Campbell, 2003).

Raiszadeh and Griffiths (2006) systematically investigated the historical evolution of oxide coatings in aluminum melts. The findings of their study demonstrated that the elevated free energy associated with the formation of Al2O3 led to the consumption of oxygen present within the double oxide film defect. This consumption occurred in two stages: first, the formation of Al2O3, followed by the reaction of nitrogen to generate AIN. These interactions are expected to result in a decrease in the size of the trapped air bubble. Moreover, the initial hydrogen content of the molten substance surpasses the equilibrium level linked to the encompassing environment. In that case, the hydrogen will undergo diffusion into the confined air bubble, causing an expansion in its dimensions (El-Sayed & Ghazy, 2017). A quasi-experimental mathematical model was constructed using the reaction rates of air confined within the defect to predict the time period during which the atmosphere remains within the defect of a double oxide layer. According to Raiszadeh and Griffiths (2008), the study's findings suggest that the utilization of oxygen and nitrogen within the defect would be at most three minutes.

Consequently, due to its distinctive characteristics, the utilization of aluminum alloys in several industrial domains has experienced substantial growth over the past few decades. The extensive use of these materials in the aerospace and automotive sectors can be attributed to their notable characteristics, including exceptional electrical and thermal conductivity, remarkable flexibility, and a notable strength-to-weight ratio (El-Sayed, 2015). According to Basuny (2016), the mechanical characteristics of aluminum castings are influenced by the existence of double oxide film defects, also known as double membrane defects. These defects have been seen to diminish the castings' tensile strength and fatigue resistance and enhance their adaptability.

Typically, mechanical and structural components encounter a wide range of temperature differences in various service situations. As a result, solidification microstructure concerning casting temperature, namely the secondary dendrite arm spacing (SDAS). The impact of the pouring temperature on the solidification structure and mechanical properties is discernible. A rise in the casting temperature leads to a more exact spacing of the arms of the secondary dendrites, increasing the hardness of the alloy accompanied by a drop in elongation percentage.

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values, poses significant challenges in industrial production. This difficulty arises from the intricate casting geometry, encompassing several cavities and varying wall thicknesses (Pavlovic-Krstic, 2010).

III. Conclusion

The microstructural composition of the hardening phase of cast aluminum alloys is the primary factor influencing their mechanical qualities. A cast component is durability depends on the microscopic arrangement within the casting, especially in areas that undergo substantial stress. The significance of accurately characterizing and forecasting the microstructure in form castings has grown in light of the prevailing inclination toward developing lightweight composites. Microstructure length scales are vital in the mechanical property models utilized to enhance design effectiveness. The application of predictive property models is highly significant due to the need to replace heavy iron components with aluminum alloy castings and the limited understanding of the long-term durability of aluminum alloy castings. The utilization of secondary dendrite arm spacing (SDAS) measurement has become increasingly prevalent in the characterization of the metallic microstructure of cast materials in recent years. SDAS, or Secondary Arm Spacing, measures the distance between prominent adjacent secondary arms within the dendritic structure. Castings with microstructures have superior static and fatigue performances, particularly in the case of aluminum cast alloys. This enhancement is directly associated with a reduced value of the secondary dendrite arm spacing (SDAS).

The present study aimed to investigate the impact of foundry factors, specifically mold materials and casting temperature, on the microstructure, secondary dendrite arm spacing (SDAS), and mechanical properties of the cast LM25 Al alloys. Metal die castings have a more refined microstructure than sand die castings due to the enhanced cooling and hardening rates. Therefore, it can be observed that the LM25 aluminum alloy exhibits a favorable dendritic morphology during solidification within a metallic mold, thereby resulting in enhanced mechanical characteristics. Thermodynamic modeling techniques substantiated the existence of the metallic compound CuAl2 and the Al-Cu-Mg-Si phases. The intermetallic phases present in the LM25 alloy contribute significantly to its enhanced mechanical capabilities. Metal die castings exhibit reduced porosity, leading to improved casting quality. The present study aims to elucidate the correlations between mechanical qualities and

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