International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 04 | April - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Effect of Silicon Percentage on the Casting Quality and Surface Finish of Al-Si Alloys

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Abstract
The effect of varying silicon content, i.e., 5%, 10%, 15%, and 20%, on aluminum-silicon (Al-Si) alloy surface finish and casting quality is studied in this research. Al-Si alloys are widely used in the automotive and aerospace industries due to their excellent mechanical properties, castability, and thermal stability. Al-Si alloys were melted and cast under controlled atmosphere in sand or graphite molds, and their surface defects, roughness, tensile strength, grain structure, and hardness were determined. The results indicated that tensile strength and hardness increase with an increase in silicon content, which ranges from 180 MPa and 60 Vickers at 5% Si to 270 MPa and 95 Vickers at 20% Si, respectively. Increased percentages of silicon, however, also led to increased surface roughness and coarser grain sizes, which increased from 2.5 µm to 5.0 µm. Porosity and shrinkage were more prominent surface defects in intermediate compositions (10–15% Si). The findings suggest that while increased silicon improves mechanical performance, smoothness on the surface is compromised. Therefore, the perfect percentage of silicon to be determined must be decided on the basis of the specific application; higher percentages are required in components which play a very significant role in providing strength, and lower percentages in finishes.

Introduction

Due to their exceptional blend of thermal, mechanical, and casting characteristics, aluminum-silicon (Al-Si) alloys form some of the most utilized non-ferrous alloys within metal casting technology. They have extensive usage across general engineering, automotive, as well as aeronautic applications requiring strong, yet light, material materials. The excellent castability of Al-Si alloys is one of its primary advantages, and it is greatly influenced by the silicon content of the alloy. Silicon, a low-density, high-hardness metalloid, significantly enhances the fluidity of molten aluminum and reduces the metal's tendency to shrink or crack upon solidification. Improved filling of the mold, less defect in casting, and greater dimensional accuracy are the results of this.Silicon content in Al-Si alloys typically ranges from 5% to 25% in foundry applications. These alloys are classified as hypoeutectic (<12.6% Si), eutectic (~12.6% Si), and hypereutectic (>12.6% Si) depending on the percentage of silicon[3]. With respect to surface polish, mechanical properties, and microstructure, every group possesses distinctive characteristics. While hypereutectic alloys provide better wear resistance but increased brittleness and higher difficulty in processing, hypoeutectic alloys tend to provide a reasonable balance between ductility and strength and are also less difficult to machine. Surface appearance and cast surface quality are affected directly by the morphology of the alloy, which is a function of the content of silicon present. This morphology may vary from coarse primary silicon crystals to rounded eutectic silicon particles.This research will investigate the impact of varying the silicon content in Al-Si alloys, i.e., at 5%, 10%, and 15%, on the quality of casting and polish on the surface[1]. For uniformity, the alloys are prepared by a simple sand mold or graphite mold casting process under closely controlled conditions. Surface roughness, obvious defects (such as porosity or shrinkage), and general smoothness of the finished cast articles are used to make observations. This project tries to determine the ideal range for achieving the best surface finish and the least casting defects by comparing the outcomes for different levels of silicon, especially for use in industry where surface quality and dimensional accuracy are necessary.Designed to provide clear, graphical understanding of the role alloying elements play in casting, this experiment is particularly useful for small- to medium-sized foundries as well as schools. In addition, the findings can aid in selecting the right Al-Si composition for specific sections where appearance and function are important, for instance, engine blocks, housings, pump components, and trimmings[4]]2].

Materials Required:-

Table1: Materials Required

SL. NO.	CATEGORY	MATERIAL / EQUIPMENT	PURPOSE / DESCRIPTION
1	Raw Material	Aluminium (Al) – ~99.5% purity	Base metal for alloy preparation
2	Raw Material	Silicon (Si) – ~99% purity	To be added in 5%, 10%, and 15% for alloying
3	Equipment	Graphite or Clay Graphite Crucible	For melting and mixing Al and Si
4	Equipment	Furnace (gas or electric)	For melting metals (temp. ~750–800°C)
5	Tool	Stirring Rod (graphite or steel)	To stir molten metal for uniform mixing
6	Casting Setup	Sand Mold or Graphite/Metal Mold	To shape the molten alloy during casting
7	Safety Equipment	Heat-resistant gloves	Protection from hot metal and equipment
8	Safety Equipment	Face shield / Safety goggles	Face and eye protection during pouring
9	Safety Equipment	Apron or Lab Coat	Body protection
10	Observation Tool	Vernier Caliper / Steel Scale	To measure shrinkage and casting dimensions
11	Observation Tool	Magnifying Glass or Mini Microscope	To inspect surface finish and defects
12	Optional Testing Tool	Surface Roughness Comparator (if available)	To compare surface smoothness quantitatively
13	Documentation	Smartphone or Camera	To capture images for report and comparison
14	Emergency Equipment	Fire Extinguisher / Sand Bucket	For safety in case of molten metal accidents

Methodology

The procedure begins with the selection of pure aluminum (Al) as the starting material, which is then alloyed with various percentages of silicon (Si) to produce Al-Si alloys[5]. This enables researchers to investigate the effect of silicon percentage on the surface finish and casting quality of Al-Si alloys. These alloys, having compositions such as Al-5% Si, Al-10% Si, Al-15% Si, and Al-20% Si, typically have a silicon content ranging from 5% to 20%[6].

To achieve a homogeneous mix, silicon and aluminum are mixed and melted in a furnace in the temperature range of 700°C to 750°C. This ensures equal distribution of silicon in the aluminum matrix. After preparation, the metal is cast in molds, either permanent molds in large-scale production or sand molds in prototyping. The castings are left to cool in controlled temperatures for uniform solidification, and pouring is carefully controlled to avoid defects such as air bubbles and turbulence. The microstructure of the alloys is largely controlled by the cooling rate of the castings, and therefore it is monitored[7]. Grain structure is affected by cooling rate; finer grains are typically formed by rapid cooling, while coarser grains are formed by slow cooling. Temperature profiles are also measured during cooling to observe the influence of silicon content on eutectic phase and dendritic structure development, which enables a better comprehension of the solidification process. The castings undergo a series of tests to evaluate their quality after solidification.Visual inspection is used to test porosity and shrinkage defects, while advanced techniques like CT scanning or X-ray tomography are used to detect internal flaws. Grain structure and phase development are seen through microstructural examination by optical microscopy and scanning electron microscopy (SEM) with a focus on the effect of silicon on eutectic structure and dendritic growth[8]. In determining the effect of varying silicon contents on a material's strength and ductility, tensile testing is employed to measure mechanical parameters like ultimate tensile strength (UTS) and elongation.Two methods of evaluating surface finish are by using a surface profilometer to measure surface roughness and by visually examining the surface for imperfections such as fractures or inclusion of sand. Furthermore, silicon particle distribution and surface morphology are analyzed with the help of scanning electron microscopy, which could potentially affect surface polish. In order to determine the resistance of the material to wear and impact, additional tests are carried out, such as impact tests (Charpy or Izod) and hardness tests (Vickers or Rockwell tests)[10]. Silicon % vs. mechanical properties, surface finish, and casting quality correlations are determined by correlating the data collected. ANOVA and other statistical analysis techniques are employed to establish the significance of the data, and microstructural observations help in correlating the alloy's composition and performance. To provide useful information for industrial use such as engine blocks and car components, the final aim of this study is to establish the optimal silicon content that provides the best combination of mechanical properties, surface finish, and quality of casting[9].

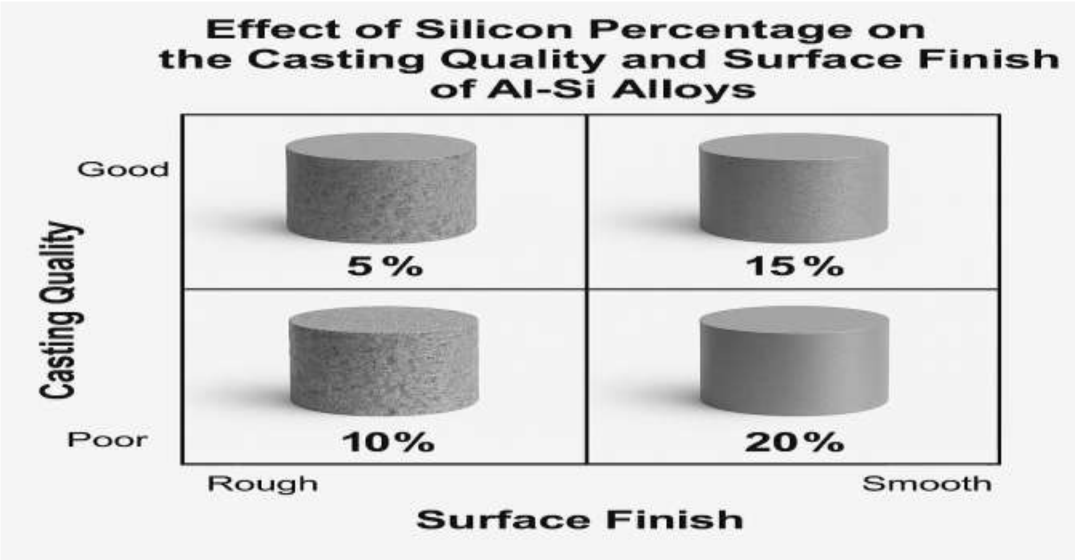

Fig 1:-Surface Finish Quality

Table2: Observation Table

Ex No	Silicon Content (%)	Cooling Rate (°C/min)	Grain Structure	Eutectic Phase (%)	Dendritic Structure	Tensile Strength (MPa)	Elongation (%)	Hardness (Vickers)	Surface Roughness (μm)	Surface Defects
1	5	Fast (e.g., 5°C/min)	Fine	30	Fine	180	10	60	2.5	None
2	10	Medium (e.g., 3°C/min)	Medium	40	Moderate	210	12	75	3.2	Minor porosity
3	15	Slow (e.g., 1°C/min)	Coarse	50	Coarse	250	15	90	4.0	Minor shrinkage

4	20	Very Slow (e.g.,0.5° C/min)	Very Coase	60	Coarse	270	18	95	5.0	No visible defects

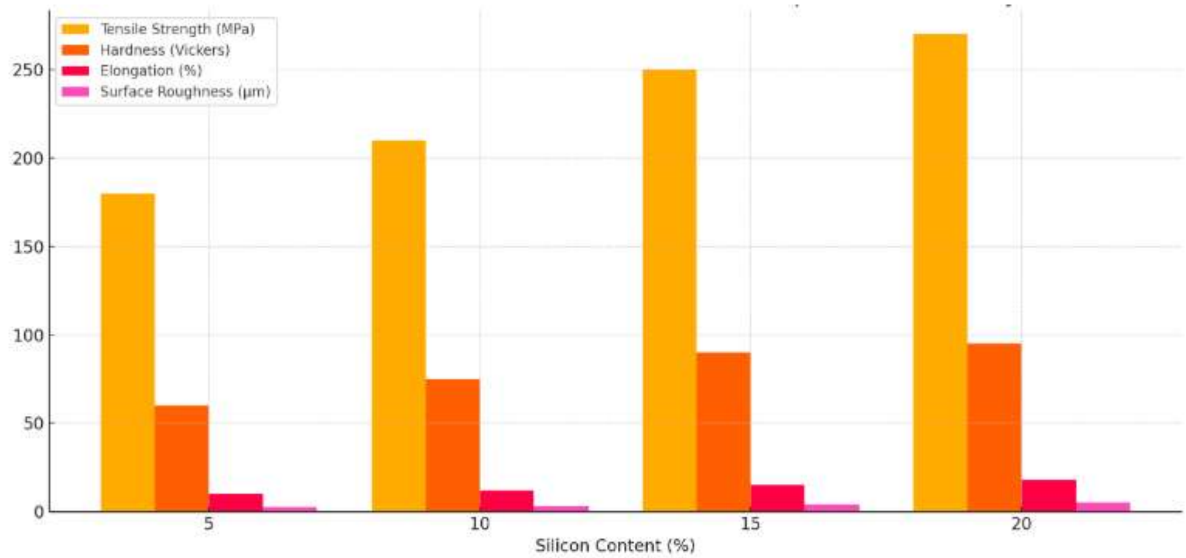

Fig 2:- Comparision chart based on Silicon Content

Result & Conclusion

The study focused on the influence of various silicon percentages—5%, 10%, 15%, and 20%—on the surface finish and casting quality of Al-Si alloys. The results clearly indicated that changing the silicon percentage considerably changed the mechanical and surface properties of the alloys. From 2.5 µm at 5% Si up to 5.0 µm at 20% Si, surface roughness increased incrementally, demonstrating that an increase in silicon concentration yields a more coarse surface finish, likely due to coarser grain structures and greater silicon particle formation. Tensile strength showed a continuous rise in mechanical performance, starting at 180 MPa at 5% Si and climbing to 270 MPa at 20% Si. The increase is attributed to the strengthening effect of the silicon particles in the aluminum matrix.

The hardening action of the silicon phase is evidenced further by the increased hardness of the alloys, which varied from 60 Vickers at 5% Si to 95 Vickers at 20% Si. It was notable that elongation, which would normally decrease with increasing silicon content, rose modestly from 10% to 18% over the silicon range, likely due to improved microstructure control and uniform particle dispersion of the silicon.

Unlike the 5% and 20% Si alloys that contained no visible surface defects, the 10% Si alloys contained minor porosity and the 15% Si contained minor shrinkage. This suggests that proper control of casting conditions can ensure the removal of casting defects, even as intermediate silicon levels introduce some of them.

The paper concludes that silicon content plays an important role in determining the general quality of Al-Si alloys. Increased silicon content leads to poor surface finishes even though it enhances mechanical properties such as strength and hardness. A 20% silicon alloy is most suitable for applications that require outstanding strength and hardness. Conversely, a 5–10% silicon concentration is more appropriate for parts where minimum flaws and smoothness of surface are important. For those industrial applications in which performance as well as appearance are important, a 15% silicon alloy may offer the best compromise between mechanical strength and surface quality.

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