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ANALYSIS OF RESEARCH CONDUCTED ON CENTRIFUGAL CASTING TECHNOLOGY

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Annotation. This paper presents a structured and comprehensive review of domestic and international scientific publications devoted to centrifugal casting technology. The evolution stages of this method, its fundamental theoretical principles, and the classification of technological schemes are examined. Particular attention is given to the influence of key technological parameters on the formation of the microstructure and the service properties of cast products. Special emphasis is placed on recent studies focused on mathematical modeling of the process and optimization of centrifugal casting regimes. The conducted review demonstrates that centrifugal casting remains one of the most promising and actively developing areas in modern foundry engineering.

Keywords: centrifugal casting, foundry production, crystallization, metal structure, technological parameters.

Аннотация. В данной работе представлен структурированный и всесторонний обзор отечественных и зарубежных научных публикаций, посвящённых технологии центробежного литья. Рассмотрены этапы эволюции данного метода, его фундаментальные теоретические основы, а также классификация технологических схем. Особое внимание уделено влиянию ключевых технологических параметров на формирование микроструктуры и эксплуатационные свойства литых изделий. Отдельный акцент сделан на современных исследованиях, направленных на математическое моделирование процесса и оптимизацию режимов центробежного литья. Проведённый обзор показывает, что центробежное литьё остаётся одним из наиболее перспективных и динамично развивающихся направлений современного литейного производства.

Ключевые слова: центробежное литьё, литейное производство, кристаллизация, структура металла, технологические параметры.

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Annotatsiya. Mazkur maqolada markazdan qochma usulda quyish texnologiyasiga bag‘ishlangan mahalliy va xorijiy ilmiy nashrlarning tizimli hamda keng qamrovli sharhi keltirilgan. Ushbu usulning rivojlanish bosqichlari, uning asosiy nazariy tamoyillari va texnologik sxemalar tasnifi ko‘rib chiqilgan. Asosiy e’tibor muhim texnologik parametrlarning quyma mahsulotlar mikrostrukturasi va ekspluatatsion xossalarining shakllanishiga ta’sirini tahlil qilishga qaratilgan. Shuningdek, jarayonni matematik modellashtirish va markazdan qochma quyish rejimlarini optimallashtirishga bag‘ishlangan so‘nggi tadqiqotlarga alohida urg‘u berilgan. O‘tkazilgan tahlil natijalari shuni ko‘rsatadiki, markazdan qochma quyish zamonaviy quyish muhandisligida eng istiqbolli va jadal rivojlanayotgan yo‘nalishlardan biri bo‘lib qolmoqda.

Kalit so‘zlar: markazdan qochma quyish, quyish ishlab chiqarishi, kristallanish, metall strukturasi, texnologik parametrlar.

INTRODUCTION

Centrifugal casting is a specialized method for producing castings and is widely utilized in mechanical engineering, power generation, oil and gas, and metallurgical industries. This method enables the production of components with high metal density, enhanced mechanical properties, and a minimal number of internal defects, making it particularly suitable for critical applications.[1]

The growing demand for high-quality castings that operate under extreme mechanical loads, high temperatures, and aggressive chemical environments has driven significant scientific interest in centrifugal casting technology. Over the past few decades, a substantial body of research has been published, addressing both theoretical foundations and practical applications of this process. These studies cover a broad range of topics, including process optimization, microstructural control, and the relationship between technological parameters and final product properties.

The aim of this paper is to provide a comprehensive analysis and synthesis of scientific publications on centrifugal casting technology. The study identifies key research directions, highlights advancements in modeling and process optimization, and discusses unresolved challenges and potential areas for future investigation. By systematically reviewing the literature, this work seeks to offer insights into the current state of the art and guide further development of centrifugal casting methods in industrial practice.

The first references to the use of centrifugal forces in casting processes date back to the late 19th century. At that time, the concept of applying rotational motion to shape molten metal was largely experimental and limited by the available technological capabilities. However, the industrial development of centrifugal

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casting only began in the 20th century, coinciding with the emergence of reliable drive mechanisms and heat-resistant molds capable of withstanding high temperatures and centrifugal stresses.[1-2]

Early studies indicate that the centrifugal casting method was initially employed primarily for the production of cast iron pipes and bushings. These applications took advantage of the method's ability to produce dense, defect-free components with relatively simple geometries. Over time, the scope of centrifugal casting expanded significantly. By leveraging advancements in mold design, material science, and rotational control, the method came to be widely used for manufacturing rings, discs, bearing blanks, and complex-shaped components from steel and non-ferrous alloys. This expansion not only reflects technological progress but also underscores the versatility and growing importance of centrifugal casting in modern industrial production.

Theoretical Foundations of the Centrifugal Casting Process

The centrifugal casting process is fundamentally based on the action of centrifugal forces generated when a mold rotates at an angular velocity, denoted as ω. The centrifugal force acting on a small element of the molten metal can be mathematically expressed as:

$$F=m\cdot\omega2\cdot rF=m\cdot\omega2\cdot r$$

where m represents the mass of the molten metal element, and r is the radial distance from the axis of rotation.

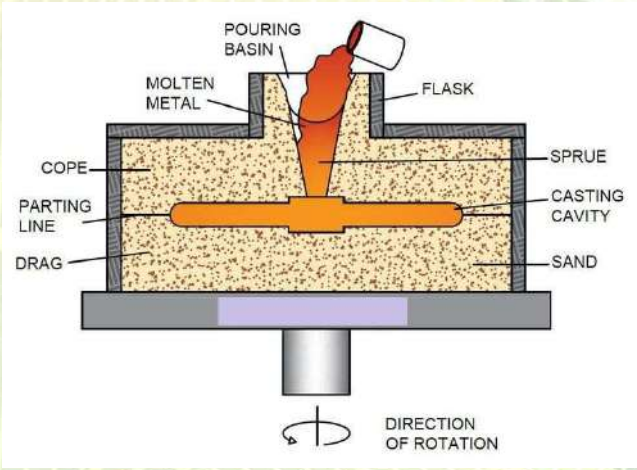


Fig.1. Semi-Centrifugal Casting Method

Under the influence of this force, the molten metal is pressed against the walls of the mold, as demonstrated by experimental and theoretical studies. This effect promotes the formation of a dense and homogeneous microstructure within the casting. Simultaneously, non-metallic inclusions and impurities are displaced towards the inner surface of the casting, thereby reducing internal defects.[3]

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This behavior is one of the principal advantages of centrifugal casting over conventional static casting methods, as it allows for the production of components with superior mechanical properties, higher density, and improved reliability. Furthermore, the controlled application of centrifugal forces enables precise manipulation of material distribution within complex geometries, making the method highly versatile for producing cylindrical, tubular, and ring-shaped components in both ferrous and non-ferrous alloys.

Modern theoretical models also emphasize the role of rotational speed, mold geometry, and metal viscosity in determining the quality of the casting. Optimization of these parameters through mathematical modeling and simulation allows engineers to predict solidification patterns, minimize porosity, and tailor the microstructure for specific operational requirements. Consequently, understanding the fundamental physics of centrifugal forces is essential for advancing both the scientific study and industrial application of centrifugal casting technology.[4]

Classification of centrifugal casting methods

Based on a comprehensive analysis of the literature, centrifugal casting methods can be broadly classified into three main types:

Horizontal centrifugal casting

Vertical centrifugal casting

Inclined (or slant) centrifugal casting

Horizontal centrifugal casting is widely employed for the production of pipes, tubes, and cylindrical bushings. The rotational axis in this method is oriented horizontally, which facilitates uniform wall thickness and high metal density along the circumference of the casting. This method is particularly effective for long, tubular components where dimensional precision and mechanical strength are critical.[5]

Vertical centrifugal casting, in which the mold rotates around a vertical axis, is commonly used for manufacturing rings, discs, and other cylindrical components with moderate height-to-diameter ratios. This orientation allows for effective control of solidification and directional microstructure development, ensuring superior mechanical properties and minimal internal defects.

Inclined (or slant) centrifugal casting represents a hybrid approach where the rotational axis is set at an angle between horizontal and vertical. This method is employed when producing components with complex geometries that require improved mold filling and more uniform material distribution. By adjusting the inclination angle, engineers can optimize metal flow, reduce turbulence, and minimize the occurrence of defects in castings with irregular cross-sections.

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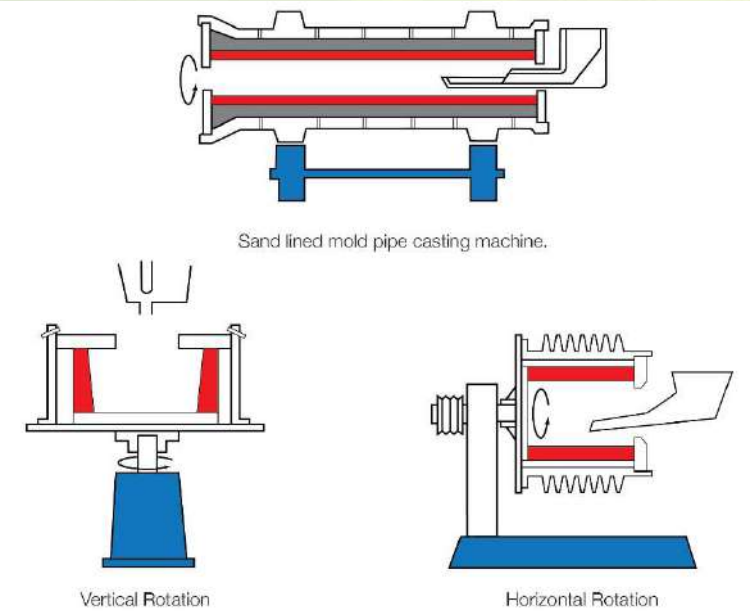


Fig.2. Types of centrifugal casting methods

The choice of casting method depends on factors such as the shape and dimensions of the component, the desired mechanical properties, and the type of alloy being cast. Advances in computational modeling and process simulation have further enhanced the ability to select the optimal casting orientation for a given application, thereby increasing efficiency and product quality in modern foundry operations.[6]

Influence of technological parameters on casting quality

One of the most critical parameters in the centrifugal casting process is the rotational speed of the mold. Studies have demonstrated that insufficient rotational speed fails to provide the necessary compaction of the molten metal, resulting in lower density and the potential formation of internal defects. Conversely, excessively high rotational speeds may cause density segregation within the metal, leading to inhomogeneous microstructures and compromised mechanical properties. Therefore, precise control of the mold's rotational velocity is essential to achieving uniform density and optimal structural integrity in the final casting.[7-8]

Another key factor influencing casting quality is the pouring temperature of the molten metal. According to experimental data, maintaining the metal within an optimal temperature range ensures directional solidification and promotes the formation of a fine-grained microstructure. Deviations from this temperature range can lead to defects such as porosity, shrinkage cavities, or coarse grain structures, which negatively affect the mechanical strength and service life of the cast component.

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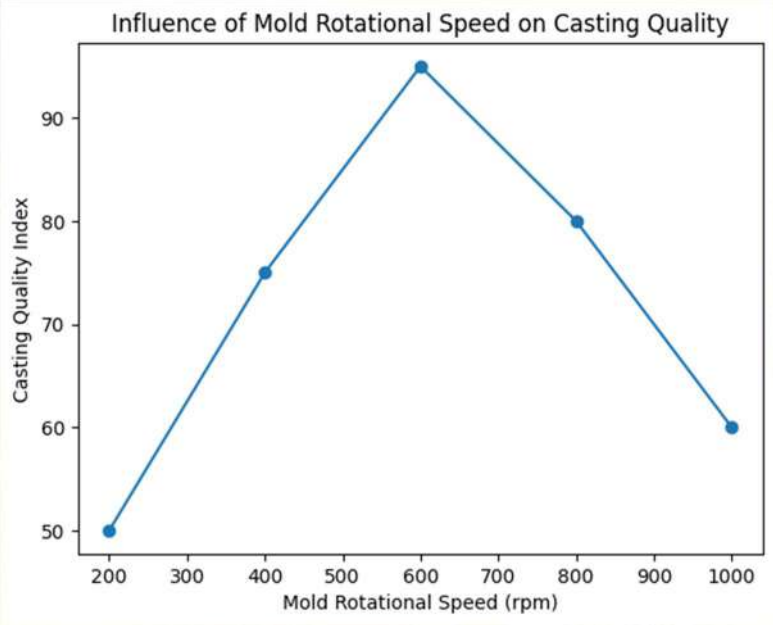


Fig.3. This graph schematically (theoretically) illustrates the relationship between the mold rotational speed (rpm) and casting quality.

At low rotational speeds, the molten metal is insufficiently compacted, resulting in low casting quality.

Within the optimal rotational speed range, maximum metal density and casting quality are achieved.

At excessively high rotational speeds, density segregation and structural inhomogeneity occur, leading to a deterioration in casting quality.

In addition to rotational speed and pouring temperature, other technological parameters—including mold preheating, metal composition, cooling rate, and vibration or pressure conditions—also play a significant role in determining the quality of castings. Proper optimization of these parameters through process modeling and empirical research allows engineers to produce components with high density, minimal defects, and superior mechanical performance.[9]

Overall, the careful adjustment of centrifugal casting parameters is crucial for tailoring the microstructure, enhancing mechanical properties, and ensuring the reliability of cast products in demanding industrial applications.

Structure and properties of castings produced by centrifugal casting

Analysis of the literature indicates that castings produced using the centrifugal casting method exhibit enhanced mechanical strength, wear resistance, and corrosion resistance. These superior properties are primarily attributed to the high density of the metal, as well as the reduced presence of gas porosity and shrinkage defects. The controlled application of centrifugal forces during solidification contributes to a more compact and homogeneous microstructure, which directly improves the durability and service life of the components.[10]

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A distinctive feature of castings produced by centrifugal casting is the property gradient across the wall thickness. In many cases, this gradient can be exploited to deliberately tailor the functional characteristics of the component. For example, the outer layers of a cylindrical casting, which experience the highest centrifugal forces, often display finer grains and higher hardness, while the inner layers retain slightly different microstructural and mechanical properties. This controlled variation in properties allows engineers to optimize castings for specific operational conditions, such as enhanced wear resistance on the outer surface or improved toughness in the core.

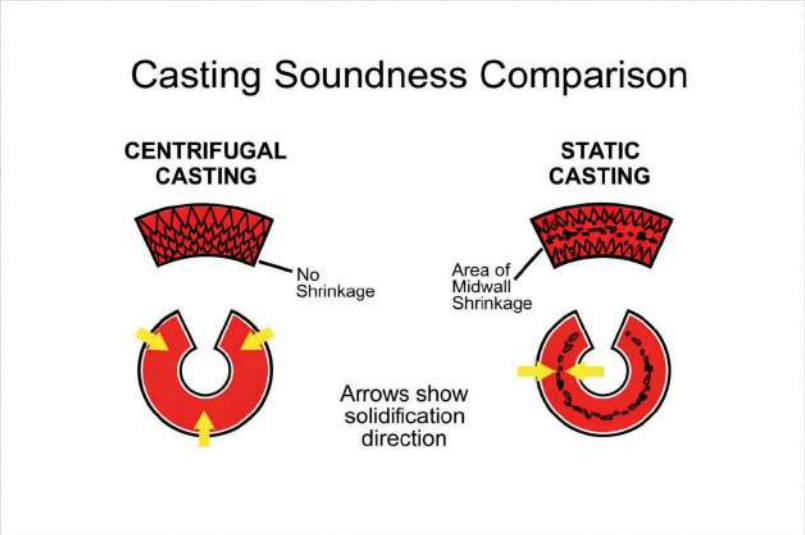


Fig.4. Advantages of the centrifugal casting process

Furthermore, the combination of high metal density and controlled microstructural gradients makes centrifugal castings particularly suitable for demanding applications in industries such as power generation, petrochemical processing, and heavy machinery. These components are capable of withstanding high mechanical loads, abrasive conditions, and corrosive environments, thereby demonstrating the technological advantages of centrifugal casting over conventional static casting methods.[11]

Modern research directions

In recent ears, significant attention has been devoted to the numerical modeling of the centrifugal casting process. Studies increasingly utilize finite element methods and computational fluid dynamics to predict key process parameters, including temperature distribution, molten metal flow behavior, and the resulting microstructure. These computational approaches allow for the optimization of process conditions, reduction of defects, and improvement of the overall quality of cast components without the need for extensive experimental trials.

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In addition to modeling, there is an active exploration of new alloys and composite materials specifically designed for centrifugal casting. Researchers are investigating the development of high-performance ferrous and non-ferrous alloys, as well as metal-matrix and particle-reinforced composites, that can withstand extreme operating conditions while maintaining superior mechanical and corrosion-resistant properties.[12]

Furthermore, the automation and digitalization of foundry processes are emerging as critical areas of research. The integration of advanced sensors, real-time monitoring systems, and digital twins enables precise control of the casting process, from mold preparation to solidification, thereby enhancing reproducibility, efficiency, and product quality. The combination of advanced materials, numerical modeling, and automated production technologies represents a modern trend in centrifugal casting research, aimed at expanding its applications and increasing its competitiveness in high-demand industrial sectors.

CONCLUSION

The review of scientific publications confirms that centrifugal casting is an effective and technologically promising method for producing castings intended for critical applications. The method's ability to generate dense, defect-free components with superior mechanical properties makes it particularly valuable in industries such as power generation, petrochemicals, automotive, and heavy machinery.

Future development of centrifugal casting is closely linked to the integration of advanced computational modeling, automation, and the use of innovative materials. Numerical simulations and process optimization techniques enable precise prediction of temperature distribution, flow patterns, and solidification behavior, thereby reducing defects and improving the uniformity and performance of cast components. Additionally, the introduction of new alloys and composite materials expands the range of applications and enhances the operational capabilities of centrifugal castings under demanding conditions.

The ongoing trend towards digitalization and smart foundry technologies is expected to further increase efficiency, reproducibility, and product quality. Overall, centrifugal casting remains a highly versatile and evolving technology with significant potential for industrial innovation, offering a combination of structural reliability, tailored material properties, and adaptability to complex component geometries. Continued research in this field will contribute to more sustainable, precise, and high-performance manufacturing solutions in modern foundry engineering.

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