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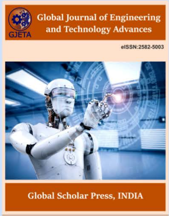

(Review Article)

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A comprehensive review on state-of-the-art applications of case based reasoning in aluminum foundries

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Abstract

An Aluminium Foundry offers multiple opportunities for implementing expert systems across various domains, including component design, process planning, rejection reduction, and determining parameter values for Die-to-Die Design to achieve cost benefits. Considering the projected growth of the Global Aluminium Die Casting market at a 15 percent CAGR until 2025, one of the key hurdles to this growth lies in the requirement for substantial investments. This paper explores the diverse applications of expert systems in different aspects of aluminium casting, focusing on the utilization of Case-Based Reasoning (CBR) systems within Aluminium foundries. Case-Based Reasoning, a problem-solving approach, leverages past cases resembling the current problem to guide solutions for new challenges. The review encompasses various expert systems applied in aluminium casting and specifically highlights the application of Case-Based Reasoning systems. Additionally, it identifies gaps within the Die Design Support System for Gravity Die Casting utilizing Case-Based Reasoning, aiming to delve deeper into this particular area for potential improvements.

Keywords: Aluminium Castings; Case Based Reasoning; Die Casting; Die Design; Manufacturing Optimization; Quality Improvement

1. Introduction

Aluminium die castings and the die casting process find extensive applications across diverse industries like aerospace, home appliances, automotive, construction, defense, electronics, medicine, and sports equipment due to their cost-effectiveness and superior performance. Forecasts suggest that the global Die-Castings market is poised to reach 150 million metric tons by 2025, primarily driven by thriving demand from sectors like automotive and industrial, owing to the preference for lightweight metal components. To maintain competitiveness and meet escalating demands, industries must continually advance technologically. This study is motivated by the necessity for such technical advancements. The current research delves into the various methodologies utilized in the aluminium foundry industry, with a specific focus on Case-Based Reasoning—an AI paradigm known for its problem-solving capabilities and adaptive nature. Case-Based Reasoning, rooted in the psychology of human cognition, addresses memory, learning, planning, and problem-solving. Moreover, it serves as the cornerstone for innovative computer systems capable of intelligently tackling problems and adapting to new scenarios. [1].

Case-Based Reasoning (CBR) has emerged as a promising methodology within the realm of die casting die design, especially for gravity casting processes. Over recent years, CBR techniques have extended their application to various problem domains, encompassing industrial tasks like die casting die design.

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As per the research conducted by Sengupta, Wilson, and Leake, three implementation models of CBR have been identified for die casting die design in gravity casting processes: task-based, enterprise-based, and web-based [2]. Additionally, CBR has demonstrated successful applications in designing various manufacturing processes, including die casting. Its effectiveness has been proven in determining process parameter settings for both die casting and injection moulding. For instance, researchers have devised an intelligent system integrating CBR with a hybrid neural network and genetic algorithm approach to establish initial process parameter settings for injection moulding. Furthermore, CBR has found applications in diverse industrial tasks, spanning architecture design, fixture design, and process planning.

The utilization of CBR in designing die casting dies for gravity casting processes presents numerous advantages. Firstly, it enables the reuse of successful past solutions for similar design issues, significantly reducing the time and effort required in creating new die casting dies. Additionally, CBR facilitates the integration of expert knowledge and experience into the design process, potentially enhancing accuracy and efficiency by learning from prior cases and adapting to new ones. Moreover, employing CBR in die casting die design enhances process transparency by tracking user interactions and self-training for new cases. This increased transparency benefits the user community and augments the system's performance in designing die casting dies. Furthermore, leveraging CBR in this domain can lead to more cost-effective and efficient designs by identifying optimal process parameter settings and enhancing overall die quality based on past successful solutions and expert knowledge. Hence, Case-Based Reasoning has proven its value in designing die casting dies for gravity casting processes, offering benefits like reusing successful solutions, incorporating expertise, improving transparency, and boosting cost-effectiveness and efficiency. The application of CBR in this context has demonstrated effectiveness and multiple advantages.

2. Enhancing Design by the Application of Case-Based Reasoning in Aluminium Foundry

The various areas where CBR has been applied are discussed herewith:

In their study, Mohammed M. Mabkhot, Ali M. Al-Samhan, and Lotfi Hidri (2019) [3] tackled the challenge of Manufacturing Process Selection (MPS), which involves identifying the best match between product features, material characteristics, and process capabilities. This task is intricate due to the myriad combinations of product features, diverse material traits, and a wide array of manufacturing processes. Additionally, the growing complexity of customer requirements, material diversity, product designs, and process capabilities has made managing manufacturing knowledge and its feasibility increasingly challenging. The authors observed that while Artificial Intelligence tools have been developed to aid in these tasks, they often struggle to encompass the comprehensive structure of manufacturing knowledge. Their research endeavours to create a decision support system (DSS) for MPS utilizing ontology-enabled case-based reasoning (CBR).

Tojal et al. (2021) [4] showcased a method for achieving sustainable maintenance within the automotive industry by emphasizing resource allocation towards analyzing critical issues and addressing them at the human, machine/process, or supplier level. Employing case-based product development and design science research (DSR), the authors crafted a subset focusing on high-pressure die casting injection. Their primary aim was to curtail the consumption and acquisition cost of spare parts, minimize waste, and decrease intervention time during maintenance operations. Simultaneously, the objective was to enhance equipment availability time, aligning with sustainability goals while bolstering overall productivity.

Zhang et al. (2020) [5] endeavoured to tackle prevalent challenges concerning scalability and flexibility in design knowledge representation methodologies. The research introduces a novel design knowledge representation framework that amalgamates Case-Based Reasoning (CBR) with knowledge graphs. Their approach involves representing design cases as a collection of knowledge graphs and suggesting an ontology model specifically tailored for design case representation. Moreover, the paper outlines an innovative method for retrieving design cases from knowledge graphs. This method utilizes a design problem query graph instead of conventional keywords. Additionally, the paper proposes a semantic similarity assessment technique based on subgraph similarity.

You et al. (2010) [6] introduced an advancement in process planning and die design for manufacturing automotive panels, emphasizing a case-based reasoning (CBR) approach. The proposed method employs a flat-bend graph to portray panel models structured with a Boundary Representation (B-rep) configuration, ensuring the preservation of geometric and topological data in the Standard for the Exchange of Product model data format. This representation utilizes a distinctive approach where flat-type faces are grouped and depicted as nodes, whereas bend-type faces are represented as arcs within the graph. Additionally, the panels' holes are treated as a separate node type within the graph structure. The graph attributes encompass geometric information and stamping parameters essential for the manufacturing process.

In order to navigate a potentially expansive design landscape more effectively, the research utilizes independent maximal cliques detection. This method aims to identify all independent maximal cliques, serving as representations of the most extensive sets of features shared among different models. By employing this retrieval approach, the system can access prior process plans and die sets applicable to new cases. The practicality of this approach is exemplified through experimental outcomes that demonstrate the integration of the Case-Based Reasoning (CBR) system with a product data management system. These results underscore the efficacy of reusing past designs to streamline the process of planning stamping procedures and designing dies for automotive panel manufacturing.

R.G. Chougule & B. Ravi (2003) [7] introduced an inventive method for casting process planning rooted in case-based reasoning. Their work involved creating a system that showcased both generative and variant process planning methodologies for castings. This system was implemented within a web-based virtual foundry environment, employing XML (eXtensible Markup Language). The utilization of this system facilitated interaction among product designers, tooling engineers, and foundry engineers during the initial design phases. This collaboration enabled early anticipation and mitigation of manufacturing issues linked to the design, contributing to the prevention of potential manufacturing problems at an early stage.

Case-Based Reasoning (CBR) has found application in process planning, particularly in an integrated product process design environment. This innovative system was deployed on the Internet, enabling active participation of a diverse team, including design engineers, foundry engineers, and tooling engineers, throughout the product development phase. This collaborative approach enabled the early evaluation of manufacturing-related challenges and tooling issues during the initial design stages. Consequently, this proactive assessment led to a significant reduction in both casting development costs and time.

E. Mares, J.H. Sokolowski (2010) [8] devised an Artificial Intelligence-Based Control System (AIBCS) that integrated Statistical Process Control methods and Artificial Intelligence techniques, specifically Case-Based Reasoning (CBR). This integration was embedded within Thermal Analysis Data Acquisition Software, utilizing NI LabView, to meticulously analyze properties of casting components. The study rigorously evaluated the thermal data's accuracy, reliability, and timeliness to enhance the effectiveness of metal casting processes. As a result of this integration, a noteworthy enhancement to accuracy, reliability, and timeliness was achieved, elevating them to a notably 'High' level. Notably, the utilization of CBR markedly improved the prediction of casting properties while significantly reducing execution time in contrast to conventional methods. Furthermore, the CBR approach demonstrated a high level of reliability in its outcomes.

Petridis, Saeed, and Brian Knight (2010) [9] introduced the ShapeCBR system, an innovative tool designed to streamline the creation and selection of cases used in populating a Case-Based Reasoning (CBR) system. This system specifically focuses on retrieving 3D shapes to aid in the design of metal castings. A distinctive feature of ShapeCBR is its utilization of graph matching algorithms as the primary method for establishing similarity among cases. This system operates on a unique similarity metric directly defined over case pairs, primarily emphasizing structural elements. The research provides an overview of prior research in this domain, illustrating the feasibility of employing a CBR approach in metal casting design. Additionally, the system allows for the association of essential documents like test documents, photographs, and blueprints with retrieved cases. This enrichment with contextual knowledge significantly enhances the utility and pertinence of advice provided by the system.

Price & Peglar (1995) [10] developed Wayland, a computer program that utilizes case-based reasoning (CBR) to address the challenge of setting parameter values for an aluminium pressure die-casting machine concerning a specific die. Their study concluded that CBR was a suitable technology for this issue due to the inherent nature of foundries, which tend to follow distinct operational methods. Foundries lacking substantial experience in specific casting types might rely on provided formulas from engineering bodies. Conversely, those with more extensive experience prefer referencing past die records with similar input requirements. Engineers adjust parameters based on these records to accommodate the diverse needs of new dies in production. These records reflect effective compromises developed through costly adjustments made in the foundry post-die construction. The Wayland system automated the identification of previous dies sharing similar characteristics, adjusted die settings considering variations between past and new designs, and validated that the new solution complied with all design limits.

Lee and Luo (2002) [11] devised a case-based reasoning (CBR) system for die-casting die design, wherein cases were characterized and retrieved based on product geometry and the correlated die structure. This methodology facilitated the efficient and feasible exploration of similar designs within the case library. The system's case representation and adaptation relied on parametric design, table-driven design, and assembly configuration, enabling the retention of designers' intentions and experiences. The system's construction of a case library facilitated the storage of past experiences and furthered its learning capability by integrating new cases. Their prototype system significantly aided die-casting designers by enhancing design efficiency and leveraging previous design resources. This approach expedited the design cycle and simplified the overall design process by storing previous design experiences. However, the researchers highlighted the complexity involved in case modification and emphasized that the retrieval of a similar case largely depended on the completeness of the index rules. The study emphasized the necessity of considering additional features in real die-casting die design, such as product geometry, die structure, material, and die-casting machine. They acknowledged that their proposed index, solely considering product geometry and die structure, was a prototype and required further refinement.

Mok et al. (2008) [12] introduced a prototype injection mold design system employing a hybrid case-based reasoning (HCBR) approach. This hybrid system seamlessly integrates CBR with generalized design knowledge, establishing a flexible and comprehensive design model. The knowledge base within this system is accessible to mold designers through interactive programs, enabling the incorporation of their individual intelligence and experience into the overall mold design process. By combining CBR with knowledge-based expert system support, this approach offers practical guidance by swiftly suggesting well-established design solutions for new design challenges in the plastic products manufacturing industry. This capability circumvents the time-consuming process of creating designs from scratch. Moreover, the system allows mold designers the autonomy to select actual solutions and finalize the development of a finished design. This autonomy ensures that their personal intelligence and experience are seamlessly integrated into the overall mold design process.

Woon et al. (2004) [13] presented a research endeavour focused on a computer-aided die design system tailored specifically for die casting. Their proposed system comprises seven discrete modules designed to enable die designers to fashion a die casting die starting from a product part model. The primary objective of their research was to create a system that seamlessly integrates various phases of the die design process, facilitating the editing of die casting designs during or after the design stages. Their research methodology involved employing feature-based and constraint-based modelling techniques, alongside parametric design principles. Additionally, they implemented a methodology for extracting geometric and topological information from a B-rep model. The culmination of their approach resulted in a prototype system, which effectively automated the die casting die design process. This automation significantly enhanced the efficiency, quality, and cost-effectiveness of die design for die casting applications.

3. Revolutionizing Die Casting Through Streamlined Automation and Advancements in Die Design Systems

J. C. Choi et al. (2020) [14] introduced a novel die design system tailored for the die casting process, outlining an automated workflow, particularly focusing on the runner-gate system. By seamlessly integrating the generation process and die design using advanced 3D geometry handling alongside process planning technology, the study aimed to illustrate the feasibility of automating die design. The incorporation of specific rules and equations for the runner-gate system aimed to minimize trial and error, especially considering the expenses involved. The research showcased a prospective avenue for engineers to execute automated and efficient die design for die casting, consequently reducing both time and cost requirements. To exemplify the methodology, the paper included an instance featuring a cap-shaped product—a motor pulley—demonstrated through the proposed flowchart.

V. Kumar et al. (2007) [15] embarked on developing Auto_Die_Caster, a system aimed at streamlining computer-aided design specifically tailored for multicavity die casting dies. The principal objective was to automate decision-making processes concerning cavity number determination, cavity layout design, die-base creation, and the generation of cores and cavities for multicavity die casting dies. The system, integrated as an add-on application within the SolidWorks solid modeling software, encompassed four primary modules: data initialization, cavity design, cavity layout and die-base design, and core-cavity design. Utilizing SolidWorks as the foundational platform for both part and die design ensured seamless data continuity, reducing loss and enhancing the system's practicality within industrial contexts. The research showcased outcomes obtained by applying Auto_Die_Caster to diverse die casting parts, underscoring its functional capabilities. The integration of Auto_Die_Caster marked a significant stride toward achieving seamless design-to-manufacturing integration in the realm of die casting. This system substantially contributed to industrial practices by automating crucial aspects of multicavity die casting die design, consequently optimizing efficiency and precision across the entire process. The review of the work in the fields highlights the need to work in a specific but important area of Aluminium area often neglected i.e. Gravity Die Casting. Majority work done encompasses the PDC Pressure die Casting area but lacks focus on GDC. Similar work can be applied to the Die designs, processes & overall improvements as well.

In conclusion, the current research delves into the utilization of Case-Based Reasoning (CBR) systems within aluminium foundries, specifically concentrating on die casting die design intended for gravity casting processes. Recognizing the paramount importance of aluminium die castings across multiple industries alongside the challenges and prospects arising from the expanding market, it emphasizes the requirement for inventive solutions within this domain.

The study underscores the adaptability of CBR in tackling various facets within aluminium foundry activities, encompassing component design, process planning, and minimizing rejection rates. Its integration into die casting die design for gravity casting processes stands out as notably advantageous. It allows for the reuse of effective prior solutions, assimilation of expert knowledge, heightened transparency, and advances in cost-effectiveness and efficiency.

The review offers an extensive survey of the current body of literature and research in the domain, illustrating the wide spectrum of applications employing CBR in manufacturing processes, maintenance approaches, and methodologies for representing design knowledge. The showcased instances in the paper, such as decision support systems for manufacturing process selection, sustainable maintenance practices in the automotive sector, and approaches to enhance scalability and flexibility in design knowledge representation, highlight the adaptability and efficacy of CBR across diverse domains.

4. Identification of Research Gaps

Recognizing the identified gaps within the Case-Based Reasoning (CBR) utilized in the Die Design Support System for Gravity Die Casting, this acknowledgment signifies the potential avenues for future research and development in this specialized domain. The delineated challenges in the Die Design Support System emphasize the necessity for continued enhancements and fine-tuning of CBR applications, specifically tailored to address the distinctive demands of aluminium foundries.

In summary, the current research offers significant insights into the integration of CBR systems within aluminium foundries, highlighting their pivotal role in augmenting efficiency, cost reduction, and tackling intricate challenges pertaining to die casting die design. With the ongoing expansion of the global aluminium die casting market, the adoption of cutting-edge technologies like CBR becomes crucial for the industry to retain competitiveness and adeptly respond to the evolving demands of modern manufacturing environments.

After reviewing the extensive body of research in the realm of Case-Based Reasoning (CBR) systems applied in aluminium foundries and die casting processes, certain gaps and areas for potential future research emerge:

Gravity Die Casting (GDC) Focus: The majority of the literature predominantly centers on Pressure Die Casting (PDC), leaving a notable gap in comprehensive research and focus on Gravity Die Casting (GDC). There's a need for increased attention and exploration in the realm of GDC-specific die designs, processes, and overall improvements.

Incomplete Case Representation: Several studies focus primarily on certain aspects, such as product geometry and die structure, for case representation and retrieval within the CBR system. There's potential for enhancing the completeness of case representation by considering additional factors, including material properties, manufacturing equipment, and operational parameters, for a more comprehensive and effective case library.

CBR Integration with Advanced Technologies: The integration of CBR with other cutting-edge technologies, such as Machine Learning (ML), Deep Learning (DL), or Internet of Things (Iota), remains an area that holds immense potential. Exploring synergies between CBR and these advanced technologies could further enhance the adaptive nature and problem-solving capabilities of CBR systems.

Real-Time Learning and Adaptation: Developing CBR systems with enhanced real-time learning capabilities and adaptability to dynamic manufacturing environments is a promising avenue for research. Systems that continuously learn from ongoing operations and adapt to changes in the production environment could significantly improve efficiency and accuracy.

Sustainability and Environmental Impact: Further exploration into how CBR systems can contribute to sustainability within the die casting processes, such as reducing waste, energy consumption, and environmental impact, presents an important yet underexplored research direction.

User Interface and Human-Computer Interaction (CHI): Enhancing the user interface and interaction design of CBR systems to facilitate seamless integration with the workflow of die designers and manufacturers could significantly improve adoption and usability.

Validation and Standardization: More studies are needed to validate the efficiency, accuracy, and scalability of CBR systems in die casting across different industrial settings and standardize their implementation to ensure consistency and reliability.

Robustness and Failure Analysis: Research on robustness testing and failure analysis of CBR systems in die casting scenarios can provide insights into potential system weaknesses, ensuring more dependable and fail-safe operations.

By addressing these research gaps, the field of CBR in die casting and aluminium foundries can advance further, leading to more robust, efficient, and adaptive systems tailored to the unique demands of these manufacturing processes.

5. Conclusion

In conclusion, this thorough exploration of Case-Based Reasoning (CBR) systems in the context of aluminium foundries, particularly focusing on gravity die casting processes, highlights the versatile applications of CBR in enhancing efficiency and addressing challenges in die casting die design. The identified research gaps, including the need for a specific focus on Gravity Die Casting (GDC), more comprehensive case representation, integration with advanced technologies, real-time learning, sustainability considerations, improved user interfaces, validation, and robustness testing, pave the way for future advancements in this domain. As the global aluminium die casting market grows, embracing these areas of research is essential for developing more adaptive, efficient, and sustainable systems, ensuring the industry remains at the forefront of technological innovation and meets the evolving demands of modern manufacturing.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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