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Abrasion Analysis and CAE Simulation's Importance in Ultra-High Strength Steel Plate Die Wear Research

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Abstract:

The production of vehicles with low oil consumption and low emissions has become an inevitable choice for the development of the automobile industry, aiming to achieve energy-saving and emission-reduction goals. Super-high strength steel, known for its high strength and lightweight properties, is widely used in critical components such as car body structural members and safety reinforcements to meet the requirements of energy-saving and emission-reduction. However, die wear is a common failure in the manufacturing process, and it significantly affects the shape, size, and surface quality of the stamped workpieces. The study of die wear, specifically in the context of super-high strength steel, is of paramount importance.

Keywords: Automobile production, Low oil consumption, Low emissions, Energy-saving, Emission-reduction, Super-high strength steel, Lightweight materials, Car body structural members, Safety reinforcements, Die wear, Manufacturing process, Stamped workpieces, Shape accuracy, Size precision, Surface quality, Wear mechanisms, Predictive methods, Maintenance practices, Automotive industry, Sustainability

Introduction:

In recent years, the automotive industry has witnessed a growing emphasis on producing vehicles with low oil consumption and low emissions. This shift in focus is driven by the pressing need to address environmental concerns and achieve energy-saving and emission-reduction goals. As a result, manufacturers are actively seeking innovative materials and technologies that can contribute to the development of energy-efficient and environmentally friendly vehicles.

One such material that has gained significant attention in the automotive industry is super-high strength steel. Super-high strength steel is renowned for its exceptional mechanical properties, combining high strength with lightweight characteristics. These properties make it an ideal choice for various critical components, including car body structural members and safety reinforcements. By utilizing super-high strength steel in these components, automakers can achieve the twin objectives of reducing vehicle weight and improving overall structural integrity, thereby enhancing fuel efficiency and minimizing emissions.[1,2]

However, despite its numerous advantages, the utilization of super-high strength steel in automotive manufacturing is not without challenges. One significant challenge is the occurrence of die wear during the manufacturing process. Dies, which are essential tools used in stamping operations, can experience significant wear over time. The wear of dies can have a profound impact on the quality and consistency of stamped workpieces, affecting their shape, size, and surface finish.[4,5]

The study of die wear, particularly in the context of super-high strength steel, is crucial for ensuring the successful implementation of this material in automotive manufacturing. Understanding the factors that contribute to die wear and developing effective strategies to mitigate its effects are essential for maintaining production efficiency, product quality, and overall cost-effectiveness.[3]

This research paper focuses on investigating the abrasion analysis of super-high strength steel plate dies. By comprehensively studying the wear behavior of these dies, valuable insights can be gained regarding the wear mechanisms, influencing factors, and predictive methods. This knowledge will enable researchers and engineers to develop optimized die designs, implement effective maintenance practices, and enhance the overall performance and durability of super-high strength steel plate dies.

By addressing the challenges associated with die wear in the context of super-high strength steel, this research aims to contribute to the advancement of automotive manufacturing processes. The findings of this study have the potential to provide valuable guidance for industry professionals, leading to improved productivity, reduced costs, and enhanced sustainability in the production of vehicles with low oil consumption and low emissions.

Related work:

The production of vehicles with low oil consumption and low emissions has become an inevitable choice for the development of the automobile industry. The industry aims to achieve energy-saving and emission-reduction goals to contribute to environmental sustainability. Super-high strength steel, known for its high strength and lightweight properties, has emerged as a key material in meeting the requirements of energy-saving and emission-reduction. It is extensively used in critical components such as car body structural members and safety reinforcements.

However, die wear is a common failure in the manufacturing process, and it significantly affects the shape, size, and surface quality of stamped workpieces. The study of die wear, particularly in the context of super-high strength steel, is of paramount importance to ensure the reliability and efficiency of automotive production.

Super-high strength steel, with its high yield strength and tensile strength, imposes more severe working conditions on the die during stamping operations. The increased loads on the die lead to more serious wear conditions, posing challenges in the design and application of dies in the automotive industry. Therefore, it is crucial to conduct research on die wear specifically focused on super-high strength steel.

Currently, research on die wear in other forming technologies such as extrusion, forging, and pressing is relatively more extensive compared to the research on die wear in super-high strength steel punching and compression molds. Since 1953, the widely used Archard theories have been employed for die wear analysis, and many scholars have conducted numerous studies to amend the theory, predict wear, and reduce wear extent. Various methods such as numerical simulation, finite element analysis, and wear estimation equations based on contact stress have been employed to analyze and predict die wear in different forming processes.[9,10]

However, existing die wear analysis methods for extrusion dies do not adequately consider the cumulative effect of multiple extrusion cycles. The linear formulas used to simulate wear patterns for a few extrusion cycles are not suitable for the analysis of ultra-high strength steel plate dies, which often have wear-out lives reaching tens of thousands of cycles. Additionally, the prediction methods based on BP neural networks, commonly used for extrusion dies, are not suitable for dies due to their significantly longer service lives and larger number of work cycles. BP neural network methods require extensive training data and are time-consuming.

Moreover, the high strength and case hardness ratio of high-strength steel sheets have a significant impact on the die's service life during the forming process, especially under high load conditions. The wear of the die becomes more severe, affecting its longevity. While experimental studies have been conducted on plate die wear, they are influenced by various external conditions and provide limited efficiency for engineering design. The development of numerical simulation technologies offers new possibilities for quantitatively predicting die wear.

Currently, there is a lack of a mature and effective CAE (Computer-Aided Engineering) analysis method for the wear problem of ultra-high strength steel plate dies. Some limited research has estimated contact stress and wear extent using ABAQUS software. However, these methods focus only on the local wear amount and contact stress at specific points of the die, neglecting the overall wear condition of the entire die face. The proposed method in this research aims to simulate the entire stamping process, providing a comprehensive analysis of the wear condition on all die faces and analyzing the influencing factors of die wear. The developed die life forecasting methodology has significant practical implications for actual production.

Additionally, the existing CAE analysis methods primarily involve parameter changes and multiple simulation iterations to obtain optimal results. The parameter selection process consumes considerable time, and the empirical parameters may not be entirely suitable for ultra-high strength steel plates.

Research:

This research paper aims to address the gap in the existing literature by analyzing the abrasion of super-high strength steel dies. While die wear research exists for other forming technologies like extrusion, forging, and pressing, the research on die wear in super-high strength steel punching and compression molds is limited. By utilizing the Archard wear theory and numerical simulation methods, scholars have made notable contributions to die wear analysis, wear prediction, and wear reduction techniques. However, these methodologies have not been extensively applied to ultra-high strength steel plate dies due to the unique challenges posed by their prolonged wear life and complex wear patterns.

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Furthermore, existing extrusion die wear analysis methods consider the cumulative wear extent before the die becomes ineffective, often neglecting the influence of prior extrusion cycles on subsequent ones. Linear wear rules obtained from a few extrusion cycles fail to accurately simulate the wear patterns observed in ultra-high strength steel plate dies, which may reach tens of thousands of cycles. Additionally, predicting die life and work cycles using backpropagation (BP) neural networks is not ideal for diel analysis, as their life spans and work cycles are typically much larger than those of extrusion dies, requiring substantial training data and significant computational resources.

The high strength and case hardness ratio of high-strength steel sheets have a significant impact on die life during the forming process, particularly under top load conditions where die wear is more severe. Although experimental studies have been conducted on plate die wear in foreign research, they often face challenges due to various external conditions and provide limited guidance for engineering design. However, the development of numerical simulation technology offers new avenues for quantitatively predicting die wear and analyzing the overall wear condition of the entire die face.

Currently, there is a lack of well-established and effective computer-aided engineering (CAE) analysis methods specifically tailored for ultra-high strength steel plate die wear. Some studies have estimated contact stress and wear extent using ABAQUS software, focusing on local die wear at fillets while neglecting the overall wear condition of the die face. This paper proposes a comprehensive CAE simulation method that can simulate the entire forming process, enabling a thorough analysis of die wear on all die faces after shaping. By considering various influential factors and establishing die life prediction methodologies, this research provides important guidance for practical production scenarios.

Moreover, the parameter selection process in existing CAE analysis methods often requires changing parameters and conducting multiple simulations to obtain optimal results. This parameter selection approach is time-consuming, particularly when applied to the forming analysis of ultra-high strength steel plates. Additionally, existing empirical parameters may not be fully suitable for ultra-high strength steel plates, necessitating further research and refinement.

The present research introduces a novel mold optimization method for fretting wear analysis based on computer-aided engineering (CAE) techniques, specifically designed to address the limitations of existing methods in analyzing abrasion of ultra-high strength steel plate dies. The method consists of the following steps:

Step	**Description**
1	Establishing the Grid Model: Create a grid model using the finite element method for the plate and the mold, defining material properties and wear behavior.
2	Determining Simulation Parameters: Select parameters such as yield strength, mold material, case hardness, stroke, speed, temperature, and friction, based on actual operating conditions.
3	Performing Simulation: Conduct the simulation under the specified constraints to obtain the formed shape of the plate and the eroded area and maximum wear extent of the mold.
4	Analyzing Parameter Influence: Vary parameters such as case hardness, mold material, stroke frequency, and speed individually while keeping other conditions constant, and analyze their influence on wear.
5	Predicting Service Life: Use a wear accumulation finite element method to predict the mold's service life before repair, considering the cumulative effect of die wear from previous cycles.
6	Verification through Experimental Validation: Validate the CAE analysis method by measuring the actual mold surface wear extent using white light scanning in real production scenarios.

Table-1 Whole Process

Step 1: Establishing the Grid Model

Using the finite element method, a grid model is created for both the plate and the mold. The model defines the material properties and wear behavior of the sheet material and the mold. Solid elements or shell units are employed for the grid cells in the plate model, while solid elements are used for the mold model. The material model for the sheet material can be chosen from elastic, plasticity, or elastic-plastic models, with elastic-plastic being the preferred option. The material model for the mold can be selected from desired stiffness, ideal elastoplastic, or ideal rigid Visco-plastic models, with the desired stiffness model being preferable. The mold's wear behavior is defined using either the Holm adhesion damage

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model or the Archard wear model, with the Archard wear model being the preferred option.

Step 2: Determining Simulation Parameters

Taking into account the actual operating conditions, parameters such as yield strength, mold material, case hardness, stroke, speed, simulation steps, operating temperature, heat transfer mode, and friction are selected. The yield strength of the sheet material should be equal to or greater than 550MPa.

Step 3: Performing Simulation

Under the constraints specified in Step 2, the simulation is conducted, yielding the formed shape of the plate and the eroded area and maximum wear extent of the mold.

Step 4: Analyzing Parameter Influence

While keeping other simulation conditions constant, the case hardness, mold material, stroke frequency, and speed of the mold are individually varied, and simulation calculations are performed. This step examines the influence of different mold parameters on eroded area and maximum wear extent.

Step 5: Predicting Service Life

Considering the cumulative effect of die wear from previous punching cycles on subsequent cycles, assuming a constant die wear amount per n cycles, a wear accumulation finite element method is utilized to predict the service life of the mold before repair. The value of N can be any integer between 500 and 2000.

Step 6: Verification through Experimental Validation

To verify the feasibility of the CAE analysis method, the actual mold surface wear extent is obtained using white light scanning in real production scenarios. Quick detection techniques are employed to measure the actual wear extent of the mold, validating the accuracy and practicality of the CAE analysis method.

By following these steps, the proposed mold optimization method based on fretting wear CAE analysis provides a comprehensive and efficient approach to analyzing and optimizing the wear behavior of ultra-high strength steel plate dies.

Conclusion:

In conclusion, this research paper emphasizes the significance of analyzing die wear in ultra-high strength steel plate applications and proposes an advanced CAE simulation methodology. The findings of this study provide valuable insights into understanding wear patterns, predicting die life, and optimizing the design and production processes for enhanced performance and durability of ultra-high strength steel plate dies.

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