Design, Development, and Analysis of Pad Main Rotor Head Grip for Helicopters

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Abstract - *The project, titled "Design, Development, and Analysis of Pad Main Rotor Head Grip for Helicopters," aims to convert metal components to PEEK using advanced injection molding to enhance performance and reduce weight, while ensuring structural integrity and durability meet aerospace standards. It involves design optimization, rigorous material selection, and the development of sophisticated manufacturing processes, including structural analysis using Mold flow simulation. The focus is on evaluating mechanical properties such as strength, stiffness, and fatigue resistance to comply with aerospace requirements. This study contributes to lightweight design strategies in rotorcraft applications and advances efficiency and sustainability in aviation technology.*

Key Words: Pad Main Rotor Head Grip, helicopter, PEEK (Polyether Ether Ketone), Mold flow simulation, injection molding, lightweight design, aerospace engineering.

1. INTRODUCTION

In aerospace engineering, optimizing materials for lightweight and high-performance components is crucial for enhancing aircraft efficiency. This project focuses on transforming the main rotor head grip of helicopters from metal to advanced plastic materials, specifically Poly Ether Ether Ketone (PEEK), using innovative injection molding techniques. The goal is to reduce weight while maintaining or improving structural integrity and performance standards. By employing advanced design and simulation tools, this project will compare the plastic grip with traditional metal versions to assess the feasibility and benefits of PEEK in aerospace applications. The initiative aims to advance lightweight design and manufacturing efficiency in rotorcraft technology.

2. METHODOLOGY

Methodology serves as the structured framework that outlines the systematic approach to achieving the objectives of the project, while aligning with its scope and requirements.

(a) Identification of Problem: The initial step involves thorough research and data collection to identify and define the problem statement accurately. This process ensures a clear understanding of the challenges associated with converting the main rotor head grip from metal to plastic.

(b) Objective of Project: The project objectives are defined to establish the desired outcomes and milestones to be achieved by its conclusion. These objectives are structured to balance the dimensions of the project management triangle: quality, time, and cost.

(c) Literature Survey: A comprehensive literature survey is conducted to review existing research and developments relevant to plastic components in aerospace applications. This section synthesizes various analyses and research findings, providing a foundation for informed decision-making and innovation.

(d) Identification of Process Parameters: Critical process parameters such as press tool clearance, tolerance levels, material properties, and cost factors are identified and defined. These parameters play a pivotal role in shaping the design and manufacturing processes to ensure optimal performance and cost-effectiveness.

(e) Trial Runs to Establish Range of Parameters: Conducting trial runs is essential to validate and establish the optimal range of process parameters. These trials enable fine-tuning and adjustment of parameters to meet specified quality standards and performance criteria.

(f) Design Optimization: Design optimization employs engineering methodologies to mathematically formulate and evaluate design alternatives. This iterative process aims to enhance the efficiency, functionality, and manufacturability of the main rotor head grip in plastic while meeting project objectives and constraints.

(g) Production of Plastic Components: The production phase involves utilizing injection molding processes to manufacture the main rotor head grip from Poly Ether Ether Ketone (PEEK). This phase includes mold design and fabrication, ensuring that the plastic components meet stringent aerospace standards for performance and durability.

(h) Result Analysis: Analysis of results from production and testing phases is conducted to assess performance metrics and validate against project requirements. If the rejection rate exceeds acceptable levels, design rectifications are implemented, followed by further trials to verify improvements.

This methodological approach ensures a systematic and rigorous exploration of the "Design, Develop, Analysis, and Manufacturing of a Pad Main Rotor Head Grip for a Helicopter" project, integrating advanced materials, innovative design practices, and rigorous testing protocols to achieve optimized outcomes in aerospace engineering.

3. ROTOR HEAD GRIP PAD

This project focuses on optimizing the Main Rotor Head Grip in helicopters, a key component of the rotor system that provides lift and thrust. The goal is to reduce the grip's weight and manufacturing costs by using materials like BS 4S 97 and Polyether Ether Ketone (PEEK). ANSYS software will be used for simulation to study dynamic forces and validate results. The project aims to improve performance and efficiency through advanced material selection, design optimization, and rigorous computational validation.

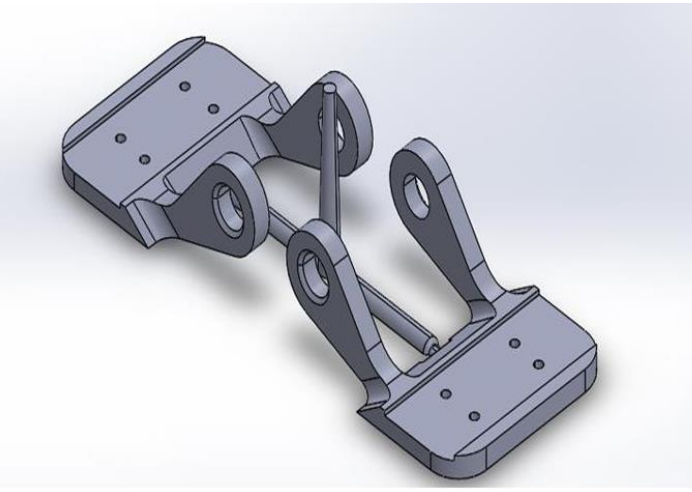

Fig -1: Part model of Main Rotor Head Grip

4. MOULD DESIGN

An injection mold is a precision tool used to shape molten material into a final product through the process of injection molding. The design and functionality of the mold are critical to producing high-quality, consistent parts. Here's a comprehensive look at the different aspects of mold design and operation:

Fig -2: Isometric View

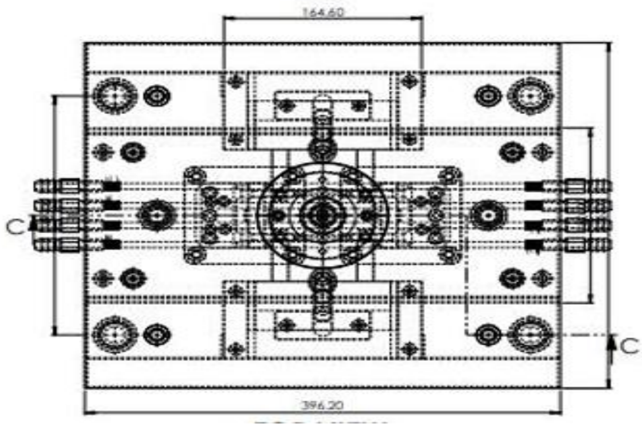

Fig -3: Top View

4.1 CAVITY PIN

Cavity Pins add precise surface features such as holes or indents to molded parts. They can be fixed or movable, with movable pins assisting in ejection and creating detailed impressions.

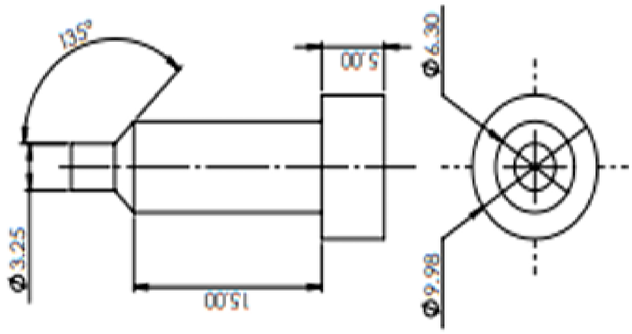

Fig -4: Cavity Pin

4.2 CAVITY INSERT

Cavity Inserts define the external shape and contours of a molded part, including features like textures or logos. They are interchangeable and form the outer surface as molten material fills the space and cools.

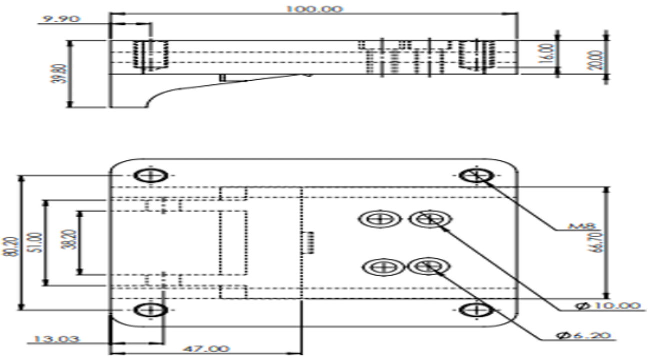

Fig -5: Cavity Insert

4.3 CORE INSERT

Core Inserts create internal features like threads or hollow sections in a molded part. They are complex, often including cooling channels, and are removable to aid in part ejection and mold maintenance.

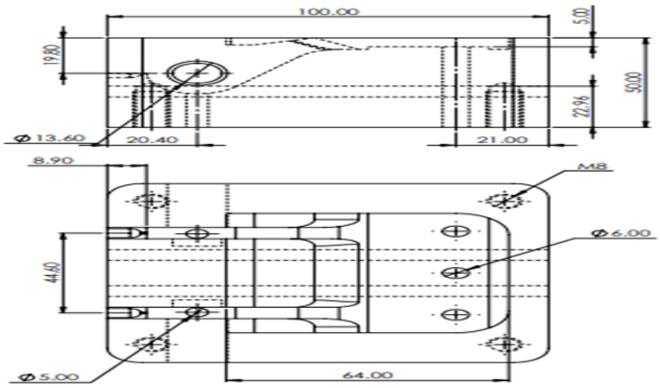

Fig -6: Core Insert

5 CALCULATION OF INJECTION MOULDING PARAMETERS:

1. Clamping Force Calculation

   Pi = 162×10=1620N/cm^2:

   $F_c = A \times P_i$

   $F_c = 20.87\,\text{cm}^2 \times 1620\,\text{N/cm}^2$

   $F_c = 33809.4\,\text{N}$

   $$F_c = \frac{33809.4\,\text{N}}{1000} = 33.81\,\text{kN}$$

2. Shot Size Calculation

   $V_s = V_p + V_r$

   $V_s = 20.7\,\text{cm}^3 + 10\,\text{cm}^3$

   $V_s = 30.7\,\text{cm}^3$

3. Cooling Time Calculation

   $$\frac{h^2}{\pi^2}\ \left(\frac{3^2}{\pi^2}\right) = \left(\frac{9}{\pi^2}\right) = \left(\frac{9}{9.8696}\right) \approx 0.912$$

   $$\frac{\rho_p \times c_p}{k_p} = \frac{1.30\,\text{g/cm}^3 \times 1.7\,\text{J/g}^\circ\text{C}}{0.25\,\text{W/cm}^\circ\text{C}} = \frac{2.21}{0.25} = 8.84$$

   $$\ln\left(\frac{T_d - T_e}{T_m - T_e}\right) = \ln\left(\frac{170 - 160}{360 - 160}\right) = \ln\left(\frac{10}{200}\right)$$

   $$= \ln\left(\frac{1}{20}\right) \approx -2.996$$

   Square of the natural logarithm value:

   $(2.996)^2 = 8.976$

   $$t_c = \left(\frac{h^2}{\pi^2}\right) \times \left(\frac{\rho_p \times c_p}{k_p}\right) \times \left(\ln\left(\frac{T_m - T_e}{T_d - T_e}\right)\right)^2$$

   $t_c = 0.912 \times 8.84 \times 8.976 \approx 72.51\,\text{s}$

4. Injection Pressure Calculation

   Calculate the injection pressure:

   $$P_i = \frac{F_c}{A}$$

   $$P_i = \frac{33810\,\text{N}}{20.87\,\text{cm}^2} \approx 1620\,\text{N/cm}^2$$

   $$P_i = \frac{1620\,\text{N/cm}^2}{10} = 162\,\text{MPa}$$

5. Cycle Time Calculation

   Calculate the cycle time:

   $t_{cycle} = t_i + t_c + t_e$

$$t_{cycle} = 5\,\text{s} + 72.51\,\text{s} + 3\,\text{s} = 80.51\,\text{s}$$

6. Volumetric Shrinkage Calculation

Calculate the volumetric shrinkage:

$$S_v = \left(\frac{V_m - V_f}{V_m}\right) \times 100\%$$

$$S_v = \left(\frac{30.7\,\text{cm}^3 - 20.7\,\text{cm}^3}{30.7\,\text{cm}^3}\right) \times 100\%$$

$$S_v = \left(\frac{10\,\text{cm}^3}{30.7\,\text{cm}^3}\right) \times 100\%$$

$$S_v \approx 32.57\%$$

6 MOULD FLOW ANALYSES

6.1 Meshing

Meshing in NX divides designs into subdomains using Midplane, Dual Domain, or 3D Technology for detailed analysis.

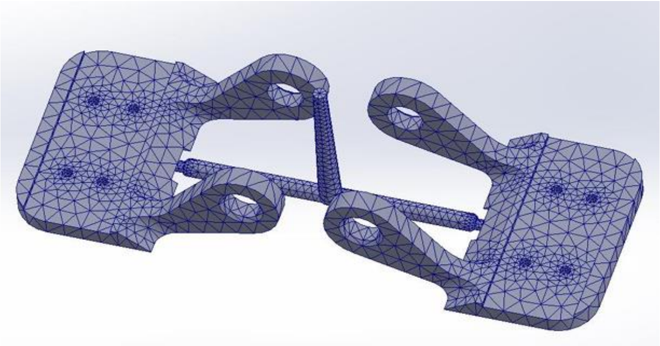

Fig -7: Mesh

6.2 Maximum Shear Stress:

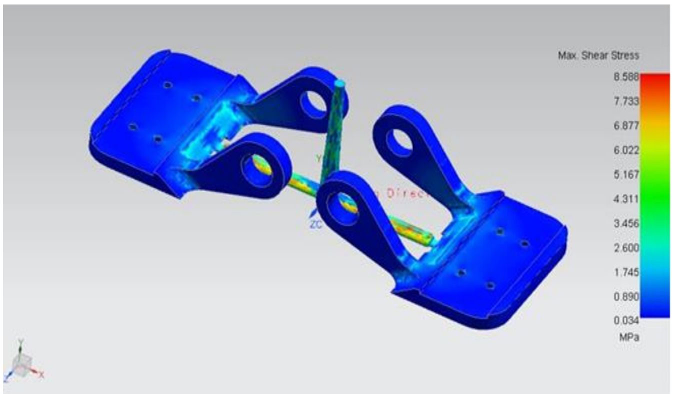

Fig -8: Maximum Shear Stress

6.3 Average Velocity

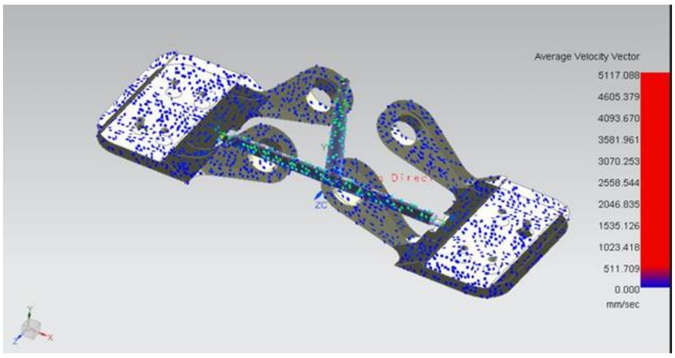

Fig -9: Average Velocity

6.4 Volumetric shrinkage:

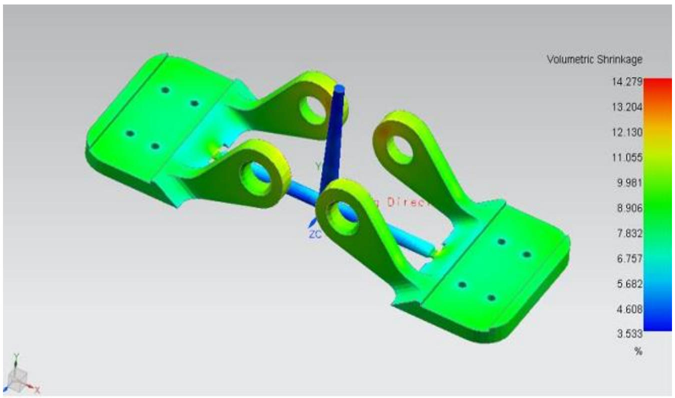

Fig -10: Volumetric shrinkage

6.5 Bulk Temperature:

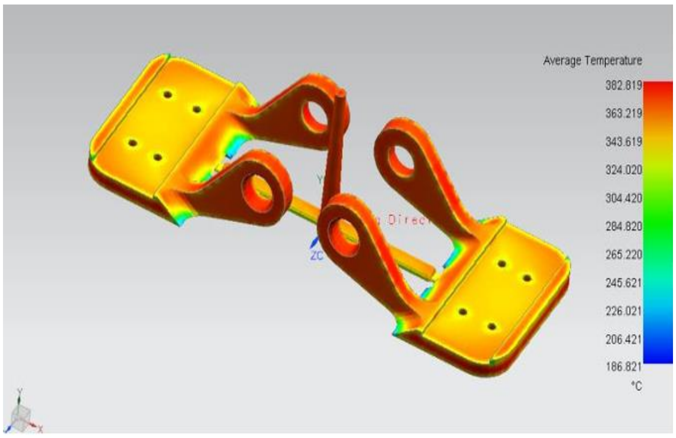

Fig -11: Bulk Temperature

6.6 Weld Lines:

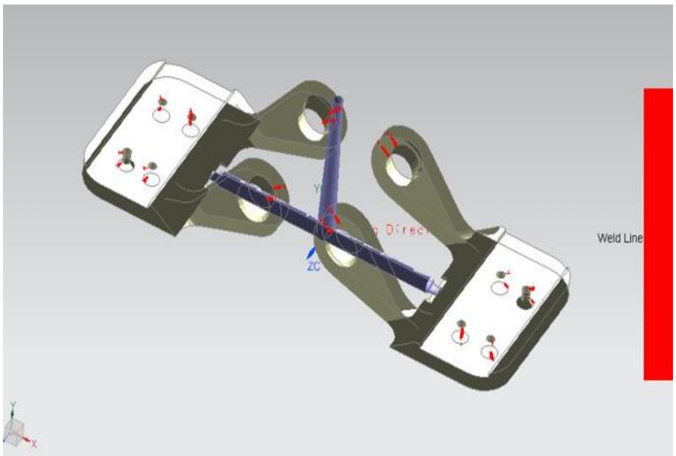

Fig -12: Weld Lines

7 CONCLUSIONS

The rotor head pad, designed using CAD and analyzed with CAE, showed that PEEK's ultimate strength of 87 MPa is suitable for its requirements. Weight was reduced by 80%, from 160 grams to 26 grams, by switching from metal to PEEK. Mold Flow analysis optimized injection molding parameters, enhancing quality and efficiency. A two-cavity mold increased productivity, while manufacturing costs were justified by lower per-part expenses. Overall, the conversion to plastic improved performance, durability, and cost-effectiveness.

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