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Design and Characterization of PPS Plastic Pistons for Automotive Brake Master Cylinders: A Lightweight Alternative to Metal Components

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Abstract—This research presents a comprehensive design methodology for Polyphenylene Sulphide (PPS) plastic pistons intended for automotive brake master cylinders offering a lightweight and cost-effective alternative mainly aimed at replacing traditional Aluminium/steel pistons for master cylinder. The study details the CAD modelling process, selection of PPS grades, and manufacturability. Using a robust design approach, the pistons were modelled, prototyped, followed by extensive validation including lifecycle, dimensional stability, brake fluid compatibility tests and physical testing including burst pressure, thermal cycling. Comparative testing against conventional Al pistons demonstrated a weight reduction of up to 55% and approximately 25% reduction in total production cost, highlighting its potential for large-scale automotive deployment while maintaining compliance with industry performance standards. The findings support the growing adoption of high-performance polymers in safety-critical automotive applications.

Keywords—PPS Pistons, Brake Master Cylinder, Lightweight Design, Production cost Reduction, Automotive Polymers, Plastic vs Al Components, Durable, High dimensional stability.

I. INTRODUCTION

In the rapidly evolving automotive industry, light weighting has emerged as a strategic priority to meet stricter fuel efficiency standards, reduce emissions, and improve overall vehicle performance. Reducing the weight of components not only enhances fuel economy but also contributes to better handling, acceleration, and reduced environmental impact.

Among the many components targeted for lightweight substitution, brake master cylinder pistons play a critical role. These pistons are integral to the vehicle's braking system, translating mechanical input from the brake lever into hydraulic pressure. As safety-critical components, they must maintain precise dimensional stability, withstand high fluid pressures, and endure exposure to aggressive brake fluids and wide temperature ranges. Traditionally, such pistons have been manufactured using metals like aluminium or steel due to their strength and durability.

However, conventional Al/steel pistons come with inherent limitations. Their high density contributes to increased vehicle weight, which runs counter to modern light weighting goals. Furthermore, Al/steel components often require complex machining processes, leading to higher production costs and longer cycle times. In some cases, metals are also susceptible to corrosion when exposed to moisture or chemicals, especially in brake fluid environments, which can affect long-term reliability.

To address these challenges, Polyphenylene Sulphide (PPS) has emerged as a promising alternative. PPS is a high-performance, semi-crystalline thermoplastic known for its excellent thermal stability, chemical resistance, and mechanical strength. It maintains its properties in high-temperature environments, resists degradation from automotive fluids, and can be efficiently processed through injection moulding. These attributes make PPS an attractive candidate for replacing metal in functional components like master cylinder pistons.

This study focuses on the design and characterization of PPS plastic pistons intended for use in automotive brake master cylinders. The core objectives are to:

- Develop a detailed design approach suitable for PPS materials,
- Validate the performance of PPS pistons under typical operational conditions,
- Quantify the weight savings compared to conventional metal pistons,
- Evaluate cost reductions in material and manufacturing,
- Assess the overall feasibility of implementing PPS pistons in production-level automotive applications.

II. MATERIAL SELECTION

The selection of an appropriate material is a critical step in the development of automotive components, particularly for systems as safety-sensitive as braking. In this study, Polyphenylene Sulphide (PPS) with added 40% glass filled was selected as a replacement for traditional metal alloys (aluminium and steel) in brake master cylinder pistons. PPS 40%GF offers a unique combination of mechanical, thermal, and chemical properties that make it well-suited for demanding under-the-hood applications.

2.1. Overview of PPS Material

Polyphenylene Sulphide is a semi-crystalline, high-performance engineering thermoplastic (Can regain original shape after heat removed) known for its high dimensional stability, low moisture absorption, and exceptional resistance to chemicals and heat. It is widely used in automotive, aerospace, and electronics applications where performance must be maintained under extreme conditions. A unique characteristic of PPS is that when dropped, it sounds just like a piece of metal hitting the floor.

2.2. Mechanical Properties

PPS exhibits high tensile strength (typically 70–120 MPa) and a modulus of elasticity ranging from 3 to 5 GPa, depending on filler content and grade. Reinforced grades, particularly those with glass or carbon fibre, offer even higher stiffness and strength, making them suitable for load-bearing applications. These mechanical characteristics enable PPS pistons to withstand the internal hydraulic pressures present in brake systems without significant deformation or failure.

2.3. Chemical Resistance

One of the standout features of PPS is its excellent chemical resistance, particularly to automotive fluids such as DOT 3, DOT 4, and DOT 5.1 brake fluids, which are known to be aggressive and hygroscopic. PPS does not degrade or swell significantly upon prolonged exposure to these fluids, which is crucial for maintaining piston function, sealing performance, and dimensional stability over the component's lifecycle.

2.4. Comparison with Al & Steel

While aluminum and steel offer high strength and proven durability, they also come with several disadvantages in this application:

1) *Higher density:* (Aluminum: ~2.7 g/cm³, Steel: ~7.8 g/cm³ vs. PPS: ~1.35–1.6 g/cm³), leading to greater component weight.
2) *Susceptibility to corrosion:* particularly in moist or chemically aggressive environments.
3) *Higher production costs:* due to machining, finishing, and material handling requirements.
4) *Thermal conductivity:* which can cause undesired heat transfer to brake fluids.

In contrast, PPS provides significant weight savings, is corrosion-resistant, and can be molded into net-shape parts, reducing the need for secondary operations.

TABLE 1: PPS 40%GF ENGINEERING PROPERTIES

SR. NO	PROPERTY		VALUE
1	Physical	Water absorption (23°C/24hrs)	0.02%
2	Mechanical	Tensile strength	200 MPa
		Tensile Modulus	17 GPa
		Tensile strain at break	1.6%
		Flexural strength	300 MPa
		Flexural modulus	16.5 GPa
		Flexural strain at break	1.9%
3	Thermal	Heat deflection temperature, 1.80MPa	270°C

III. DESIGN METHODOLOGY & PROTOTYPE

3.1. Cad Modelling

1) Geometric considerations:

The initial design was modelled using Creo 4.0, taking account into dimensions of existing brake master cylinder assemblies. Critical features such as piston diameter, length, internal channels, and retention grooves were defined based on industry specifications and benchmarks from existing Al piston designs.

Due to the material differences between PPS and aluminum, the design had to accommodate the lower modulus of elasticity and slightly higher dimensional tolerances of thermoplastics. Features were added to manage stress concentrations and enhance structural stability, such as fillets at sharp corners and controlled draft angles to aid in molding.

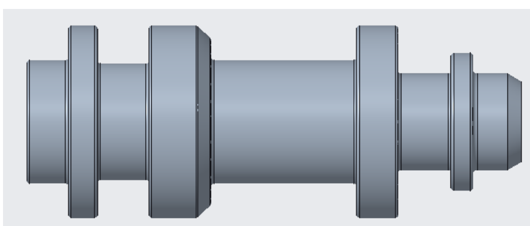

FIGURE 1: EXISTING Al PISTON

2) Part Integration with Existing Brake Cylinder Architecture:

The piston was designed to be a drop-in replacement for existing Al pistons of master cylinder assembly. This meant preserving key interface dimensions, such as the seal contact surfaces, pushrod mounting location, and guide rail alignment. Care was taken to ensure that the PPS piston would not require changes to the master body, brake fluid reservoir, or actuation components—ensuring seamless integration and reducing the risk of sub-system level redesign costs.

3.2. Design Optimization

1) Wall Thickness, Ribbing, and Sealing Surfaces:

To balance strength and manufacturability, the wall thickness of the PPS piston was optimized based on material flow characteristics during injection molding and load-bearing requirements. In regions of expected high pressure, reinforcement ribs were introduced to increase stiffness without significantly increasing mass or material usage.

The sealing surfaces were particularly critical, as they must maintain tight dimensional tolerances to ensure a leak-proof hydraulic seal. These surfaces were designed with precision, using material shrinkage compensation.

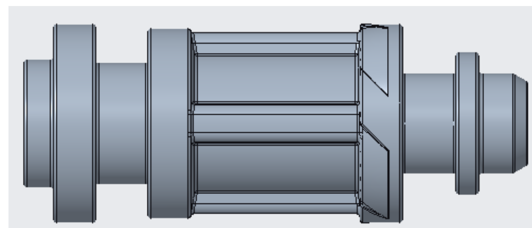

FIGURE 2: PPS PISTON

3.3. Prototype Development

The successful realization of the PPS piston design required the selection of an appropriate manufacturing method that could achieve the desired dimensional accuracy, surface finish, and mechanical performance. Given the geometry, production volume potential, and material characteristics of PPS, injection molding was selected as the preferred manufacturing process

1) Manufacturing Method: Injection Molding

Injection molding is a widely used process for producing thermoplastic components with high repeatability and excellent surface quality. For this project, glass fiber (40%) reinforced PPS pellets were used due to their superior strength and dimensional stability.

FIGURE 3: PPS PISTON PROTOTYPE

IV. TESTING AND VALIDATION

4.1. Performance Testing

In this section, we focus on the validation of the designed PPS pistons for automotive brake master cylinders. The performance of the PPS pistons was rigorously tested and validated through a series of performance tests like ineffective distance, high pressure, low pressure, Piston sliding load test, Load vs pressure vs travel likewise and all the performance tests were passed with both the pistons i.e. existing Al as well as PPS Piston.

4.2. Static Pressure Strength Testing

In this section, we focus on the strength of the designed PPS pistons for brake master cylinders. The strength of the PPS pistons was rigorously tested and validated through a predefined DVP test with test condition of applying hydraulic pressure up to 250 Bar thereafter some stabilization time the hydraulic pressure was increased till failure of the sub assembly and data were recorded

4.3. Endurance/Durability Test

An endurance or durability test for a brake master cylinder is a controlled procedure designed to evaluate the component's long-term performance and reliability under simulated real-world conditions. The test typically involves subjecting the master cylinder to a hydraulic pressure of 40 Bar and for that up to 5 lakhs of pressure cycles using brake fluid, mimicking regular and extreme braking events mainly to assess the part's resistance to wear, leakage, seal degradation, and mechanical failure. The cylinder must maintain consistent performance, fluid tightness, and structural integrity throughout the test to pass. This testing is essential for ensuring the safety and durability of brake systems in vehicles.

4.3. Thermal Testing

Given that brake systems experience high operating temperatures due to friction, it was essential to assess the thermal performance of PPS pistons. Thermal testing was conducted to evaluate the material's ability to retain its mechanical properties at elevated temperatures. The pistons were exposed to temperatures ranging from -40°C to 100°C under hydraulic pressure of 40 Bar for up to 1 lakhs of pressure cycles using brake fluid, mimicking extreme braking events mainly to assess thermal stability and heat resistance of the material. These tests also revealed the thermal expansion properties, which were crucial to ensuring that the PPS pistons do not deform under high temperatures.

V. RESULTS AND DISCUSSION

This section presents the outcomes of both simulation and experimental testing performed on PPS pistons, and compares their performance with existing Al pistons.

5.1 Performance and Endurance Test

1) Performance: The PPS pistons demonstrated commendable mechanical performance across a range of tests. And based on the test results it deemed sufficient for the functional requirements of brake master cylinder pistons due to the compressive nature of loading in these systems.
2) Strength: PPS piston successfully qualified the minimum DVP requirements while furthermore sustaining pressure up to 300 Bar which is quite adequate for the expected hydraulic forces during braking operations. Al pistons still outperform in this category, but PPS remains within acceptable safety margins.
3) Durability: Al pistons successfully outperform in this category as well as compared to PPS pistons, but the results we observed were passed with bare minimum OD wear, no seal damage, no seal degradation or any mechanical failure. We have recorded the before performance and after performance in both the pistons refer fig. 4 for post durability performance degradation with Al pistons and fig. 5 For the PPS pistons respectively.
4) Thermal durability: PPS demonstrated excellent thermal stability when subjected to extreme temperatures ranging from -40°C to 100°C under hydraulic pressure of 40 Bar for up to 1 lakhs of pressure cycles using brake fluid and showed no excessive piston wear, no seal damage, no seal degradation or any mechanical failure and the results were recorded and analyzed further. Refer

fig. 4 and fig. 5 for the post performance after thermal durability.

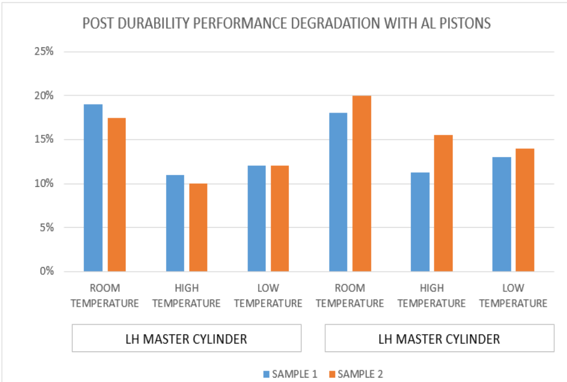

FIGURE 4: Post Performance with Al Pistons

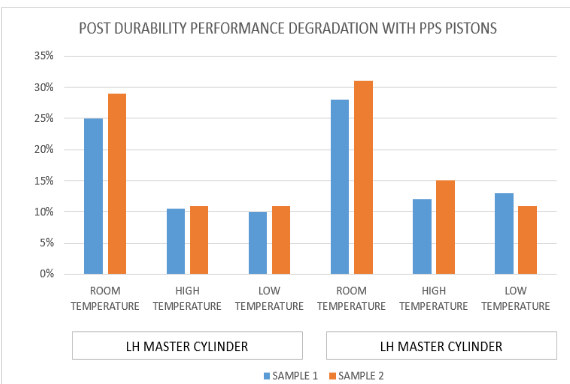

FIGURE 4: Post Performance with PPS Pistons

VI. SUMMARY

This research explored the design, development, and validation of Polyphenylene Sulfide (PPS) 40% glass-filled plastic pistons as a lightweight and cost-effective replacement for traditional aluminum (Al) or steel pistons in automotive brake master cylinders. By leveraging PPS's superior thermal stability, chemical resistance, and mechanical properties, a drop-in replacement was designed using CAD modeling and optimized for injection molding. The prototypes were subjected to rigorous performance, pressure, thermal, and endurance tests. Results demonstrated that PPS pistons achieved up to 55% weight reduction and approximately 25% lower production costs, while maintaining dimensional stability and meeting functional and durability benchmarks set by existing metal counterparts. The study highlights PPS as a viable material for safety-critical automotive applications.

VII. CONCLUSION

This study successfully demonstrates the feasibility of utilizing 40% glass-filled Polyphenylene Sulphide (PPS) as a lightweight and cost-effective replacement for existing aluminium pistons in automotive brake master cylinders. Through a systematic design methodology—including CAD modelling, material selection, and prototype development via injection moulding—PPS pistons were engineered to serve as direct drop-in substitutes without requiring modifications to existing brake system architecture.
Comprehensive validation through performance testing, static pressure tests, thermal cycling, and durability assessments confirmed that PPS pistons meet the critical functional and safety standards expected of such components. Although aluminium pistons continue to exhibit superior mechanical endurance, PPS pistons remained within acceptable performance margins, with no observed failures in seal integrity, dimensional stability, or mechanical structure after rigorous testing conditions.

Key advantages observed include:

- Up to 55% weight reduction compared to aluminium pistons,
- Approximately 25% reduction in production cost, and
- Robust resistance to high temperatures and aggressive brake fluids.

These findings affirm the suitability of PPS for large-scale integration into safety-critical automotive systems, aligning with industry trends toward vehicle light-weighting and cost optimization. Future research may focus on long-term field validation and iterative design improvements to further enhance durability and facilitate broader industry adoption.

REFERENCES

[1] Ticona Engineering Polymers. (2012). Product Guide: Fortron® PPS – Polyphenylene Sulfide. Celanese Corporation. https://www. celanese. com/

[2] Saeed, A., & Khan, S. (2019). "Performance Evaluation of Thermoplastic Materials in

Automotive Brake System Components." International Journal of Automotive Technology, 20(4), 693–700. https://doi.org/10.1007/s12239-019-0066-1
[3] Bakker, A., & Zuidema, H. (2016). Lightweight Materials in Automotive Applications. Elsevier.