

PERFORMANCE ENHANCEMENT OF STAINLESS STEEL BASED ECO-FRIENDLY BRAKE-PADS

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by

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CERTIFICATE

This is to certify that the thesis entitled “**Performance Enhancement of Stainless –Steel Based Eco-friendly Brake-pads**” being submitted by **Mr. Kalel Navnath Ramchandra** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy**, is a record of bonafide research work carried out by him. **Mr. Kalel Navnath Ramchandra** has worked under my guidance and supervision and has fulfilled the requirements for the submission of the thesis. The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Performance Enhancement of Stainless Steel Based Eco-friendly Brake-pads

Copper (Cu) is one of the vital ingredients of good quality friction materials (FMs) since it provides high thermal conductivity, diffusivity, fade resistance, and lubricity at high temperatures. However, the recent legislation about Copper indicates the need for Cu-free FMs due to the adverse effect of Cu wear debris on aquatic life, forcing the world to move towards Cu-free FMs. After reporting some success in developing the Cu-free NAO (Non-Asbestos Organic) FMs by using stainless-steel swarf (SSS), it was necessary to make efforts for full success. The current research work was thus focused on using particles of stainless steels (SSPs) of various grades to explore if these could be more successful and, if yes, which type. It was also thought worthwhile to explore the potential of plasma treatment to the SSPs to enhance their performance in brake-pads since it was expected to increase particles-matrix adhesion. It was felt necessary to make the right selection of gas or mixture for the right kind of plasma, its power, duration, etc., to achieve the best possible benefits and then use in pads.

It was also felt necessary to optimize the amount of matrix (phenolic resin) in the formulation for both tribo and noise-vibration (NV) performance of Cu-free FMs since it is not reported.

Aramid pulp is one of the most vital ingredients of the FMs, and no replacement is yet reported, which could compete with it in the performance. Hence it was thought necessary to explore the potential of Zylon (PBO) short fibers of various lengths to replace Aramid pulp or fibers in FMs. With these in view, this research was focused on the following themes.

- ❖ To optimize the amount of straight phenolic resin in stainless –steel based brake-pads for the best tribological and NV properties.
- ❖ To explore the potential of stainless-steel particles (SSPs) (various types and sizes) instead of stainless-steel swarf (SS434) SSS in the brake-pads to compete with SSS based and Cu-based pads.
- ❖ To employ two types of plasma treatments (air plasma and argon plasma) with variation in power and duration on SS particles to further enhance the performance of brake-pads. It was also required to understand the reasons behind the improvement if any.
- ❖ To explore the potential of aramid (fibers and pulp) and Zylon fibers (varying aspect ratios) in SSPs-based brake-pads for the best tribological and NV properties.
- ❖ To understand the wear mechanisms responsible for the improved performance if any.

A series of four types of brake-pads was developed with varying amounts of phenolic resin (6, 8, 10, and 12 wt.%) as a theme ingredient by keeping parent composition constant. The resin content of 6 wt.% in the brake-pads proved best for overall performance.

The various types of SSPs (stainless steels particles) (SS304, SS316, SS410, and SS434) in the eco-friendly brake-pads and compared the performance with pads containing SSS and Cu particles. SSPs-based brake-pads excelled in almost all tribological performance properties compromising slightly on the fade resistance. No significant difference in brake-noise level for SSP and Cu particles-based pads was observed. In addition, the effect of the shape and size of SS particles was studied. Results revealed that smaller particles proved a better choice for both tribo and NV performance of pads.

Further, plasma treatment was done on the SS and Cu particles to improve the adhesion/wettability with the matrix (resin). The results exhibited that pads with treated particles augmented the wear resistance of the pads and proved to be excellent for replacing Cu in brake-pads. Finally, the role of aramid (fibers and pulp) and novel Zylon fibers with varying aspect ratios in the SSP-based brake-pads was studied. Zylon and aramid short fibers proved best for both tribo and NV performance compared to the aramid pulp and reference pads.

सार

स्टेनलेस-स्टील आधारित पर्यावरण के अनुकूल ब्रेक-पैड के प्रदर्शन में वृद्धि

कॉपर (Cu) अच्छी गुणवत्ता वाली घर्षण सामग्री (FMs) के महत्वपूर्ण अवयवों में से एक है क्योंकि यह उच्च तापमान पर उच्च तापीय चालकता, प्रसार, फीका प्रतिरोध और चिकनाई प्रदान करता है। हालाँकि, कॉपर के बारे में हालिया कानून जलीय जीवन पर Cu पहनने के मलबे के प्रतिकूल प्रभाव के कारण Cu-फ्री FM की आवश्यकता को इंगित करता है, जिससे दुनिया को Cu-फ्री FM की ओर बढ़ने के लिए मजबूर होना पड़ता है। स्टेनलेस-स्टील स्वारफ (एसएसएस) का उपयोग करके सीयू-फ्री एनएओ (गैर-एस्बेस्टस ऑर्गेनिक) एफएम को विकसित करने में कुछ सफलता की रिपोर्ट करने के बाद, पूर्ण सफलता के लिए प्रयास करना आवश्यक था। इस प्रकार वर्तमान शोध कार्य विभिन्न ग्रेडों के स्टेनलेस स्टील्स (एसएसपी) के कणों का उपयोग करने पर केंद्रित था ताकि यह पता लगाया जा सके कि क्या ये अधिक सफल हो सकते हैं और यदि हां, तो किस प्रकार के। एसएसपी को ब्रेक-पैड में अपने प्रदर्शन को बढ़ाने के लिए प्लाज्मा उपचार की क्षमता का पता लगाने के लिए भी सार्थक माना गया क्योंकि इससे कण-मैट्रिक्स आसंजन बढ़ने की उम्मीद थी। सर्वोत्तम संभव लाभ प्राप्त करने और फिर पैड में उपयोग करने के लिए सही प्रकार के प्लाज्मा, उसकी शक्ति, अवधि आदि के लिए गैस या मिश्रण का सही चयन करना आवश्यक समझा गया।

Cu-फ्री FM के ट्राइबो और ध्वनि-कंपन प्रदर्शन दोनों के लिए फॉर्मूलेशन में मैट्रिक्स (फेनोलिक रेजिन) की मात्रा को अनुकूलित करना भी आवश्यक समझा गया क्योंकि इसकी रिपोर्ट नहीं की गई है।

अरामिड पल्प FM के सबसे महत्वपूर्ण सामग्री में से एक है, और अभी तक कोई प्रतिस्थापन रिपोर्ट नहीं किया गया है, जो प्रदर्शन में इसके साथ प्रतिस्पर्धा कर सके। इसलिए यह आवश्यक समझा गया कि FMs में अरामिड लुगदी या फाइबर को बदलने के लिए विभिन्न लंबाई के Zylon (PBO) शॉर्ट फाइबर की क्षमता का पता लगाया जाए। इन्हीं को दृष्टिगत रखते हुए यह शोध कार्य निम्नलिखित विषयों पर केन्द्रित था।

- सर्वोत्तम ट्राइबोलॉजिकल और ध्वनि-कंपन गुणों के लिए स्टेनलेस-स्टील आधारित ब्रेक-पैड में स्ट्रेट फेनोलिक रेजिन की मात्रा को अनुकूलित करना।
- ब्रेक-पैड में स्टेनलेस-स्टील के स्वारफ़ (SS४३४) SSS के बजाय स्टेनलेस-स्टील कणों (SSPs) (विभिन्न प्रकार और आकार) की क्षमता का पता लगाने के लिए SSS आधारित और Cu-आधारित पैड के साथ प्रतिस्पर्धा करने के लिए।
- ब्रेक-पैड के प्रदर्शन को और बढ़ाने के लिए स्टेनलेस-स्टील कणों पर शक्ति और अवधि में भिन्नता के साथ दो प्रकार के प्लाज्मा उपचार (वायु प्लाज्मा और आर्गन प्लाज्मा) को नियोजित करना। सुधार के पीछे के कारणों, यदि कोई हों, को समझना भी आवश्यक था।
- सर्वश्रेष्ठ ट्राइबोलॉजिकल और ध्वनि-कंपन गुणों के लिए एसएसपी-आधारित ब्रेक-पैड में aramid (फाइबर और लुगदी) और Zylon फाइबर (भिन्न पहलू अनुपात) की क्षमता का पता लगाने के लिए।
- यदि कोई बेहतर प्रदर्शन हो, तो उसके लिए जिम्मेदार वियर मैकेनिज्म को समझना।

चार प्रकार के ब्रेक-पैड की एक श्रृंखला को मूल संरचना को स्थिर रखते हुए थीम घटक के रूप में फेनोलिक रेजिन (६, ८, १०, और १२ वजन.%) की अलग-अलग मात्रा के साथ विकसित किया गया था। ब्रेक-पैड में ६ वजन.% की रेजिन सामग्री समग्र प्रदर्शन के लिए सर्वोत्तम साबित हुई।

पर्यावरण के अनुकूल ब्रेक-पैड में विभिन्न प्रकार के स्टेनलेस स्टील्स कण (SS३०४, SS३१६, SS४१०, और SS४३४) और प्रदर्शन की तुलना SSS और Cu कणों वाले पैड से की जाती है। एसएसपी-आधारित ब्रेक-पैड लगभग सभी जनजातीय प्रदर्शन गुणों में उत्कृष्ट प्रदर्शन करते हैं जो फीका प्रतिरोध पर थोड़ा समझौता करते हैं। SSP और Cu कण-आधारित पैड के लिए ब्रेक-ध्वनि स्तर में कोई महत्वपूर्ण अंतर नहीं देखा गया। इसके अलावा, SS कणों के आकार और आकार के प्रभाव का अध्ययन किया गया। परिणामों से पता चला कि पैड के ट्राइबो और ध्वनि-कंपन प्रदर्शन दोनों के लिए छोटे कण बेहतर विकल्प साबित हुए। इसके अलावा, मैट्रिक्स (रेजिन) के साथ आसंजन/वेटेबिलिटी में सुधार के लिए SS और Cu कणों पर प्लाज्मा उपचार। परिणामों ने प्रदर्शित

किया कि उपचारित कणों वाले पैड के पहनने के प्रतिरोध को बढ़ाते हैं और ब्रेक-पैड में Cu को बदलने के लिए उत्कृष्ट साबित होते हैं। अंत में, एसएसपी-आधारित ब्रेक-पैड में अलग-अलग पहलू अनुपातों के साथ अरामिड (फाइबर और लुगदी) और नया Zylon फाइबर की भूमिका का अध्ययन किया गया। कुल मिलाकर, Zylon फाइबर और अरामिड शॉर्ट फाइबर अरामिड लुगदी और संदर्भ पैड की तुलना में ट्राइबो और ध्वनि-कंपन प्रदर्शन दोनों के लिए सर्वश्रेष्ठ साबित हुए।

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LIST OF ACRONYMS

Symbols/Notations	Abbreviation
μ	Coefficient of friction
NAO	Non-Asbestos Organic
FM	Friction material
KT	Potassium titanate
TC	Thermal conductivity
FR	Fade resistance
F and R	Fade and recovery
W_R	Wear resistance
MOORA	Multiple Objective Optimizations based on Ratio Analysis
SEM	Scanning electron microscope
EDAX	Energy-dispersive X-ray analysis
SS	Stainless Steel
SSPs	Stainless steel particles
Cu	Copper
PBO	Phenylene benzobisoxazole
IUPAC	International Union of Pure and Applied Chemistry
JASO	Japanese Automotive Standards Organization
NV	Noise and Vibration
SAE	Society of Automotive Engineers
ASTM	American Society for Testing and Materials
ISO	International organization for standardization
CEA	Complex Eigenvalue Analysis
RMS	Root Mean Square
TOI	Tendency of Instability