

DEVELOPMENT OF ENVIRONMENTAL FRIENDLY METALWORKING FLUID

AJAY PRATAP SINGH LODHI



**CENTRE FOR AUTOMOTIVE RESEARCH AND TRIBOLOGY
(FORMERLY ITMMEC)
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by

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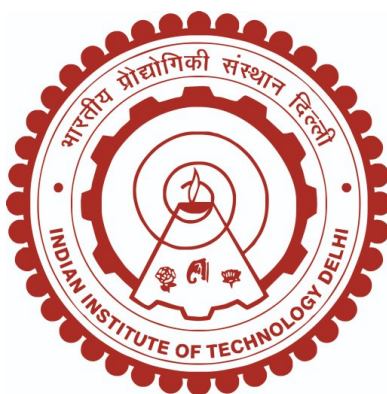
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*Dedicated to my grandparents,
Shree Raghuraj Singh Lodhi and Smt. Sabodra Bai*

Certificate

This is to certify that the thesis entitled, “**Development of Environmental Friendly Metalworking Fluid**” being submitted by **Mr. Ajay Pratap Singh Lodhi** to the **Indian Institute of Technology, Delhi** for the award of degree of **Doctor of Philosophy** is a bonafide record of original research work carried out by him under the guidance and supervision. In my opinion, the thesis has reached the standard of fulfilling the requirements of all the regulations related to the degree. The research report and results presented in this thesis have not been submitted in part or in full, to any other university or institution for the award of any degree or diploma, I certify that he has pursued the prescribed course of research.

Dr. Deepak Kumar

Associate Professor

Date: _____

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Abstract

It has been decades to mitigate the human and environmental health-related issues associated with mineral oil-based Metalworking fluids (MWFs). Mineral oil-based MWFs consist of toxic chemicals that are detrimental to human health. This highlights the need for the development of environmental-friendly MWF (oil-in-water emulsion). Environmental needs, human health issues, and government regulations have motivated this work to develop an alternative to mineral oil-based MWFs. It is planned to explore the natural resources and vegetable oils to develop the non-toxic, environmental friendly, corrosion-resistant, and lubricious MWFs.

This thesis presents the selection and use of natural ingredients soybean oil (SO), water, and gum acacia (GA), neem oil (NO), guar gum (GG). The concentration of each ingredient is very critical, which is optimized through surface/interfacial energetics using Goniometer. The emulsion characteristics (droplet size and zeta potential, pH, wetting dynamics) are evaluated using dynamic light scattering (DLS), pH glass electrode, Goniometer, respectively. The worn steel surfaces are analyzed using Fourier transform infrared (FTIR) spectroscopy and field emission scanning electron microscope (FESEM), scanning electron microscope (SEM), energy dispersive spectroscopy (EDS). The tribological responses are recorded using Four-ball-tester (FBT). The tribological response of the formulated metalworking fluids (FFs) is benchmarked with that of commercial fluid (CF). The key screening

criterion for the performance of the developed MWFs is the frictional response, corrosion inhibition ability, toxicity, and actual machining performance.

The results indicate that the FF is much better than CF under severe loading conditions. Further, the concentration of natural emulsifiers (GA) influences the emulsion stability, wettability, and lubricity. To explore this aspect, the concentration of GA is selected with respect to its critical micelle concentration (CMC), i.e., CMC, below CMC, and above CMC. The physical characteristics and tribological responses suggest that the FF @ CMC of GA exhibited better stability, lubricity, and antiwear properties than other formulations. FF @ CMC of GA showed a better anti-friction and similar anti-wear response as compared to CF. The excellent lubricity of the FF @ CMC of GA is attributed to the formation of the low shear strength stable lubricious film due to the active participation of GA molecules at the tribo-pair interface. The improved tribological characteristics and corrosion responses for FFs are attributed to the pressure and temperature-assisted activation of GA molecules and physisorption of guar gum molecules to the sliding surfaces. This activation leads to the chemisorption of emulsifier molecules (GA) to the tribological contact, aiding the tribology. The SEM micrographs and corresponding EDS mappings confirmed the presence of carbon-rich lubricious Tribofilm on the worn surface that also aids the tribological process. The novel and composite use of guar gum and neem oil has improved the corrosion resistance comparable to that of CF, as indicated by the potentiodynamic polarization study. The tribological response confirmed that the FFs were lubricious and wear-resistant. In comparison to highly cytotoxic CF, the FFs demonstrated no cytotoxicity to human osteoblast-like cells (MG-63) in MTT assay and Live-dead cell assay.

The developed FFs are to be used in metalworking operations; therefore, the grinding operation is selected for performance evaluation. The performance of the FFs is evaluated in terms of grinding characteristics (grinding force, surface roughness,

and morphology) during the surface grinding. The performance of FFs is benchmarked with that of CF. Taguchi method is adopted to design the experiments. It is noted that FFs performed better globally (low grinding forces, better surface finish, and surface morphology) relative to CF and dry grinding. ANOVA indicated that coolant (MWFs) type had a great influence on grinding characteristics compared to wheel speed. Further, the improved performance of FFs is attributed to the formation of lubricious Tribofilm on the ground steel surface. This lubricious film assists in lubrication by reducing the friction between the trio-pair interface. The SEM-EDS mapping confirmed the presence and nature of lubricious Tribofilm while FTIR spectroscopy confirms the chemisorption of Tribofilm constituents at ground steel surface that aids in tribology of metalworking operation.

सार

खनिज तेल-आधारित धातु प्रसंस्करण द्रव (एमडब्ल्यूएफ) से जुड़े मानव और पर्यावरणीय स्वास्थ्य से संबंधित मुद्दों को कम करने के लिए दशकों हो गए हैं। खनिज तेल आधारित एमडब्ल्यूएफ में जहरीले रसायन होते हैं जो मानव स्वास्थ्य के लिए हानिकारक होते हैं। यह पर्यावरण के अनुकूल एमडब्ल्यूएफ (जल-में-तेल पायस) के विकास की आवश्यकता पर प्रकाश डालता है। पर्यावरणीय जरूरतों, मानव स्वास्थ्य के मुद्दों और सरकारी नियमों ने इस काम को खनिज तेल आधारित एमडब्ल्यूएफ का विकल्प विकसित करने के लिए प्रेरित किया है। गैर विषैले, पर्यावरण के अनुकूल, संक्षारण प्रतिरोधी और चिकना एमडब्ल्यूएफ विकसित करने के लिए प्राकृतिक संसाधनों और वनस्पति तेलों का पता लगाने की योजना बनाई गई है।

यह शोध प्रबंध प्राकृतिक अवयवों सोयाबीन तेल (एसओ), पानी, और गम बबूल (जीए), नीम के तेल (एनओ), गम ग्वार (जीजी) के चयन और उपयोग को प्रस्तुत करती है। प्रत्येक घटक की सांद्रता बहुत महत्वपूर्ण है, जिसे फलक-कोणमापी उपकरण का उपयोग करके सतह / उक्त- सतहों के बीच ऊर्जा विज्ञान के माध्यम से अनुकूलित किया जाता है। इमल्शन (पायस) विशेषताओं (छोटी बूंद आकार और जीटा क्षमता, पीएच, क्लेदन गतिकी) का मूल्यांकन क्रमशः गतिशील प्रकाश प्रकीर्णन (डीएलएस), पीएच ग्लास इलेक्ट्रोड, फलक-कोणमापी का उपयोग करके किया जाता है। घिसे हुए स्टील की सतहों का विश्लेषण फूरियर ट्रांसफॉर्म इन्फ्रारेड (एफटीआईआर) किरण-वर्णक्रम मापी और फील्ड उत्सर्जन क्रमवीक्षण इलेक्ट्रॉन सूक्ष्मदर्शी (एफईएसईएम), स्कैनिंग इलेक्ट्रॉन सूक्ष्मदर्शी (एसईएम), ऊर्जा फैलाव किरण-वर्णक्रम मापी (ईडीएस) का उपयोग करके किया जाता है। अभिघर्षकी प्रतिक्रियाओं को चार गेंद परीक्षक (एफबीटी) का उपयोग करके दर्ज किया जाता है। तैयार किए गए धातु प्रसंस्करण द्रव (एफएफ) की अभिघर्षकी प्रतिक्रिया को वाणिज्यिक धातु प्रसंस्करण द्रव (सीएफ) के साथ तलचिह्न किया जाता है।

विकसित एमडब्ल्यूएफ के प्रदर्शन के लिए महत्वपूर्ण जाँच मानदंड घर्षण प्रतिक्रिया, संक्षारण निषेध क्षमता, विषाक्तता और वास्तविक मशीनिंग प्रदर्शन है।

परिणाम बताते हैं कि एफएफ गंभीर भार स्थितियों के तहत सीएफ की तुलना में बहुत बेहतर है। इसके अलावा, प्राकृतिक पायसीकारी (जीए) की सांद्रता पायस स्थिरता, गीलापन और चिकनाई को प्रभावित करती है। इस पहलू का पता लगाने के लिए, जीए की सांद्रता को इसकी महत्वपूर्ण मिसेल सांद्रता (सीएमसी) के संबंध में चुना जाता है, यानी, सीएमसी, सीएमसी के नीचे, और सीएमसी के ऊपर। भौतिक विशेषताओं और अभिघर्षकी प्रतिक्रियाओं से पता चलता है कि जीए के एफएफ @ सीएमसी ने अन्य सूत्रीकरणों की तुलना में बेहतर स्थिरता, चिकनाई और एंटीवियर गुणों का प्रदर्शन किया। जीए के एफएफ @ सीएमसी ने सीएफ की तुलना में बेहतर घर्षण-रोधी और समान घिसाव-रोधी प्रतिक्रिया दिखाई। जीए के एफएफ @ सीएमसी की उत्कृष्ट चिकनाई को उक्त- सतहों के बीच जीए अणुओं की सक्रिय भागीदारी के कारण कम कतरनी ताकत वाली स्थिर स्नेहक परत के निर्माण के लिए जिम्मेदार ठहराया जाता है। एफएफ के लिए बेहतर अभिघर्षकी विशेषताओं और संक्षारण प्रतिक्रियाओं को जीए अणुओं के दबाव और तापमान-सहायता प्राप्त सक्रियण और फिसलन सतहों पर ग्वार गम अणुओं के भौतिक शोषण के लिए जिम्मेदार ठहराया जाता है। यह सक्रियण पायसीकारी अणुओं (जीए) के रसोवशोषण को अभिघर्षकी संपर्क की ओर ले जाता है, जिससे अभिघर्षकी में सहायता होती है। एसईएम सूक्ष्मछवि और संबंधित ईडीएस मानचित्रण ने घिसे हुए सतह पर कार्बन समृद्ध स्नेहक अभिघर्षकी की उपस्थिति की पुष्टि की जो अभिघर्षकी प्रक्रिया में भी सहायता करता है। ग्वार गम और नीम के तेल के नए और मिश्रित उपयोग ने सीएफ की तुलना में संक्षारण प्रतिरोध में सुधार किया है, जैसा कि जंग परीक्षण ध्रुवीकरण अध्ययन द्वारा इंगित किया गया है। अभिघर्षकी प्रतिक्रिया ने पुष्टि की कि एफएफ स्नेहक और घिसाव रोधी थे। अत्यधिक कोशिका विषाक्तता सीएफ की तुलना में, एफएफएस (FFs) ने एमटीटी परख और जीवित-मृत कोशिका परख में मानव अस्थिकोशिका प्रसू जैसी कोशिकाओं (एमजी -63) के लिए कोई कोशिका विषाक्तता का प्रदर्शन नहीं किया।

विकसित एफएफएस का उपयोग धातु प्रसंस्करण संचालन में किया जाना है; इसलिए, अपघर्षण संचालन को प्रदर्शन मूल्यांकन के लिए चुना जाता है। सतह पीसने के दौरान एफएफ के प्रदर्शन का मूल्यांकन पीसने वाली विशेषताओं (पीसने वाले बल, सतह खुरदरापन और सतह आकारिकी) के संदर्भ में किया जाता है। एफएफ के प्रदर्शन को सीएफ के साथ तलचिह्न किया जाता है प्रयोगों की रचना करने के लिए तागुची पद्धति को अपनाया जाता है। यह ध्यान दिया जाता है कि एफएफ ने सीएफ और सूखा अपघर्षण के सापेक्ष बेहतर प्रदर्शन किया (कम अभिघर्षी बल, कम सतह खुरदरापन, और बेहतर सतह आकारिकी)। एनोवा ने संकेत दिया कि शीतलक (एमडब्ल्यूएफ) प्रकार का पहिया गति की तुलना में अभिघर्षी विशेषताओं पर बहुत प्रभाव पड़ा। इसके अलावा, एफएफ के बेहतर प्रदर्शन को अपघर्षित स्टील की सतह पर स्नेहक अभिघर्षी परत के गठन के लिए जिम्मेदार ठहराया जाता है। यह स्नेहक परत अभिघर्षी जोड़ा उक्त- सतहों के बीच घर्षण को कम करके स्नेहन में सहायता करती है। एसईएम-ईडीएस मानचित्रण ने स्नेहक अभिघर्षी परत की उपस्थिति और प्रकृति की पुष्टि की, जबकि एफटीआईआर किरण-वर्णक्रम मापी अपघर्षित स्टील की सतह पर अभिघर्षी परत घटकों के रसोवशोषण की पुष्टि करती है जो धातु प्रसंस्करण संचालन के अभिघर्षकी में सहायता करती है।

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Symbols

α	Alpha
β	Beta
C	Celsius
°	Degree
GPa	Gega-Pascal
h	Hour
s	Second
m	Meter
nm	Nanometer
μm	Micrometer
μL	Microlitre
mL	Mililitre
mm	Milimeter
mN	MiliNewton
N	Newton
ζ	Zeta

Abbreviations

GA	Gum Acacia
GG	Guar Gum
SO	Soybean oil
NO	Neem oil
DLS	Dynamic Light Scattering
FTIR	Fourier Transform Infrared Spectroscopy
SEM	Scanning Electron Microscopy
FESEM	Field Emission Scanning Electron Microscopy
EDS	Energy Dispersive X-ray Spectroscopy
FBT	Four Ball Tester
WSD	Wear Scar Diameter
WSB	Worn Steel Ball
MFL	Minimum Fluid Lubrication
MWF	Metalworking Fluid
Wt. %	Weight percentage
COF	Coefficient of Friction
MTT	(3-(4,5-dimethylthiazol-2-yl) -2,5-diphenyltetrazolium bromide)
IARC	International Agency for Research on Cancer
EPA	Environmental Protection Agency
OSHA	Occupational Safety and Health Administration
