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# APPLICABILITY OF WEAR MODELS FOR MATERIAL PARAMETER PREDICTION BASED ON PIN-ON-DISC WEAR DATA

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***Abstract:*** *In the literature, several analytical models are put forth to forecast wear behavior under various assumptions [1]. When analyzing wear data, the linear models (Archard, abrasive, etc.) and the non-linear power models (Evans and Wilshaw, Kato, etc.) are typically employed*[1][2] *Our prior research has demonstrated that, for pure or single-phase materials, linear models are better suited to forecast volume loss concerning load, but power models are more suited for composites or when the microstructure contains heterogeneities*[1][3] *. This study uses the inverse problem method of statistical analysis to try and predict material properties (pin material) based on pin-on-disc data. A comparison is made between the predicted parameter "hardness" and the standard known (or published in the literature) material hardness. Statistical analysis for optimization is done with MATLAB, which is free and open source.*

***Keywords:*** *Wear, Wear equations, Pin-on-disc, Wear rate, Wear volume, Hardness.*

## 1. INTRODUCTION

The analysis of wear test data will help us better understand the development and application of engineering materials and composites for high-quality materials that are prone to wear, such as brake pads, bearings, aircraft, turbine blades, nuclear reactors, fuel rods, sealants, etc. The wear performance of materials is influenced by a number of factors, which include testing conditions and material properties.[4][5]

Predicting hardness from pin-on-disc data can be challenging to explore various approaches, developing an empirical relationship between wear rate and hardness, using wear models to relate wear volume to hardness, and applying machine learning algorithms

This research attempts to employ the inverse problem technique in statistical analysis to estimate the properties of the pin material from pin-on-disc data. A comparison is conducted between the estimated hardness parameter and the established hardness values found in existing literature. Optimization through statistical analysis is performed using MATLAB.

Hardness refers to the resistance against scratching, cutting, abrasion, wear, and indentation. While hardness is considered a surface characteristic, toughness is viewed as a bulk property. It can be assessed using Brinell's and Rockwell's hardness tests, etc. Toughness defines a material's ability to resist tearing, including fractures and cracks. It specifically indicates how well a material can absorb sudden shocks without breaking or shattering. Toughness relates to the energy a material can absorb before it fails. Materials with low fracture toughness values are considered brittle, whereas those with high fracture toughness are usually more ductile. Toughness encompasses impact resistance and the energy that a material can store under strain before failure occurs.

## 2. LITERATURE REVIEW

Influence of volume fraction and size of SiC reinforced alumininum (AA1080) wear behaviour was explored by Cert et al,[6] and reported that hardness of composite increases with volume of SiC and shown that wear resistance increases with increase in hardness.

1. **Increasing Volume Fraction**: When the volume fraction of SiC particles is increased, the hardness improves due to the higher proportion of hard reinforcements. This creates a denser and more rigid composite structure, enhancing its ability to resist deformation.
2. **Effect of Particle Size**: Larger particles can reduce hardness because they may lead to weaker interfacial bonding with the matrix or cause stress concentrations. Smaller particles, in contrast, disperse more evenly in the matrix, improving load transfer and contributing to increased hardness.

Monikandan et al.[7] fabricated AA6061-10 wt % $B_4C$-$MoS_2$ hybrid composites through stir casting with the concentration of 2.5, 5, and 7.5 wt% of $MoS_2$ reinforcement particles. The test specimen was prepared of 8mm diameter and 30mm height. The Pin on disc tribometer (Ducom, TR-20 LE) is used as the counter face hardness 65HRC and surface roughness 0.1µm. The findings show an increase in molybdenum disulfide $MoS_2$ decreases the hardness, fracture toughness, coefficient of friction, and wear rate of hybrid composites.

(Nayak) et al.[8] Developed Aluminum Metal Matrix Composites (AMMCs) due to their excellent mechanical properties, light weight, and high strength. Silicon Carbide (SiCp) of 7 vol. % of 220 mesh size and 1.75 vol.% % of graphite as reinforcements. The Zirconia content was varied as 2.75, 4.5 and 6 vol. %, by stir casting technique to develop hybrid composites with varying zirconia content

The progressive improvement in tensile strength (90 MPa, 120 MPa, 130 MPa) with increasing zirconia content highlights zirconia's contribution to strengthening the matrix. The composite with 6 vol. % zirconia exhibits the highest tensile strength, making it ideal for applications requiring robust load-bearing capabilities. Similar to tensile strength, hardness improves with zirconia content (80.25 VHN, 103.22 VHN, 103.77 VHN). This increase suggests that zirconia enhances wear resistance while maintaining structural integrity.

K.K. Ikpambese et al.[9]provides significant insights into the potential of palm kernel fibers as a sustainable replacement for asbestos in brake pads. Evaluating a range of properties—including wear rate, porosity, noise level, and microstructural behavior—helps establish the versatility and performance of these composites.

Interestingly, the wear rate and coefficient of friction increased with speed, aligning with standard brake pad behavior under dynamic conditions. Additionally, the consistent properties like porosity and moisture resistance suggest stability in various environmental conditions. The inertia dynamometer results for hardness, spanning 5.6 to 21 hours, highlight the variability across samples, which likely correlates with their compositions and processing conditions.

Muna Khethier Abbass et al.[10] demonstrates the significant improvement in the mechanical properties of the AA6061-T6 alloy through friction stir processing (FSP), especially when reinforced with hybrid additions of SiC and $Al_2O_3$ particles. The increase in microhardness (from 75 HV to 89.3% improvement) and enhanced wear resistance indicate the potential of this composite for applications requiring durability and strength. The hybrid reinforcement approach also seems to outperform the single-particle reinforcements, emphasizing the synergy between SiC and $Al_2O_3$.

Asifiqbal M. Doddamania et al[11] developed innovative composites by using stir-casting to integrate carbon nanotubes (CNT) and nano clay (NC) as dual reinforcement materials in an Al6063 matrix. with an increase in carbon nanotubes tubes CNT and Nano clay NC on the Al6063 matrix, increases the mechanical properties like tensile strength, hardness, flexural strength, and compressive strength rise from 225-245 MPa, 45-74 BHN, 218-298 MPa, and 140-152 MPa, CNT improves hardness of material from 52 to 74 BHN and decreases the wear loss.

Mukudadas Prasanna Kumar et.al.[12] developed aluminum (ZA-27) alloy composites reinforced with garnet particles wear. The composites were produced using the liquid metallurgy process. In weight-based increments of 5%, the reinforcement content was adjusted from 0% to 20%. Using a pin-on-disc wear testing equipment, the composites' wear loss. The findings show that while the wear loss of composites was lower than that of the zinc-aluminum alloy, it rose as load and sliding speed increased with reinforcement. It was found that when the amount of garnet increases, the wear resistance will also increase.

L Avinash et al.[13] investigated the wear behavior and hardness of A357 (Al-7%Si) alloy composites reinforced with 6 wt% bimodal silicon carbide particles (SiCp) of ~250 µm (L) and ~38 µm (S) sizes. Composites with three bimodal distributions (3% L + 3% S, 4% L + 2% S, and 2% L + 4% S) and the unreinforced alloy were produced via permanent mold die casting. Pin-on-disc wear tests were conducted at 1 m/s under loads of 10-30 N (5 N intervals). Characterization included hardness and microstructure analysis. The results showed that bimodal SiCp reinforcement significantly enhanced both hardness and wear resistance. Notably, the 4% L + 2% S combination yielded the highest wear resistance and hardness, suggesting that a greater proportion of large particles is more effective in improving wear resistance than a higher proportion of small particles at a constant reinforcement weight percentage.

## 2.1 Wear data analysis and parameter estimation

In a previous study, authors reported [1]Ref ours) that the Linear Archard model equation is useful in analysing data of homogeneous materials of pin-on-disc experiments. Whereas, Evans-Wilshaw and Marhall type equations are useful in the analysis of wear data of composite materials.

Archard's equation states that:

$$V=\frac{K}{3H}PD \qquad [1]$$

Where D is the sliding distance, *P* is the normal load pressing the two surfaces together,
*H* is the penetration hardness of the softer material, and *K* is the wear coefficient, which is a dimensionless constant of proportionality. Archard's equation provides a useful starting point for estimating the wear coefficient K for operating conditions.

The Evans-Wilshaw-Marshall (EWM) equation states that:

$$V = C\,\frac{P^{9/8}}{K_{IC}^{1/2}\,H^{5/8}}\left(\frac{E}{H}\right)^{4/5} D \qquad [2]$$

Where *P* is the load in N
*D* is the Sliding Distance in m
$K_{IC}$ fracture toughness
*H* is the Hardness
Where, *C* is a material-independent constant that depends upon experimental operating conditions and *E* is the elastic modulus.

The EWM model equation provides a framework for understanding lateral crack extensions in the wear of brittle materials.

In this report, *C* of EWM equation is assumed to be proportional to *K* of Archard equation for a given experimental condition.

Strategy for estimation of parameter, hardness from wear data using EWM model equation is as follows:

- K is estimated using Archard equation without addition of SiC reinforcement for a relatively homogeneous material as initial guess for fitting in EWM model equation.
- C is equated to K as initial guess and then mulitpied with sliding distance to obtain a constant = 3.5232 in *m*.

Equivalent equation for EWM, is as follows

$$V=\frac{3.5232\times d}{b\times a^{1.425}}\times p^{1.25}$$

Using MATLAB's curve fitting and optimization tools, parameters were estimated, for the data tabulated in tabular column.

**Table 1**. Load vs volume loss as reported by Agarwal et al.[14]

| | LOAD | VOLUME LOSS |
|---|---|---|
| 0% SiC | 20 | 22.879 |
| | 40 | 55.900 |
| | 60 | 136.185 |
| | 80 | 180.768 |
| | 100 | 221.904 |

**Table 2**. Load vs volume loss as reported by Agarwal et al.[14]

| Load, N | V_exp, Cu. M | V_EWM, Cu. M | Residuals |
|---|---|---|---|
| 20.00 | 9.36 | 16.48 | -7.13 |
| 40.00 | 10.63 | 35.95 | -25.32 |
| 60.00 | 44.88 | 56.73 | -11.85 |
| 80.00 | 82.92 | 78.41 | 4.51 |
| 100.00 | 114.09 | 100.78 | 13.31 |

From the data when fitted with equivalent EWM equation in MATLAB curve fitting tool, and after optimization, following parameters were estimated.

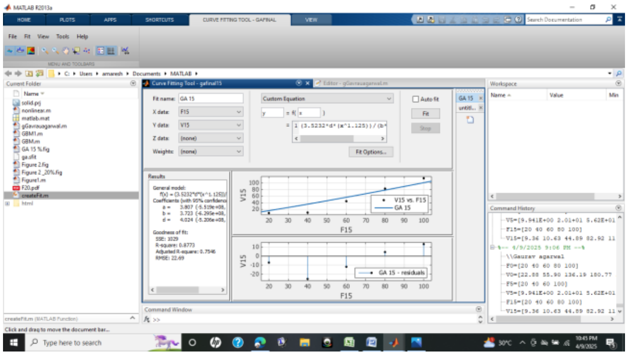

**Figure 1.** Shows fitting of EWM equation for estimation of parameters.

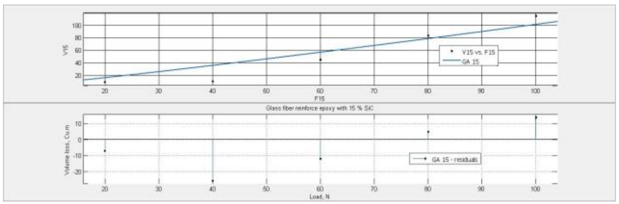

**Figure 2.** Residuals after fitting the curve.

Goodness of fit parameters, $R^2$ is 0.87 and Root mean square errors (RMSE) is 22.69 from which it can be attributed that model equation is reasonably explain s the variance in data with RMSE is around 22 cu.m. Estimated parameters as per equivalent equation of EWM and estimated hardness and young's modulus along with stastitcial goodness of fit parameters are tabulated in table 3

**Table 3.** Shows estimated parameters for one data of 15 % SiC data as per Gaura Agarval et al.

| $R^2$ | a | b | d | $K_{IC}$, MPa.m$^{1/2}$ | E, Gpa | H, N/m$^2$ |
|---|---|---|---|---|---|---|
| 0.87 | 3.807 | 3.723 | 4.024 | 13.9 | 5.7 | 38070 |

Although estimated statistical parameter like RMSE indicates higher error in fitment of data, but $R^2$ indicates that variance in data is reasonably well explained by EWM model equation.

In summary, the EWM model equation provides a framework for understanding and calculating material parameters. Yet, its empirical character restricts the capacity to accurately ascertain material-specific characteristics.

## 3. CONCLUSIONS

- Analytical models are useful in the inverse problem technique for the estimation of material-specific parameters from wear data.
- In this present study, it is shown that using EWM model and statistical methods material material-specific parameters may be estimated.
- In the future, rigorous models may be developed for the estimation of parameters from experimental data.
- In the future, more experimental data is to be considered for accurate estimation of parameters.
- In the Inverse method for material specific estimation from wear data can be applied in the development of new materials for specific condition. It may be useful in industry in specific development of new composite material.

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