

Optimisation Of Brake Block Material Composition to Minimise Train Wheel Wear: A Case Study of Tanzania Metre Gauge Railway.

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ABSTRACT:

In railway systems, maintaining wheels that experience premature wear from use in tread brakes to stop or slow the vehicle is a significant problem. In this study we employed a commercially available carbon steel 1050 wheel commonly used in railway networks. We also examined the 27 different formulations of the brake block from three families of materials which are grey cast iron; organic composite; and sintered materials, using Taguchi experimental design for the grey cast irons, and constrained mixture design for the two other types. Each formulation was subjected to identical geometrical conditions, surface normal pressure and wheel velocity. However, each of the three families of materials had its own fixed value of coefficient of friction. Contact pressure, frictional stress, sliding distance and temperature rise in the wheel/brake interface were determined by transient structural and thermal analyses. The ranking of the formulations was based upon the products of the mean values of contact pressure and sliding distance for each formulation. The organic composite formulation having 70% fillers, 20% silicones and 10% rubbers exhibited a composite indicator of 10.6056 MPa·m. A sintered formulation and a grey cast iron formulation both produced indicators greater than this at 11.2727 and 11.5501 MPa·m respectively. The composite indicator was therefore 5.92% and 8.18% less than the respective family benchmarks. The temperature rise calculated for this organic composite formulation was 251.79°C.

KEYWORDS:

Railway tread braking; brake-block composition; wheel wear; finite element analysis; Archard wear indicator; Tanzania metre-gauge railway

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I. INTRODUCTION

Tread braking has remained widely used in passenger and freight railway vehicles because it is relatively mechanically simple to use, comparatively economical and straightforward to maintain. During braking, force is applied to a block against the rotating wheel. The Kinetic energy of the rotating wheel is converted into heat generated by frictional heat during braking. This results in contact pressure, tangential stress, sliding motion and temperature field acting simultaneously on both the wheel and brake block. If this process occurs over time, it will produce material removal, thermal cracking, microstructural transformation of the wheel's surface, roughness of the tread and changes in braking performance (bekesi & varadi, 2013; Vernersson et al., 2012) and may result in premature wheel degradation.

The brake block material determines the interface response. Gray cast iron offers good friction stability, good thermal conductivity. However, it generates noise, roughness and particulates. Composite blocks can reduce noise and allow customized friction behavior; however, their low thermal conductivity will transfer a greater fraction of braking heat to the wheel. Sintered blocks provide high-temperature capability and reproducible

properties; however, they require controlled powder-metallurgy manufacture. Lyu et al. (2019) use pin-on-disc testing to confirm that railway brake materials made from cast-iron, composites and sintering techniques have markedly different friction and wear responses under nominally similar conditions

Material properties of the brake block affect the density, elastic modulus, thermal conductivity, specific heat capacity, coefficient of thermal expansion, hardness and friction of the brake block. The physical characteristics of the brake block will influence how it deforms under pressure as it contacts the wheel tread surface, distribute both vertical and horizontal forces that are applied during braking and also partition frictional heating. Because contact is non-uniform over what appears to be an area on the wheel's tread and local high-pressure regions or "hot-spots" move during braking, they may contribute to localized wear and thermal distress in the wheel (Békési & Váradi, 2013; Voortman Landström et al., 2024). As such, wheel performance is a multi-faceted thermomechanical and tribological issue instead of a simple property selection process.

Early studies investigated tread-brake temperature maps, brake-hot-spots, residual stresses, classification of brake materials, and recursive modeling of wheel wear (Voortman Landström et al., 2024; Kuciej et al., 2020; Pradhan & Samantaray, 2019). Nevertheless, these studies did not provide a thorough systematic evaluation of the effects of formulation variations in different brake-block families under the operating condition of the Tanzania meter gauge Railway. Specifically, there is a need to use numerical methods to determine which composition used in the present investigation resulted in the least amount of sliding exposure as it relates to pressure at a carbon steel 1050 wheel while maintaining constant values of geometries, speeds, applied pressures, contact treatments and durations of braking.

Therefore, the purpose of this research project was to Optimise the material composition of brake blocks in order to produce the smallest possible wheel-wear tendencies in accordance with Tanzania Railway Corporation meter gauge conditions. More specifically, the objectives were to create a representative 3-Dimensional wheel block model, formulate compositions based upon their respective materials, calculate structural and thermal responses for twenty-seven cases, rank those cases using an Archard-based indicator of relative wear propensity, and find the formulation(s) that are best overall and within each family of grey cast iron, composites and sintered.

II. MATERIALS AND METHODS

2.1 Study design and operating context

A Comparative Numerical Design was employed. The Case was developed to represent a Tanzanian metre gauge Passenger Coach employing Tread Brakes. The dimensions and operating input parameters listed below are those that were based on the Tanzania metre gauge railway for this particular numerical study. They do not provide an independent verification of the current operating limits for all vehicles in this class. A wheel diameter of 851 mm and an operating speed of 100 km/h resulted in a rotational speed of approximately 625 rpm. The Brake-Block Envelope was defined as being $330 \times 76 \times 65$ mm. Normal pressure of 0.5 MPa was applied to the rear face of the Block for five seconds from a reference temperature of 25°C. The same Carbon Steel 1050 Wheel, Geometry, Contact Definitions, Meshing Strategy, Solution Controls and Result Locations were employed when assessing all Formulations. The equation 2.1 provide the insight over speed conversion to revolutions per Minute.

$$N = 60V / (\pi D) \quad (2.1)$$

Where:

N is the Rotational Speed of the Wheel in Revolutions Per Minute,

V is Vehicle Speed in Metres/Second,

D is the wheel diameter in Metres.

2.2 Material formulation and numerical design

Three Families of Formulation were considered. Grey Cast Iron was formulated using a Taguchi L9(3⁴) array wherein the variables of carbon, silicon, manganese and phosphorus were varied at three different levels; whilst sulphur, chromium, molybdenum, titanium, vanadium and niobium were held constant and iron was added to each mixture to balance its chemical composition. Composite Formulations consisted of constrained mixtures of filler, rubber and silicone, where filler and rubber were taken as independent fractions and silicone was computed as the remainder. Sintered Formulations consisted of a combination of graphite and silicon carbide with a single metallic matrix containing internally 54% Copper, 25% Iron, 15% High-Speed Steel and 6% Bronze. The quantities of graphite and silicon carbide were variable while the metallic matrix provided the chemical balance. In the above descriptions the abbreviations GCI, COM and SINT have been used to represent the Families of Formulation namely grey cast iron, composite and sintered materials, respectively, followed by a sequential number identifying each specific test case. Table I provides a summary of the Formulation Design and Composition Levels.

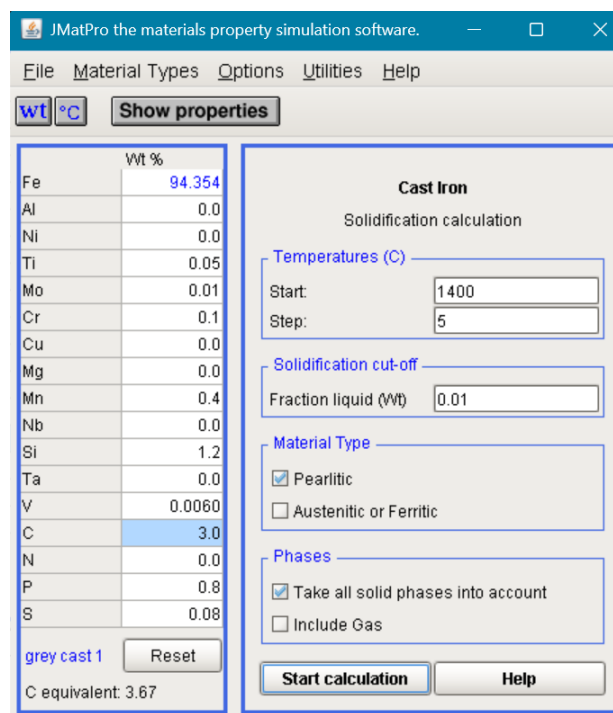
Table I: Numerical design and composition factors.

Family	Numerical design	Varied components and levels (wt.%)	Balance	Runs
Grey cast iron	Taguchi L9(3 ⁴)	C: 3.0/3.2/3.4; Si: 1.2/1.6/2.0; Mn: 0.4/0.6/0.8; P: 0.8/1.1/1.4	Fe	9
Composite	Three-level mixture (3 ²)	Filler: 60/65/70; rubber: 5/10/15	Silicone	9
Sintered	Three-level mixture (3 ²)	Graphite: 5/10/15; SiC: 5/10/15	Metallic matrix	9

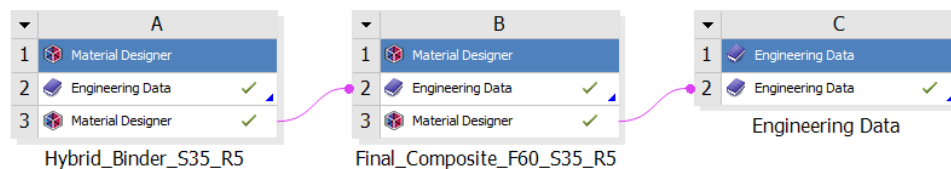
Source: Numerical study design; all composition levels are mass fractions.

Properties of the cast iron case were determined based on composition in JMatPro Version 7 a software that was used to perform the material formulation. Composite and sintered brake block effective homogeneous material properties were established using a Representative Volume Element (RVE) model in ANSYS Material Designer 2024 Release 1. Prior to homogenizing mass fraction into volumetric fractions, constituent density was used as a conversion factor. The resultant property set was assigned to each brake block case in the Engineering Data portion of ANSYS.

Figure 1, shows the entry of the Grey Cast Iron composition material in the JMatPro Software for calculating the overall properties of the resulting composition. The overall properties of the resultant composition were used in the ANSYS Workbench for material properties.

**Figure 1:** Entry of Grey cast iron formulation in JMatPro V7 (Author's JMatPro GUI).

Properties The composite was generated in two stages. In Stage 1, silicone and rubber were homogenized to form a hybrid binder. In Stage 2, the Stage-1 hybrid binder was combined with the filler to generate the final composite formulation. The hierarchical link between the hybrid binder and final composite is presented in Figure 2.

**Figure 2:** Two-stage composite material workflow in ANSYS Material Designer (Author's ANSYS Material Designer 2024 R1 Model).

The constituent phases are then assigned, distributed in terms of geometry, meshed and homogenized to predict the composite's mechanical and thermal behaviour through an effective property estimation. As shown in figure 3.

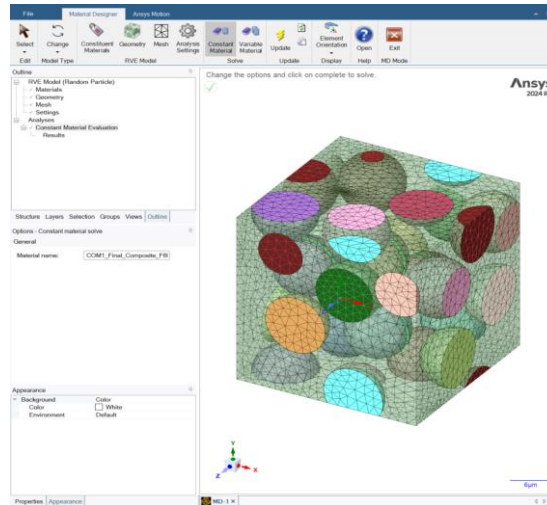


Figure 3: Representative homogenised composite microstructure (Author's ANSYS Material Designer 2024 R1 model).

A three-dimensional wheel and brake block was created using the data that had been acquired. Features such as small fillets, holes and chamfers, which were considered to have no effect on the contact behavior of the system, were removed in order to Minimise the computational costs. The wheel tread and the contact surface of the wheel with the brake block were kept. The CAD-assembly was then converted to a STEP-file (geometry) and subsequently loaded into ANSYS Workbench. Figure 4 shows the representative model.

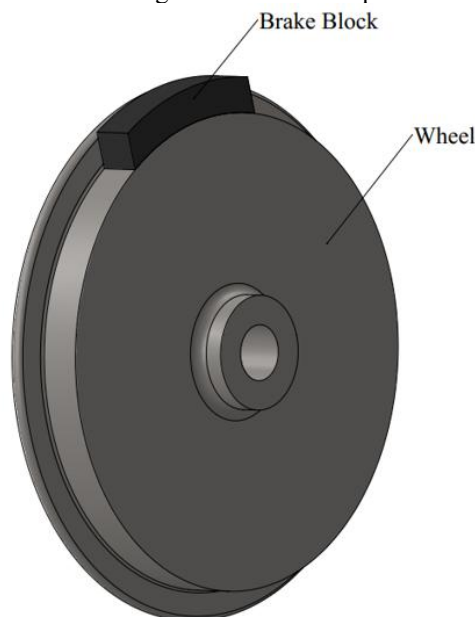


Figure 4: Representative three-dimensional brake-block and wheel model used in the numerical study.

A frictional asymmetrical contact-pair was created with the brake-block being the contact side and the wheel-tread being the target. Augmented-Lagrange Contact (ALC) and Large Sliding were used. The wheel was allowed to rotate around its axis while constraints prevented it from undergoing rigid body motions. Three separate literature-based friction coefficients were used to define the three different material-families: 0.38 for Grey Cast Iron, 0.25 for Composite and 0.30 for Sintered Materials. All of these values were fixed at their respective values in each family; therefore, the property changes based on the composition within the family did not influence the coefficient of friction. The finite-element mesh and rotational degree of freedom are shown in Figure 5.

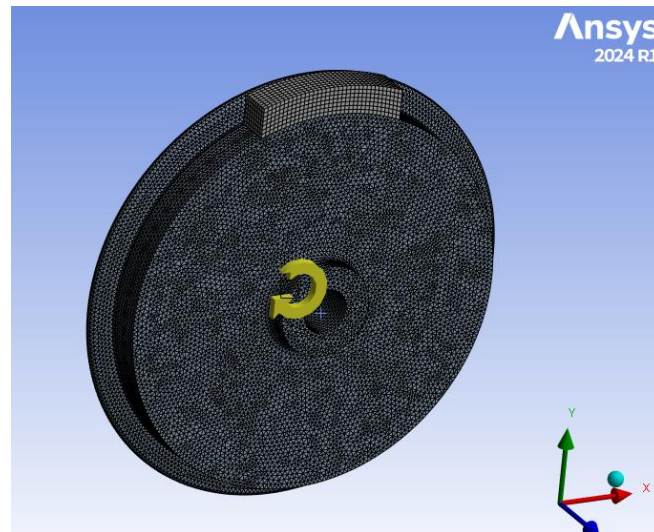


Figure 5: Finite-element mesh and rotational degree of freedom of the wheel-brake-block model.

2.4 Structural and thermal analyses

Transient structural analysis generated the average and peak contact pressure, the peak frictional stresses and total sliding distances. A transient thermal analysis of the same geometric shape and with similar materials defined was performed to calculate the temperature distribution and the temperature increase. Although both structural and thermal models were developed from the same engineering data, geometry and model definition as shown in Figure. 6, they are independent structural and thermal analyses.

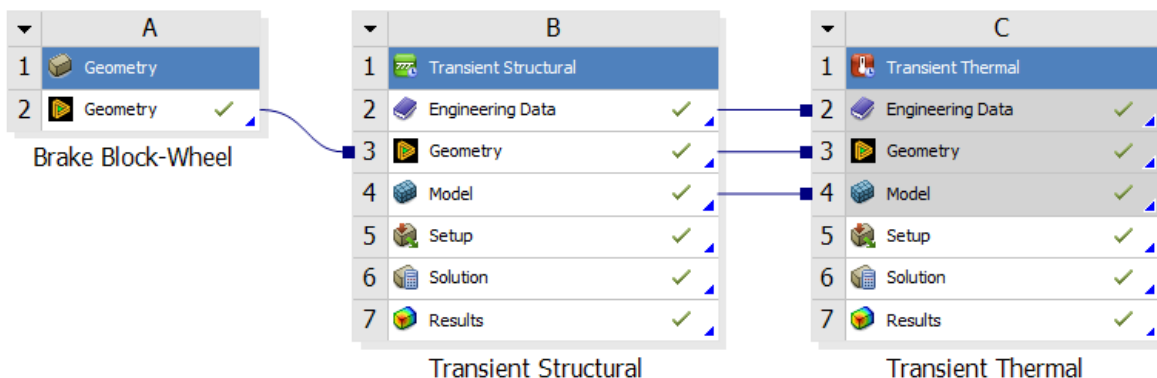


Figure 6: ANSYS Workbench workflow linking the common geometry to transient structural and thermal analyses.

Table II lists the common simulation settings and the adopted family-specific friction coefficients.

Table II: Common simulation control conditions.

Parameter	Adopted condition
Wheel material and diameter	Carbon Steel 1050; 851 mm
Brake-block dimensions	330 × 76 × 65 mm
Wheel speed	625 rpm, constant (approximately 100 km/h)
Applied pressure and duration	0.5 MPa on block rear surface; 5 s
Reference temperature	25 °C
Contact	Frictional asymmetric; Augmented Lagrange; large sliding
Friction coefficients	GCI 0.38; composite 0.25; sintered 0.30
Primary outputs	Average/maximum pressure, maximum frictional stress, sliding distance and temperature rise

Source: Common control settings used for the twenty-seven simulations.

2.5 Relative wear indicator and ranking

The classical Archard relationship expresses wear volume as directly proportional to both the normal load and sliding distance of an element. The Archard model indicates that wear volume will decrease as the hardness of the wheel increases. A local contact model would describe wear depth in similar terms wear depth being directly

proportional to contact pressure and sliding distance. Equation (2.2) provides the relationship between these variables.

$$h_w = kps / H \quad (2.2)$$

where h_w is local wear depth,
 k is the dimensionless wear coefficient,
 p is contact pressure,
 s is sliding distance and
 H is wheel hardness.

In this study, k and H were not the parameters under investigation. So the wheel hardness H and wear coefficient k were treated as a constant. Consequently, the ratio k/H was maintained as a common constant for all formulations.

Accordingly, let:

$$C = k / H \quad (2.3)$$

where C is a constant common to all simulated brake-block formulations. Substituting Equation (2.3) into Equation (2.2) gives:

$$h_w = Cps \quad (2.4)$$

Since C is constant for every formulation, the relative variation in predicted wheel wear is governed by the product of contact pressure and sliding distance. Therefore:

$$h_w \propto ps \quad (2.5)$$

The finite element comparison used the reported mean contact pressure, $\bar{p}$, rather than a pointwise local pressure. Hence, Equation (2.5) becomes:

$$h_w \propto \bar{p}s \quad (2.6)$$

On this basis, a relative wheel-wear screening index was defined as:

$$I_w = \bar{p}s \quad (2.7)$$

The relationship between the original Archard expression and the screening index can therefore be written as:

$$h_w = (k / H) I_w \quad (2.8)$$

Thus, k and H were controlled because they were not parameters under study. Keeping them constant allows the effect of the varying contact response associated with each brake-block formulation to be compared consistently through $I_w = \bar{p}s$. A lower I_w therefore indicates a lower relative predicted wheel-wear tendency under the same numerical conditions. The index has units of $\text{MPa}\cdot\text{m}$.

III. RESULTS AND DISCUSSION

3.1 Family response

The sliding distances of all twenty-seven test results differed minimally; the variations in I_w values for these tests were largely affected by the average contact pressures. As can be seen from this data, the composite family had the lowest mean value for both the average contact pressure and the I_w . In contrast, the grey cast iron produced the highest mean value for contact pressure and I_w as well as the largest variation (range) between its "best" and "worst" case. Although sintered material generated the greatest mean increase in temperature it is evident that there was no correlation between a favorable pressure-sliding behavior and a favorable thermal behavior. The family summaries are reported in Table III.

Table III: Family-level summary of simulated responses.

Family	Mean $\bar{p}$ (MPa)	Mean I_w ($\text{MPa}\cdot\text{m}$)	Minimum I_w ($\text{MPa}\cdot\text{m}$)	Maximum I_w ($\text{MPa}\cdot\text{m}$)	Mean ΔT ($^{\circ}\text{C}$)
Sintered	0.2890	12.9215	11.2727	14.6286	358.67
Grey cast iron	0.3204	14.3329	11.5501	18.2855	261.76
Composite	0.2576	11.5233	10.6056	12.6840	285.81

Source: Calculated from the ANSYS simulation results; I_w = average contact pressure $\times$ sliding distance.

3.2 Sintered formulations

SINT-1 was ranked number one in the sintered family with average contact pressure of 0.252164 MPa, max contact pressure of 0.266863 MPa, max frictional stress of 0.069382 MPa, total sliding distance of 44.704 meters and I_w of 11.2727 $\text{MPa}\cdot\text{m}$. SINT-9 had the largest sintered I_w at 14.6286 $\text{MPa}\cdot\text{m}$; therefore, using SINT-1 decreased the indicator by 22.94 percent compared to SINT-9. The thermal ranking showed: SINT-3 generated the least amount of heat rise (205.93°C) while SINT-5 generated the most at 559.84°C . SINT-1 generated

404.45°C, indicating there is considerable cost associated with its favorable wear performance and low thermal resistance.

3.3 Grey cast iron formulations

GCI-6 was at the top of the Grey Cast Iron Family for overall performance, with an average of 0.2582 MPa, and a max value of 0.27273 MPa, max frictional stress of 0.12843 MPa, total sliding distance of 44.733 m and an Iw of 11.5501 MPa·m. The highest Iw in the cast iron family was GCI-7, with a value of 18.2855 MPa·m. GCI-6 had the greatest best to worst improvement in all three families reducing the indicator by 36.83% compared to GCI-7.

3.4 Composite formulations

The COM-8 formulation had the highest strength among all of the twenty-seven formulations that were tested. Among the twenty-seven formulations tested, it had the lowest Indicator. COM-8 generated an average pressure of 0.23707 MPa, a maximum pressure of 0.2509 MPa, a maximum frictional stress of 0.09534 MPa, a sliding distance of 44.736 m, a temperature rise of 251.79 °C and an Iw of 10.6056 MPa·m. COM-1 produced the largest value in the Family Maximum (Iw) at 12.6840 MPa·m. COM-8 reduced the Iw indicator by 16.39% compared with COM-1. Additionally, COM-8 provided the least amount of average pressure, max pressure, frictional stress and temperature rise as well as providing the most balance compared to an Optimisation that would be based solely on Iw.

3.5 Comparison of the family optima

Under common wheel-brake block geometries, with respect to loading, rotational speeds, contact definitions and durations of analyses, COM-8 yielded the lowest relative wear indicator out of all the three family-optimal formulations considered in this study. Compared to SINT-1, the Iw values were 5.92% less; compared to GCI-6, the Iw values were 8.18% less. Therefore, there is a clearly defined quantitative basis for rating COM-8 as the best formulation from the entire design space studied.

The optimal formulations and their corresponding mechanical and thermal responses are presented in Table IV. Figure 7 further illustrates the relative differences in the Iw values of the three family optima.

Table IV: Final ranking and composition of the optimum formulation from each family.

Rank	Case	Optimum composition (wt.%)	$\bar{p}$ (MPa)	Max. τ (MPa)	ΔT (°C)	Iw (MPa·m)
1	COM-8	Filler 70; silicone 20; rubber 10	0.23707	0.09534	251.79	10.6056
2	SINT-1	Metallic matrix 90; graphite 5; SiC 5	0.252164	0.069382	404.45	11.2727
3	GCI-6	C 3.2; Si 2.0; Mn 0.4; P 1.1; Fe balance	0.25820	0.12843	266.41	11.5501

Source: Simulation results and formulation matrices.

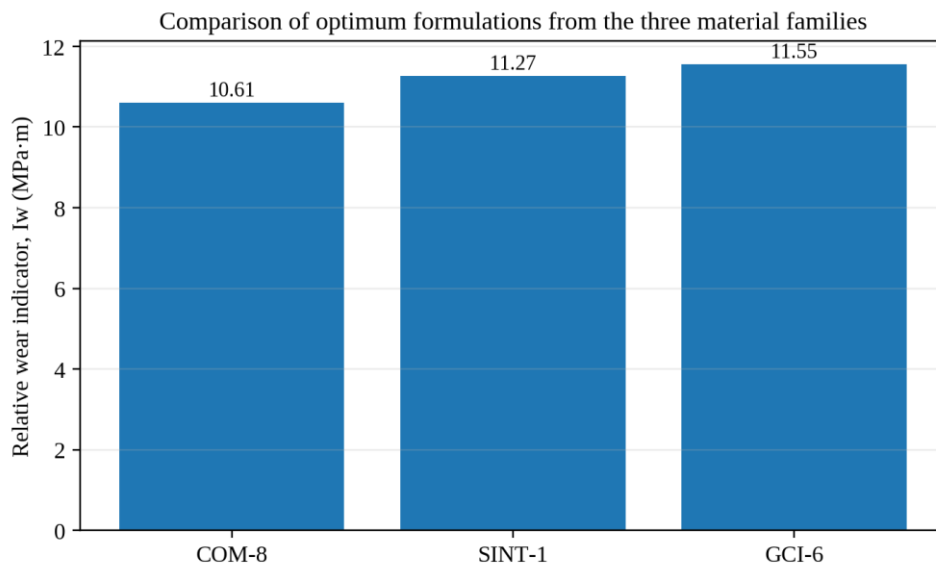


Figure 7: Comparison of the relative wear indicator for the optimum composite, sintered and grey-cast-iron formulations.

3.6 Interpretation of composition effects

A key aim of this research was to numerically achieve its objectives by selecting an optimum formulation within each material family under a single, controlled wheel-block operating condition. The relatively small range of sliding distance suggests that variations in the contact pressure between the two surfaces of the block largely contributed to the outcome of the experiment. As expected from previous experience (see Section 2), the composite family produced the lowest mean I_w and COM-8 the lowest individual I_w . In addition, COM-8 did not exhibit the marked temperature increase experienced with SINT-1. Thus, the best balance of performance among all three optimal formulations was achieved by COM-8.

In general, the deterministic results supported expectations regarding the influence of composition dependent brake-block properties upon the interaction between the brake-block and wheel. Across each family, modifying the formulation resulted in varying levels of average and peak pressure, frictional stress and temperature rise despite having identical geometrical characteristics and input parameters.

The large GCI spread of predicted wheel exposure indicates how sensitive the predicted wheel exposure will be to the properties developed through the Taguchi compositions. While the composite family exhibited a smaller range of responses compared to the other families, the best-case result obtained for the composite family was less than all other formulations examined. Since no inferential testing was performed, the differences illustrated are those based on simulations alone.

3.7 Contact pressure and the wear indicator

The Pressure multiplied by sliding distance defines a term that follows a similar form to a local version of the Archard-type description used in many models of brake-contact interactions (Békési & Váradi, 2013). Provided that there exists a common value of k/H , then a lower product implies a lower comparative wear driving term. Because sliding distances have been nearly constant throughout these experiments, contact pressure determines the order of the arithmetic ranking of products.

In addition, the wear indicator provides a measure of averaged values across space. Although maximum values of pressure and frictional stress may indicate localized areas where crack formation or severe wear may occur even if the average values are moderate, they too were maintained as additional output data to support the decision process. Therefore, a local wear model in the future should include pressure and relative sliding velocity integrated over time and across the active contact region, should utilize a calibrated temperature dependent coefficient and should update geometry as material is lost during wear.

3.8 Thermal trade-offs

Temperature in the tread-brake zone will depend on frictional heat generated, contact conditions and the thermophysical properties of both contacting bodies (Kuciej et al., 2020). The current results demonstrate that rank in terms of wear exposure and rank in terms of thermal exposure do not always coincide. SINT-1 produced the second-lowest average I_w but produced the highest temperature (404.45°C) compared to COM-8 and GCI-6. On the other hand, GCI-1 produced the least amount of grey iron temperature rise but produced poor wear rankings. Hence, while a formulation selected solely for low pressure-sliding exposure could provide acceptable thermal behavior, it would likely produce unfavorable friction behavior.

Past research has demonstrated that tread braking generates uneven temperature distribution across the tread face (Faccoli et al., 2020; Voortman Landström et al., 2024); transient hot spots; residual stresses; and surface damage. All these factors further emphasize why a multi-criteria approach must be employed. Hence, in addition to evaluating friction stability; brake-block wear; wheel wear; noise; particulate emissions; manufacturing costs; and thermal conductivity; heat capacity; and expansion characteristics must be considered. COM-8 appears attractive since it exhibits favorable I_w and temperature rise in the current results. However, like all candidates, friction stability and material integrity at service temperature have yet to be verified experimentally.

3.9 Comparison with published studies

Published studies have shown that the materials used to make a brake block will affect how well it performs; i.e., the friction generated when sliding against another surface, how much wear occurs from repeated braking, and how hot it gets. Studies by Lyu et al. (2019) examined three different types of brake blocks — cast iron, sintered and composite and found that each type performed differently under the same conditions. This is similar to what was observed in this study using the variables of contact pressure, frictional stress, the increase in temperature of the brake block and the variable I_w . In addition, using $I_w = p_s$ is based on a model of pressure versus sliding distance that is typical of an Archard-type model (Békési & Váradi, 2013). Although the hardness of the brake blocks and their coefficients of wear were not studied here, both were considered constant across all options so that comparisons could be made based solely upon performance.

The ability to model brake blocks using the finite element method has been demonstrated by Kuciej et al. (2020) for modelling temperatures associated with braked treads in rail vehicles. Both Kuciej et al. (2020) and Voortman Landström et al. (2024), along with Pradhan and Samantaray (2019), indicated that poor uniformity in temperature during braking can cause problems with vehicle performance and high rates of wear. Thus, there is merit in evaluating temperature as part of an overall assessment of brake block performance using the pressure-sliding parameter I_w .

Faccoli et al. (2020) have shown that factors such as temperature cycling, material transfer and presence of third bodies significantly influence service wear. The purpose of these simulation studies is to isolate the effects of composition on service wear prior to introducing other service-related effects. As evidenced above, COM-8 had I_w values 5.92% and 8.18% less than those of SINT-1 and GCI-6, respectively. Additionally, COM-8 exhibited the best thermal performance among the optimal designs identified in this investigation.

3.10 Impact for Tanzania metre-gauge operation

For Tanzania Railway Corporation has an immediate benefit from this study as the study provides a reasonable basis for evaluating potential new brake materials against those already being used on the railways. COM-8 should therefore be given priority consideration in further simulation and laboratory studies to confirm its suitability for the railways, with SINT-1 and GCI-6 acting as family reference points.

3.11 Study limitations

This analysis was performed numerically. There have been no experiments conducted at a brake dynamometer or on the railway to measure wear rates of wheels or brake blocks, braking distances, or service life reductions. I_w is an absolute sliding pressure indicator. While there exists an Archard Coefficient that has been determined experimentally, a temperature dependent wheel hardness relationship and a validated method to calculate wear depth do not exist. The five second constant speed condition is representative of a controlled comparison rather than a complete braking cycle, multiple-duty cycle or a long-term history of route conditions. Family-specific friction coefficients were assumed to be identical within families. Friction behavior due to variation in composition and temperature across different formulations was modeled as constants for each family. Therefore, cross-family variations are due to both differences in material properties and differences in assigned friction coefficients among families. These differences may not be entirely due to differences in material properties.

Material properties that are homogenized and generated need to be confirmed through laboratory testing particularly for composites and sintered materials and their respective manufacturing processes. The Optimisation focused on predicting the likelihood of wear patterns for the wheels. Braking performance, noise levels, particulate emissions, fatigue resistance, costs, and manufacturability were all excluded from one multi-objective function.

3.12 Recommended validation programme

There needs to be a series of sequential steps taken before COM-8 can be evaluated for inclusion onto the railway system. First the numerical designation needs to be converted into a reproducible material specification. Next the model needs to be verified prior to experimental verification followed by dynamometer testing and finally a small-scale monitored service test. Table V identifies the recommended sequence of verification or validation activities.

Table V: Minimum evidence required before operational consideration.

Stage	Recommendation
1. Material confirmation	Manufacture COM-8 coupons; verify constituent fractions, density, hardness, modulus and thermal properties
2. Bench tribology	Pin-on-disc or block-on-wheel tests across pressure, speed and temperature
3. Dynamometer	Full-scale repeated braking with a Carbon Steel 1050 wheel and reference blocks
4. Controlled service trial	Limited TRC fleet trial with baseline comparison and periodic wheel-profile measurement
5. Compliance review	Assess interchangeability, safety, manufacturing quality and applicable railway requirements

Source: Validation sequence proposed from the limitations of the numerical study.

IV. CONCLUSION

Twenty-seven different brake-block formulations have been compared on a common basis of wheel, geometrical, applied pressure, speed, contact formulation and duration a Case study of Tanzania's meter gauge railway with family-specific friction coefficients. Numerical results indicated that formulation-dependent characteristics impacted contact pressure, frictional stress, temperature rise and an Archard-based relative wear indicator. COM-8; formulated from 70 wt% filler, 20 wt% silicones, and 10 wt% rubber, generated the lowest value of I_w ($I_w = 10.6056 \text{ MPa.m}$) and ranked number one overall. SINT-1 ranked second with $I_w = 11.2727 \text{ MPa.m}$ while GCI-6 ranked third with $I_w = 11.5501 \text{ MPa.m}$.

COM-8 provided the smallest temperature increase among the three optimal solutions. Intrafamily comparisons were made such that COM-8 was 5.92% lower than SINT-1 and 8.18% lower than GCI-6. COM-8 provided greater decreases in the relative wear indicators within families when compared to the other two optimums, specifically 16.39% lower than COM-1, 22.94% lower than SINT-1 (when comparing to SINT-9), and 36.83% lower than GCI-6 (when comparing to GCI-7). As a result, these results confirm that COM-8 has the lowest predicted indicator of all of the candidates in the obtained results.

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