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K.L. Sundarkrishnaa

Friction Material Composites

Copper-/Metal-Free Material Design Perspective

Second Edition

Springer

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Dedicated to my parents
Lakshminarayana Moorthy and
Seethalakshmi

Preface

The publication of this book is a culmination of high level interest evinced by the industrial, scientific, and academic communities worldwide in the subject of brake friction material composite. It provided the stimulus to publish the monograph of the second edition of the first volume. This monograph is intended to support beginners with the basic insight into the essentials of friction material composite, with a broader sense of evolution of brake friction material formulation from the materials point of view. This second edition of the First Volume which is an introductory volume of the five volumes has been written and brought out from the author's experience and expertise with wide ranging friction material manufacturers, brake manufacturers, vehicle manufacturers, researchers, and testing labs with whom the author has been associated worldwide for the last 28 years. Recent work by the author in North America on copper-free, non-metallic BFMC with ceramic replacement finds an interesting place in this volume with solutions in hand excelling any other BFMC systems currently in vogue as it addresses various terrain requirements with sound techno-commercial value.

This monograph does not cater to any specific process/product formulations as each industry operates with its own manufacturing setup with process variables and other operating variables and none of the information provided is proprietary. In this monograph, automotive brake pads have been dealt with under the class of friction materials group. Although friction materials find wide ranging applications in domestic appliances, industrial appliances, automotive, rail brake friction pads, composition brake blocks, liners, and clutch part members, brake pads for automotive applications have been selected by the author for easy understanding. For the friction material group by virtue of its high volume content, the author has plans to present core issues of design, development, test procedures in detail and sequentially in the subsequent volumes to come. The environmental issues arising out of copper inclusion in the formulations and the legislation banning its usage have led the author to design and develop copper-free, non-metallic ceramic brake pads, which has been dealt with in this volume.

The author would like to express his sincere gratitude to all colleagues engaged in the brake friction material composite discipline who assisted with valuable advice and suggestions. The support provided for developing and implementing copper-free, non-metallic ceramic substitutes from New World Friction, Canada is acknowledged. The author wishes to acknowledge research support from NSW, Canada which deserves a strong mention in this volume.

Chennai, India K.L. Sundarkrishnaa

Contents

Acronyms

AFM	Atomic force microscopy
AMS	Auto motor sports
BFMC	Brake friction material composite
CNSL	Cashew nut shell liquid
DTV	Disc thickness variation
EDAX	Energy dispersion X-ray analysis
FIM	Field ion microscope
FT.NMR	Fourier transformed nuclear magnetic resonance
FMC	Friction material composite
GPC	Gel permeation chromatography
JASO	Japanese Association of Standards and Organisation
LCV	Light commercial vehicle
PFMEA	Product, process failure mode effect analysis
RPM	Revolutions per minute
MD	Molecular dynamics
SABS	South African Bureau of Standards
SOP	Standard operating procedures
TS	Test standards
SAE	Society of Automotive Engineers
SANS 601	South African Standards
SEM	Scanning electron microscopy
SSTM	Small sample test machine
STM	Scanning tunneling microscope
XRD	X-ray diffraction

Units with Conversion Factors

Thermal conductivity—1 W/Km = 0.86 kcl/m h °C
1 W/Km = 0.579 BTU/ft h °F

Acceleration

	Multiply by	To get	Multiply by	To get
Feet/sec^2	0.308	Meters/sec^2	3.281	Feet/sec^2
Inches/sec^2	0.025	Meters/sec^2	39.370	Inches/sec^2

Area

	Multiply by	To get	Multiply by	To get
Inches^2	645.160	Millimeter^2	0.016	Inches^2
Inches^2	6.425	Centimeter^2	0.155	Inches^2
Feet^2	0.093	Meter^2	10.764	Feet^2
Yard^2	0.837	Meter^2	1.196	Yard^2
Acres	0.405	Hectares	2.471	Acres
Miles^2	2.590	Kilometer^2	0.387	Miles^2

Force

	Multiply by	To get	Multiply by	To get
Ounces-f	0.278	Newtons	3.597	Ounces-f
Pounds-f	4.448	Newtons	0.225	Pounds-f
Kilograms	9.807	Newtons	0.102	Kilograms

Fuel Consumption

	Multiply by	To get	Multiply by	To get
Miles/US gallon	0.425	Kilometers/litre	2.352	Miles/gallon

Illumination

	Multiply by	To get	Multiply by	To get
Footcandles	10.760	Lumens/meter^2	0.093	Footcandles

Linear

	Multiply by	To get	Multiply by	To get
Inches	25.400	Millimeters	0.039	Inches
Feet	0.305	Meters	3.281	Feet
Yards	0.914	Meters	1.094	Yards
Miles	1.609	Kilometers	0.621	Miles
Microinches	0.025	Micrometers	39.370	Microinches

Mass

	Multiply by	To get	Multiply by	To get
Ounces	28.350	Grams	0.035	Ounces (av)
Pounds	0.454	Kilograms	2.205	Pounds
Tons (2000 lb)	907.180	Kilograms	0.001	Tons (2000 lb)
Tons (2000 lb)	0.907	Metric tons	1.102	Tons (2000 lb)

Power

	Multiply by	To get	Multiply by	To get
Horse power	0.746	Kilowatts	1.340	Horse power
Ft-lbsf/min	0.022	Watts	44.250	Ft-lbf/min

Speed (or Velocity)

	Multiply by	To get	Multiply by	To get
Miles/hour	1.609	Kilometers/hour	0.621	Miles/hour
Feet/second	0.305	Meters/sec	3.281	Feet/sec
Kilometers/hour	0.278	Meters/sec	3.600	Kilometers/hour
Miles/hour	0.470	Meters/sec	2.237	Miles/hour

Torque

	Multiply by	To get	Multiply by	To get
Pounds-inches	0.119	Newton-meters	8.851	Pound inches
Pound-feet	1.356	Newton-meters	0.738	Pound-feet
Kgf-cm	0.098	Newton-meters	10.197	Kgf-cm
Kgf-m	9.807	Newton-meters	0.102	Kgf-m

Pressure

	Multiply by	To get	Multiply by	To get
Pounds/inches^2	6.895	Kilopascals	0.145	Pounds/Inches^2
Inches H_2O 60 degree Farenheit	0.249	Kilopascals	4.019	Inches H_2O 60 degree Fahrenheit
Bars	100	Kilopascals	0.010	Bars
Pounds/ft^2	47.800	Pascals	0.021	Pounds/ft^2
Kgf/cm^2	98.070	Kilopascals	0.010	Kgf/cm^2
Inches (Hg 960 Degree Fahrenheit)?	3.377	Kilopascals	0.296	Inches Hg

Volume

Inches^3	16387	Millimeters^3 (mm^3)	0.000061	Inches^3
Inches^3	16.387	Centimeter^3 (cm^3)	0.061	Inches^3
Inches^3	0.016	Litres (L)	61.024	Inches^3
Quarts (US)	0.946	Litres (L)	1.057	Quarts (US)
Gallons (US)	3.785	Litres (L)	0.264	Gallons (US)
Feet^3	28.317	Litres (L)	0.035	Feet^3
Feet^3	0.028	Meters^3 (m^3)	35.315	Feet^3
Fluid ounce	29.570	Milliliters (mL)	0.034	Fluid ounce
Yards^3	0.765	Meters^3 (m^3)	1.303	Yards^3
Teaspoons	4.929	Milliliters (mL)	0.203	Teaspoons
Cups	0.237	Litres (L)	4.227	Cups

Work (or Energy)

Foot-pounds	1.355	Joules (J)	0.737	Foot-pounds
Calories	4.187	Joules (J)	0.238	Calories
Btu	1055	Joules (J)	0.001	Btu
Watt-hours	3600	Joules (J)	0.001	Watt-hours
Kilowatt-hours	3600	Megajoules (MJ)	0.278	Kilowatt-hour

Temperature

°Fahrenheit (°F)	(°F−32)/1.8	°Centigrad (°C)	1.8 + 32	°Fahrenheit (°F)

Common Metric Prefixes

Mega (M)	1,000,000 or 10^6	Centi (c)	0.01 or 10^{-2}
Kilo (k)	1,000 or 10^3	Milli (m)	0.001 or 10^{-3}
Hecto (h)	100 or 10^2	Micro (μ)	0.000001 or 10^{-6}

Physical Constants

	Quantity	Magnitude
N	Avogadro's number	6.023×10^{23} mol^{-1}
k	Boltzmann's constant	1.380×10^{-23} J K^{-1}
		8.614×10^{-5} eV K^{-1}
e	Electron charge	1.602×10^{-19}C
m_0	Electron rest mass	9.109×10^{-31} kg
F	Faraday's constant	96.49 K C mo1^{-1} (of electrons)
R	Gas constant	8.314 J mol^{-1} K^{-1}
G	Gravitational constant	6.673×10^{-11} N m^2 kg^{-2}
M_H	Hydrogen atom mass	1.007825 amu
		938.285 MeV/c^2
m_n	Neutron mass I .0	Q8 665 amu
		939.55 MeV/c^2
μ_0	Permeability of free space	$4\pi \times 10^{-7}$ H m^{-1}
		1.257×10^{-6} H m^{-1}
ϵ_0	Permittivity of free space	8.854×10^{-12} m^{-3} kg^{-1}s^4 A^2
h	Planck's constant	6.6255×10^{-34} J s
m_d	Proton mass	1.007 276 amu
		938.2 MeV/c^2
E/m_0	Specific charge of electron at rest	1.759 × 1011 C kg
σ	Stefan's constant	5.67×10^{-8} W m^3 T^{-4} c
	Velocity of light in vacuum 3×10^8 in	2.99776×10^8 in s^{-1}
	Wein's constant	2.892×10^8 m K
g	Acceleration due to gravity	9.81 m s^{-2}

Shorthand for Very Large and Very Small Numbers Powers of Ten are Really Powerful

10^{-12}	0.00000000000001	Pico (p)
10^{-9}	0.0000000001	Nano (n)
10^{-6}	0.0000001	Micro (μ)
10^{-3}	0.001	Milli (m)
10^{-2}	0.01	–
10^{-1}	0.1	–
10^0	1	–
10^1	10	–
10^2	100	–
10^3	1,000	Kilo (k)
10^6	1,000,000	Mega (M)
10^9	1,000,000,000	Giga (G)
10^{12}	1,000,000,000,000	Tera (T)
10^{15}	1,000,000,000,000,000	Peta (P)

Notes on Safety

Safety Precautions

With increasing demand for vehicle performance requirements and the growing demands, the important aspect of safety is to be borne in mind while designing a frictionmaterial composite system.

For example, one of the standards included recently for FMVSS105 rule is the new FMVSS135 standard that the 2001 model year car and 2003 model year trucks have to meet. FMVSS135 is a minimum braking performance standard of the national highway Traffic and Safety Administration. It is tougher than the former FMVSS105 rule, but with 25 % less pedal effort. To meet this specification, manufacturers have to switch to more aggressive material design on the product. This is one of the application-specific standards toward better safety.

Be it primary fitments such as original equipment manufacturers, secondary fitments or the service segments, it becomes mandatory to follow the stringent rules of safety while selecting the frictionmaterial brake product design, whether it is a brake pad/liner/or a clutch facing.

Care should be taken for selecting materials that are not hazardous because hazardous materials can generate dust which will lead to severe physiological disorders on prolonged continuous exposure.

Hence it is necessary that regulations of the government and the authorities concerned be strictly adhered to. The rules prescribed by the respective agencies have to be strictly adhered to in order to avoid health and other environmental hazards.

Brakepad safety procedure for secondary market as a sample is explained here below, which is an assessment for safety, as per a legislation adopted in a region. Similar procedures have to be adopted taking into account the local and global legislations in force from time to time for brake liners/pads and for other brake friction material products. Strict compliance of the same is important for effective, safe friction material usage in any application.

Safety of Brake Pads Based on ECE90 Safety Index (ECE 90^{Si})

The purpose of ECE 90^{si} is to apply the safety index procedure to compare relative safety of disk brake pads. The compulsory specifications determine the minimum requirements for brake pad safety applied to original equipment and aftermarket applications as a secondary or service fitment. Consumer expectations are ever changing and more demanding. Drivers expect the brake system to stop the vehicle under any possible condition. Compulsory specifications are given, with fade indices under varying conditions, along with key safety and environmental considerations to determine overall safety of a brake pad.

The scope of the index given here is based on International quality standard for component manufacturing (ISO/TS 16949), International health and safety standards (ISO14001/168001), dynamic friction, initial cold and hot performance, and fade characteristics (based on AMS test schedule adopted for dynamometer testing).

It broadly includes six key factors that are used to determine the index.

1. Consistency of Supply—Quality Accreditation TS 16949.

   The internationally recognized quality accreditation for automotive component manufacturers is the ISO/TS 16949. This important certification ensures that the manufacturing facility has all the necessary procedures in place to consistently produce a safe critical component.

   Conformance to minimum physical compulsory specifications, based on The United Nation Regulation for replacement brake pad assemblies. The regulation requires that all brake pads comply with minimum standards for shear strength, cold compressibility, and hot compressibility. Shear is the force required to detach the friction material from the backing plate. The specification is minimum 2.5 N/mm^2. Compressibility is that amount the pad will compress by when subjected to maximum pedal pressure. The specification for cold compressibility is maximum 2 % and for hot compressibility (at 400 °C) it is maximum 5 %. Products not conforming to above standards are deemed to be unsafe.
2. Conformance to Compulsory Dynamic Testing—Compulsory Specification as per Standards. The specification given here is based on the United Nations Regulation 90. There are three elements to this test.

   a. The first element of the test is to determine the pressure sensitivity of the brake pads. This is done by first determining the reference pressure required for a deceleration of 5 m/s^2 from the speed of 80 km/h, and, drawing theoretical pressure–deceleration graph. The deceleration at incremental pressures from 1.5 to 10 mpa is then measured. The specification is a maximum deviation of ±15 % when compared to the theoretical pressure—deceleration graph. The lower the variation, the more consistent the pad performance at different pressures will be. The result from three to five batches must be used to determine the rating.

b. The second element of the test is to determine the speed sensitivity of the brake pads. This is a measure of how consistently the brake pad performs when braking from speeds of 75, 120, and 160 km/h. The specification is that deceleration at higher speeds must not vary by more than ±15 % to that recorded at the lowest speed. The higher the variation, the greater the adjustments with respect to pedal pressure that the driver will need to make to obtain the same rate of deceleration. Results from all five batches must be used to determine the rating.
c. The third element of the test is to determine the hot fade characteristics of the brake pads. The specification is that when the pads reaches high temparatures (up to 450 °C) then the deceleration must not be less than 3.5 m/s^2. Also the greater the variation of the deceleration, the more inconsistent the brake pad will be when braking at high temperatures. Results from three to five batches must be used to determine the rating.

3. Conformance to Health and Environmental Requirements.

   Asbestos has been banned internationally. Bills SB 6557 and S346 passed in USA and California, respectively, require that copper content in excess of 0.5 % be banned by year 2025. Copper brake dust washes into the groundwater system and contaminates it. Companies that have ISO 14001 and ISO 18001 have procedures and practices in place that safeguard people and the environment. Manufacturers showing better compliance to all of the above will clearly have a safer product in terms of environmental health and safety.
4. Initial Cold and Hot Performance Characteristics of Brake Pads.

   While it is recommended good practice to bed-in brake pads before expecting desired braking performance, many users often do not follow correct bedding—in procedures. Therefore, if the pads take long to bed-in to have low friction during initial cold and hot applications, performance will be less than optimum. Newer generation friction materials and innovative processing technologies have generally overcome this problem, making for a safer product. The average coefficient of friction of the first three applications of the bedding-in cycle is used to determine the initial cold performance. The average coefficient of friction of all ten stops during "the hot bedding—in cycle" is used to determine initial hot performance. The bedding-in procedure taken here for reference is specified in SANS601 as is specified in United Nations Regulation 90. A friction value coefficient of 0.30 μ is deemed to be an acceptable level for initial cold and hot performance (80 % of lower limit of compulsory specification). Results from five batches must be used to determine the rating.
5. Fade Characteristics of Brake Pads (AMS Test).

   The AMS test (European Auto Motor Sport) is a widely accepted test used to determine the fade characteristics of a brake pad. It requires ten consecutive stops from 100 km/h with acceleration after each stop based on vehicle manufacturer's data. The ECE 90 test using an inertia dynamometer is done at speeds of 60, 80, 100, and 120 km/h which are the legal speed limits in most of the countries. Five stops are performed at 120 km/h so that unrealistically high temperatures are not attained.

6. Safety Index rating with "data recording and assessment form" are to be assessed and complied with.

Similarly different countries that have their own legislations with index and procedures for pad/liner and related materials with local and global legislations integrated which needs to be complied for brake liners/brake pads.

Safety of BFMC Sample as Stipulated in the Automotive Regulations Index. Safety Index Rating

Safety Index for Brake pad Specimens: $ECE90^{si}$

Procedure for Safety Index has been brought forward to determine safety of brake pads based on ECE90 Safety Index ($ECE90^{Si}$). Application of safety index to compare relative safety of disk brake pads as a sample procedure is given here. The compulsory specifications which determine the minimum requirements is enumerated here for brake pad safety. Consumer expectations are ever changing and more demanding day by day. Drivers expect the brake system to stop the vehicle under all possible conditions. Therefore this indexing measures on brake pad safety using compulsory specifications, fade indices under varying conditions, and key safety and environmental considerations will determine the overall safety of a brake pad.

Requirements of testing audit registration and marking requirements for leaf-mark registration Scheme (LMRS) services by the National Science Foundation NSF international which covers the requirements of SAE J2795 Dec 2011 for measurement of Copper and other elements in Brake Friction materials and SAE J866 Jan 2012 for revised Friction Coefficient Identification and Environmental marking system for brake linings.

Third parties are to follow the designated procedures and maintain the quality accuracy and ISO17025 accreditation of testing services in accordance with the current accepted applicable standards.

The index provided is based on SA legislation (Government Gazette No. 33897 Notice No. 1228), international quality standard for component manufacturing (ISO/TS16949), International health and safety standards (ISO 14001/18001), dynamic friction, initial cold and hot performance, and fade characteristics (based on AMS test schedule adapted to dynamometer testing).

Refer attached safety index form—Table 1.

Refer attached data recording and assessment form—Table 2.

Table 1 Safety index form—a model for illustration

100 point safety index: ECE90[si]	Rating	Scale					
Criteria	Max	Scale	0	1	2	3	4
		Scale for ISO TS16949	0	6	8	10	12
1 ISO TS16949 or equivalent	12	Y/N	No	–	IP	–	Yes
2.1 Enviromental health and safety: ISO 14001	4	Y/N	No	–	IP	–	Yes
2.2 Enviromental health and safety: ISO 18001	4	Y/N	No	–	IP	–	Yes
2.3 Enviromental health and safety: Copper	4	<0.5 %	>7.5 %	7.5–5.1 %	5.0–2.6 %	2.5–0.6 %	≤0.5 %
3 Cold shear (SANS 20090)	4	2.5 N/mm^2 Spec = 13.5 kN	<100 %	–	–	–	≥100 %
4.1 Compressibility cold (SANS 20090)	4	<2 %	>2.0 %	–	–	–	≤2.0 %
4.2 Compressibility hot (SANS 20090)	4	<5 %	>5.0 %	–	–	–	≤5.0 %
5.1 Pressure sensitivity SANS 601 (average result)	4	<0.75 m/s^2 bet 2 and 6 m/s^2	>1.00	1.00–0.76	0.75–0.51	0.50–0.26	≤0.25
5.2 Pressure sensitivity maximum result	4	<0.75 m/s^2 bet 2 and 6 m/s^2	>1.00	1.00–0.76	0.75–0.51	0.50–0.26	≤0.25
5.3 Speed sensitivity SANS 601 (average result)	4	±15 %	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
5.4 Speed sensitivity maximum result	4	±15 %	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
5.5 Fade SANS 601 (average result)	4	SANS 601 > 3.5 m/s^2	<3.5	3.5–3.8	3.9–4.2	4.2–4.5	>4.5
5.6 Fade SANS 601 maximum variation	4	–	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.1 Bedding-in cold friction (average result)	4	0.3 amu (average of 9 results)	<0.30	0.32–0.34	0.35–0.37	0.38–0.40	0.41–51

(continued)

Table 1 (continued)

100 point safety index: ECE90[si]	Rating	Scale					
Criteria	Max	Scale	0	1	2	3	4
		Scale for ISO TS16949	0	6	8	10	12
6.2 Bedding-in Hot friction (average result)	4	>0.3 amu (average of 30 results)	<0.30	0.32–0.34	0.35–0.37	0.38–0.40	0.41–51
6.3 Average stopping distance at 60 km	4	10 stops 60 km/h to 0 using MFDD of 9 m/s^2	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.4 Stopping distance % variation at 60 km	4	–	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.5 Average stopping distance 80 km	4	10 stops 80 km/h to 0 using MFDD of 9 m/s^2	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.6 Stopping distance % variation at 80 km	4	–	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.7 Average stopping distance at 100 km	4	10 stops 100 km/h to 0 using MFDD of 9 m/s^2	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.8 Stopping distance % variation at 100 km	4	–	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.9 Average stopping distance at 120 km	4	5 stops 120 km/h to 0 using MFDD of 9 m/s^2	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
6.10 Stopping distance % variation at 120 km	4	–	>20 %	20–16 %	15–11 %	10–6 %	≤5 %
Total points	100	–	–	–	–	–	–
Rating	–	–	–	–	–	–	–

Rating A = 80–100, B = 70–79, C = 60–69, D = 50–59

Table 2 Refer attached data recording and assessment form

Endorsement	Recommendation	
No	Increase overall weighting and include customer ppm when doing assessment	
Yes	Production and field rejects disposal mechanism to be evolved for the future	
Yes		
Yes	Fine nickel and titania as a substituent for copper will improve the wear	
Yes	Include hot shear JASO C437-76 test standard. Also look at 500–600 °C separation	
Yes	Can address high speed judder	
Yes	Can address high speed judder	
Yes	Check on dyno with specific tests with validation every 3 months	
No	Formulation designer to be consulted, improved to scale 4 after validation	
No	Rating of 3, 2 to be improved to 4 through design alteration. Look at the rotor metallurgy	
No	Rotor micro/Macro hardness and assay	Chemical assay after formulation design change
No	Ref pt8. Also recommend wet fade evaluation as well JASO C406-74 test standard	
Yes		
No	Please refer general motors bedding in schedule and adopt its versatility	
No	Please follow general motors bedding in schedule meant for GM models, versatile	
Yes	Scale 3, 4 to be sustained	As it services 90–95 % of the braking needs
Yes	Scale 3, 4 to be sustained	As it is meant for larger population of the vehicle
Yes	Scale 3, 4 to be sustained and other pads to be eliminated	
Yes	Larger population on the highway users	
Yes	Recommend also use Daimler Chrysler AMS test method	
Yes	Scale 4 recommended	
Yes	Scale 4 recommended	
Yes	Scale 3, 4 to be sustained other pads to be eliminated	

Current Compulsory Performance Specification.

Environmental heavy metal copper legislation (USA bill SB6557 California bill SB346) and NSF (LMRS) Leaf Mark Registration Service introduced in USA with requirements stipulated above.

Constituent requirements for Level A, B, C are stipulated below:

	A	B	C
	% by weight		
Asbestiform fiber	≤0.10	≤0.10	≤0.10
Cadmium and its compounds	≤0.10	≤0.10	≤0.10
Chromium VI salts	≤0.10	≤0.10	≤0.10
Lead and its compounds	≤0.10	≤0.10	≤0.10
Mercury and its compounds	≤0.10	≤0.10	≤0.10
Copper	–	0.5–5 %	≤0.5 % (N level)

AMS test—Internationally accepted test (Fig. 1).

Index weighting	–
Quality	12
EHS	12
Compulsory specifications	36
Initial cold and hot performance	8
Fade	32
–	100

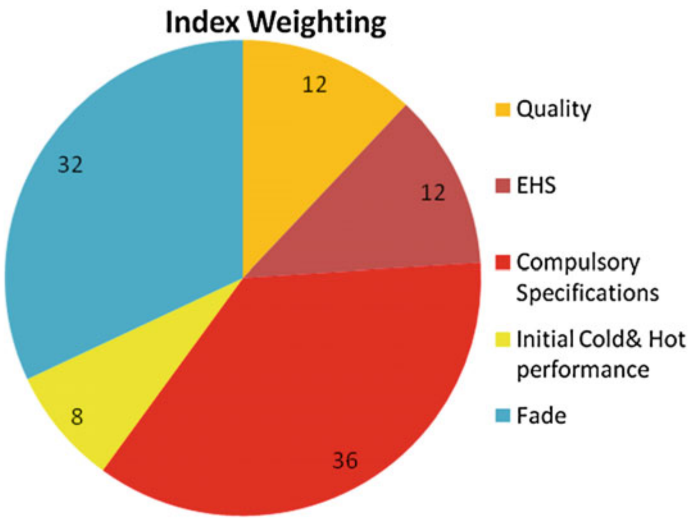

Fig. 1 Safety index rating

A model of the endorsements done for a brake pad with recommendations are given in the Table 2.

DOT Edge Codes with Coeffecient of Friction at 250 °C and at 600 °C with Fade Probability is given below:

Chart with Definitions of Different DOT Automotive Friction Edge Codes

DOT edge code	Coeffecient of friction	Fade probability
HH	0.55–0.65	Carbon–Carbon only glow at about 3,000 °F
GG	0.45–0.55	Very rare
FF	0.35–0.45 at both temperatures	0–22 % fade at 600 °F
FE	0.25–0.35 at 250 °F 0.35–0.45 at 600 °F	26–44 % fade at 600 °F
EE	0.25–0.35 at both the temperatures	0–25 % fade at 600 °F

The last two letters with the lining/pad numbers identify the material as hot and cold coeffecients of friction. Based on the above chart one should decode in brake parts catalogue to determine whether it will suit a particular vehicle model based on the requirements.

Qualifying Simulated Tests on Dynamometer and on Vehicle, Followed Worldwide on Brake Systems Integrated with Brake Pads, Liners and Clutch Friction Members

AMS high speed fade
BEEP using SAE J2430
Brake torque variation—BTV
CTA-FMVSS 121 static torque capacity
Drum-in-hat performance
Dry friction clutch durability
Dry friction clutch performance
DTV generation and correction
D 465—test prescription for brake pads
ECE R13 type approval for categories N and O
ECE R90 type approval categories M, N and O
FMVSS 105 and 135 simulations
FMVSS 121D-RP628 qualification
ISO 11157-ECE R13 performance
JASO C406 passenger car brake performance
JASO C419 caliper durability
JIS D 4411—Brake lining for automobiles
Laurel Mountain durability
LACT noise and wear simulation
Parking brake performance
Parking brake drive away

Rotor low speed shock
Rotor crack
Rotor thermal deflection
Rotor thermal fatique
Rotor thermal shock
SAE J 2115 commercial vehicles performance and wear
SAE J 2521 noise squeal matrix
SAE J 2522 AK-master
SAE J 2681 friction behavior assessment
Structural integrity test
SAE J 2707—JASO C427 wear
Tata- TMS 75054 Automotive disc brake pad (mould type)
GM, Ford motor co, DCX, TRW, Bosch, FMO, Toyota, Honda protocols

Vehicle Testing

ABS operation
AMS fade
Atlanta corrosion cycle
Brake balance
Brake pedal feel
Brake roller testing for passenger cars and commercial vehicles
Cold judder evaluation
City traffic circuit mapping for inertia dynamometer simulation cold weather noise and brake performance
Detroit city, Los angeles traffic on brake DTV, dust, noise and wear
Detroit suburban traffic off-brake DTV
ECE R13 vehicles M, N and O types approval (passenger cars to trailers and semi trailers)
ECE R58 drive-by noise
ECE R78 vehicles L type approval motorcycles
ECE R90 M and N approval (passenger and cargo)
FMVSS 105 hydraulic and electric brake systems above 3,500 kg
FMVSS 121 air brake systems
FMVSS 135 passenger car brake systems less than 3,500 kg
ISO 6597 brake performance for M and N vehicles with hydraulic brake
Laurel mountain descent
Loss Angeles city traffic wear and noise
Mountain descent for brake fluid boil (Death valley, Pikes peak, Utah)
PBBT
Special vehicle test protocols for refuse, dolly, city bus, mining, articulated and military vehicles.

The above given test schedules act as a valid preliminary screening process for qualifying BFMC materials, with the appropriate brake assembly, knuckles, in respective vehicles.

Qualifying areas for servicing the original equipment fitments (OE) for passenger car are classified under AMECA, DTV, and wear classifications.

For original equipment service segments it is classified under Light duty truck-SUV with BEEP and friction behavior testing.

For secondary fitments or aftermarket, medium duty truck, commercial vehicle components are tested for ECE and NVH. FMVSS and performance for servicing the overseas segments in the secondary market in-vehicle testing.

For the sample and component-level testing the following are tested for:

Dry Friction Materials

AK compressibility
AK thermal conductivity
AMECA edge code certification
Chase speed sensitivity
Chase pressure sensitivity
Chase temperature sensitivity
Chase wear and FAST,
ISO 6310 compressibility
ISO 6312 shear strength
ISO 6314 corrossion and contamination resistance
Low pressure wear—rotor kindness
SAE J160 swell and growth
SAE J2468 compressibility
SAE J840 adhesive strength
SAE J 661 friction quality control

Component Testing

ASTM B 117 corrossion
Belgian–bumps durability
Caliper drag measurement
Contaminated environment durability
Cyclic corrosion with or without dynamic brake applications
ECE R13 air actuators
ECE R13 spring brakes
ECE R 90 draft type approval for rotors and drums
JASO C 448 comprehensive caliper performance
Natural frequency and damping
Shaker table based durability
SAE J 1469 air brake actuator
SAE J 1462 automatic slack adjuster
SAE J 2530 sheet certification for cornering fatique
Rotor mapping for UTV
Torque flex durability

Wet Friction Materials and Clutches

SAE J 2487, 3600 rpm stepped power test
SAE J 2488, 6000 rpm stepped power test
SAE J 2489 Durability test
SAE J 2490, μ-PVT performance test