Selection of composite material for disk brake by using MCDM tool and techniques: An comparative Approach

[1]Prof.R.K.Pohane, [2]Dr. S.C.Kongare, [3]Prof.S.P.Daf

[1]Ph-D Scholar, [2]Hod(Mech. Engg.) A.S.Polytechnic, Wardha, [3]Asst.Prof. P.B.C.O.E. Nagpur

[1]raj.pohane@gmail.com, [2] suhas_kongare@rediffmail.com., [3]shailu_daf@rediffmail.com

Abstract:

The purpose of friction brakes is to decelerate a vehicle by transforming the kinetic energy of the vehicle to heat, via friction, and dissipating that heat to the surroundings. Automobile braking systems normally use brake discs of steel or grey cast iron, which are then paired with composite organic brake pads. The essential propertyes of brake materials are Good Compressive Strength, Higher Friction Coefficient, Density, Light Weight, Good Thermal Capacity, Optimum Hardness, Economically Viable. In this research the alternate materials for automobile brake applications with special attention to titanium composites has been done. Redesigning of the braking system by substitution of titanium base alloyed and compare it with tradictional cast iron by appling the MCDM tool and techniques (PROMETHREE).

Keyword: *Disc Brake, Titanium Composites, Material Selection, PROMETHREE*

I. Introduction:

The main purpose of decelerating of vehicle is done by frictional element called brake, in which the kinetic energy gets converted in to heat which results in the damaging the disc as well as friction pads and ultimately lowering the life of braking system. Brake is not only required in performance but also to suit the safety purpose. The finite element method provides the optimal calculations regarding the stress developed in the friction area.(1,11) The assembly of disc brake generally consists of brake disc, caliper, brake pads as a friction material and counter body.(3) The brake material used have some additional requirement to be fulfilled such as minimum wear rate, less noise, stable friction, anticorrosive, easy for maintenance and low cost too.(9) Now days there are so many different components which can be used for braking purpose. The new materials with their own unique combination, still performing and proving themselves better than the previous material used. The braking system is a vital safety component of ground based transportation systems, and the structural materials used in brakes have to fulfill a combination of functions.(2) They must be dependable, durable, corrosion resistant, structurally sound, and economically viable.(4,6) Two general types of brake designs are currently used on heavy trucks: (a) drum brakes in which curved contact surfaces ('shoes') are forced outward against the inner diameter of a circular drum, and (b) disc brakes in which flat pads are clamped against a circular rotor that is attached to the wheel hub. Disc brakes are commonplace on automobiles and on some types of buses and trucks. The rotor/pad design of disc brakes tends to exhibit better resistance to fade (the decrease in friction when the brake temperature rises too high) than do drum/shoe type brakes.

II. Brake friction material

The five main component of brake pad are

1) reinforcing fibers
2) binders
3) fillers
4) frictional additives
5) Abrasive

1. Reinforcing fiber:-

The purpose of reinforcing fibers is to provide mechanical strength to the friction material recent research had shown that braking load is actually carried by tinny plateaus that rise above the low lands of friction. These pleteaus are formed by the reinforced fibers surrounded by the softer compact components therefore the importance of reinforcing fiber in friction material cannot be under estimated. Friction material typically used a mixture of different types of reinforcing fiber with complementary properties.

2. Binders

The purpose of binder is to maintain the brake –pad structural integrety under mechanical and thermal stresses. It has to hold the component of brake pad together and to prvent its constituents from clumbing apart. the choice of bindres for a brake pad is an important issue if it does not remain structurally intact at all times during the braking operation. The other constituent such as reinforcing fiber or lubricant will disinttrigate therefore it has to have a high resistance . For this reason epoxy and silicon modified resins would generally be ideal as binder for most braking application.

3. Fillers:

Filler in a brake pad are present for a purpose of improving its manufacturability as well as to reduce overall cost of the brake pad. Filler while not as a critical as other component such as reinforcing fibers play an important role it modifying certain characteristics of brake friction material. The actual choice of filler depend on the particular component in friction material as well as type of friction material

4. Frictional additives

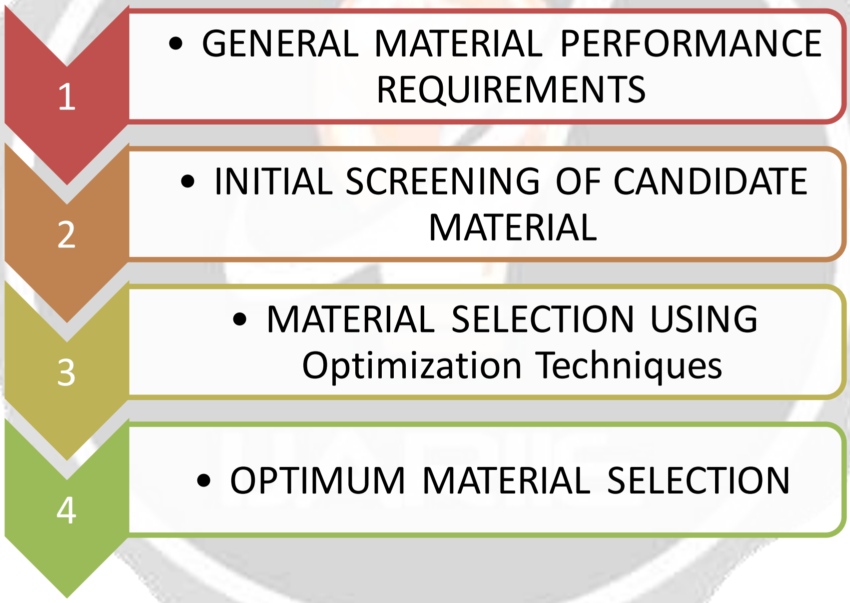
Frictional additives are components added to brake friction materials in order to modify coefficient as well as wear rate. The main frictional additives are lubricants which decrease the friction coefficient and wear rate. The main purpose of lubricant is to stabilize the developed friction coefficient during braking. Particularly at high temperature. Common used lubricant include graphite and various metals sulphide.

5. Abrasive:

The abrasive in friction material increase the friction coefficient while also increase the rate of wear of counter face material. They remove iron oxide from the counter friction material as well as other undesirable surface film formed during the braking however friction material with high abrasive content exhibit a greater variation of friction co efficient it resulting in instability of braking torque. Abrasive are hard particles of metal oxide and silicate. The abrasive have to be hard enough to at least abrade the counter friction material which is typically cast iron. Few commonly used abrasives are:

III. Material selection method.

Fig.01 Material selection method.



IV. 1. General Material Performance Requirements

A. Good compressive strength.
B. Higher friction coefficient.
C. Wear resistant.
D. Light weight.
E. Good thermal capacity.
F. Optimum hardness.
G. Economically viable.

2. Initial Screening Of Candidate Material

1. Cast Iron:

Metallic iron containing more than 2% dissolved carbon within its matrix (as opposed to steel which contains less than 2%) but less than 4.5% is referred to as gray cast iron because of its characteristic color. Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, gray cast iron), is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. It minimizes distortion in machining; provide good wear characteristics, damping vibration and resist cracking in subsequent use.

2. Ti6Al4V, Ti-6Al-4V

Ti 6-4, is the most commonly used alloy. It has a chemical composition of 6% aluminum, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen , and the remainder titanium. It is significantly stronger than commercially pure titanium while having the same stiffness and thermal properties (excluding thermal conductivity, which is about 60% lower in Grade 5 Ti than in CP Ti). Among its many advantages, it is heat treatable. This grade is an excellent combination of strength, corrosion resistance, weld and fabricability. "Applications: Blades, discs, rings, airframes, fasteners, components. Vessels, cases, hubs, forgings. Biomedical implants."(4,6)

3. TI-6242

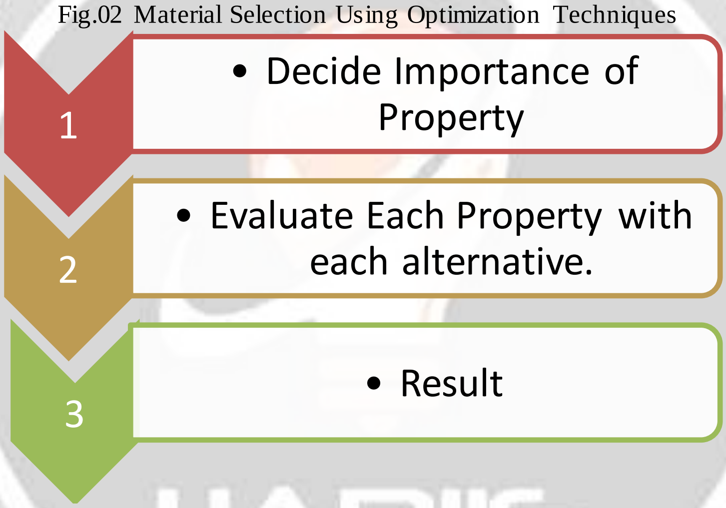
It consist of 6% Aluminum, 2 % Molybdenum, 88% Titanium and 4% Zirconium, It is also known as Ti 6-2-4-2, is a near alpha titanium alloys known for its high strength and excellent corrosion resistance. It is often used in the aerospace industry for creating high-temperature jet engines and the automotive industry to create high performance automotive valves. It finds application in High-temp jet engines, Gas turbine compressor components (Blades, Discs, Spacers and Seals) High performance automotive valves, Sheet metal parts in afterburners and hot airframe sections.(12)

4. CermeTi composite (WTiC)

New composited material produced by Dynamet Corp., Burlington. CermeTi composite (WTiC) Particle reinforced composite produced by cold plus hot isostatic Pressing (CHIP); 7.5 wt% W mixed with an composite of Ti-6Al-4V containing 7.5 wt% TiC .(14,15)

3. Material Selection Using Optimization Techniques

Fig.02 Material Selection Using Optimization Techniques



The PROMETHEE (Preference Ranking Organization method for Enrichment Evaluation) is a multi-criteria decision- making method developed by Brans et al. (Brans and Vincke 1985; Brans et al. 1986)(). It is a quite simple ranking method in conception and application compared with other methods used for multi-criteria analysis.

Table No.01 Importance of Property

Properties	Value	Importance
Good Compressive Strength	MIn	2.2
Higher Friction Coefficient	max	3.2
Density	max	1.5
Light Weight	min	0.9
Good Thermal Capacity	max	1.0
Optimum Hardness	max	0.8
Economically Viable	min	0.4
Total		10

It is well adapted to problems where a finite number of alternatives are to be ranked according to several, sometimes conflicting criteria (Albadvi et al. 2007). The evaluation table is the starting point of the PROMETHEE(1) method. In this table, the alternatives are evaluated on the different criteria. The implementation of PROMETHEE requires two additional types of information, namely : (1) Information on the relative importance that is the weights of the criteria considered. (2) Information on the decision-makers preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion.

The information on the relative importance that is the weights of criteria (wj) can be determined by various methods (Nijkamp et al. 1990; Mergias et al. 2007).Numerical scale method is used to determine the criteria weights in this study. After calculating the weights of the criteria, the next step is to have the information on the decision maker preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion. The preference function (Pj) translates the difference between the evaluations obtained by two alternatives (a and b) in terms of a particular criterion, into a preference degree ranging from 0 to 1. Let Pj(a,b) be the preference function associated to the criterion fj(i).

Table No.02 Evaluate Each Property with each alternative.

		Good Compressive Strength	**Higher Friction Coefficient**	**Density G/Cc**	**Light Weight**	**Thermal Capacity (Thermal Conductivity) *W/(M K)***	**Optimum Hardness**	**Economically Viable**
1	**Cast Iron**	1293	0.41	7.2	NO	5.5	97	YES
2	**Ti-64**	950	0.342	4.3	Yes	6.7	36	No
3	**Ti-6242**	1080	0.32	4.54	Yes	7.1	34	No
4	**Cermeti Composite (Wtic)**	1022	0.31	4.68	Yes	6.57	40	No

$\mathrm{Pj}(\mathrm{a,b}) = \mathrm{Gj}[\mathrm{fj}(\mathrm{a}) - \mathrm{fj}(\mathrm{b})]$ ... (1)

$0 \leq \mathrm{Pj}(\mathrm{a,b}) \leq 1$ ....(2)

Where Gj is a non-decreasing function of the observed deviation (d) between two alternatives a and b over the criterion fj. In order to facilitate the selection of a specific preference function, six basic types were proposed. These include “usual function”, “linear function”, “U-shape function”, “V-shape function”, “level function” and “Gaussian function”. Preference “usual function” which is equal to the simple difference between the values of the criterion fj for alternatives ‘a’ and ‘b’ is adapted in this paper because of its simplicity. PROMETHEE permits the computation of the following quantities for each alternative a and b:

$\pi\ (\mathrm{a,b}) = \sum_{\mathrm{j=1}}^{\mathrm{k}} \mathrm{Pj}(\mathrm{a,b})\mathrm{Wj}$ ....(3)

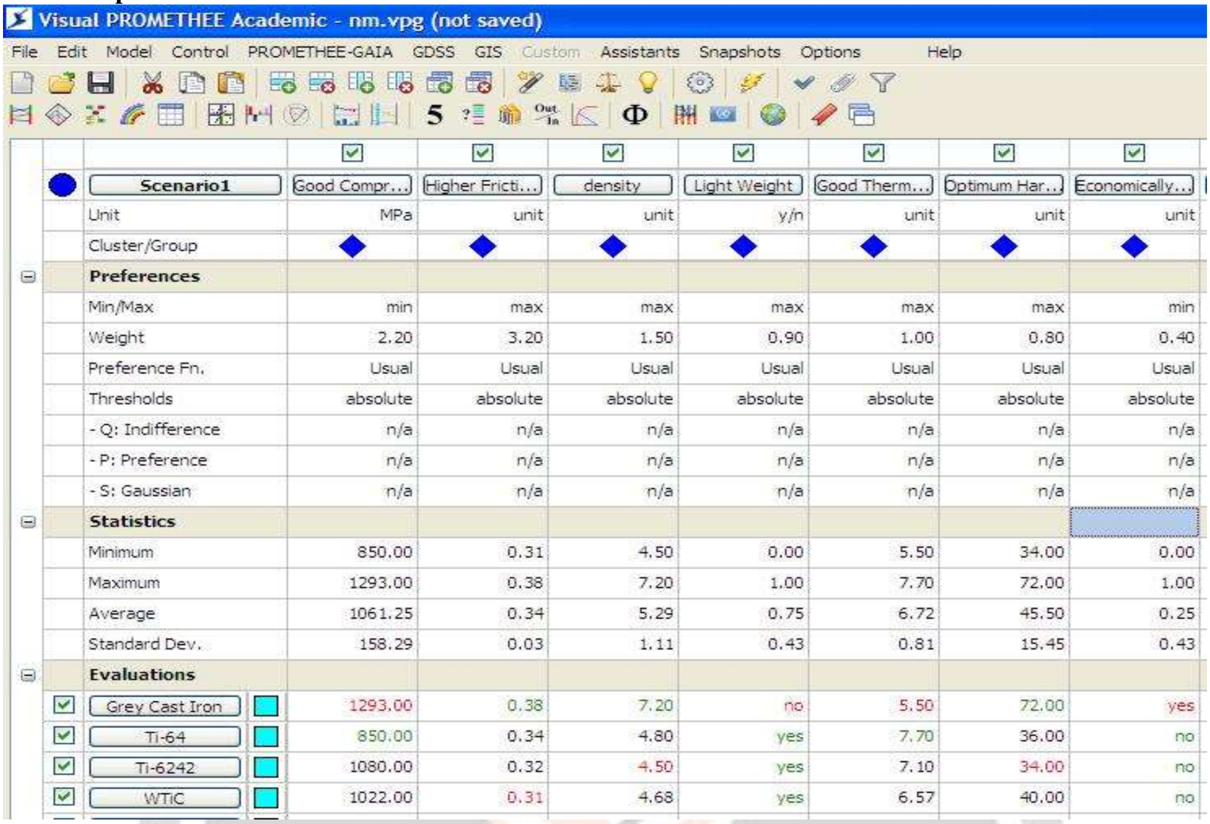
$\varphi^{+}(\mathrm{a}) = \sum_{\mathrm{x}\in \mathrm{A}} \pi(\mathrm{x,a})$ ….(4)

$\varphi^{-}(\mathrm{a}) = \sum_{\mathrm{x}\in \mathrm{A}} \pi(\mathrm{a,x})$ ....(5)

$\varphi(\mathrm{a}) = \varphi^{+}(\mathrm{a}) - \varphi^{-}(\mathrm{a})$ ....(6)

For each alternative a, belonging to the set A of alternatives, π (a, b) is an overall preference index of a over b. The leaving flow φ+ (a) is the measure of the outranking character of a (how a dominates all the other alternatives of A). Symmetrically, the entering flow φ− (a) gives the outranked character of a (how a is dominated by all the other alternatives of A). φ (a) represents a value function, whereby a higher value reflects a higher attractiveness of alternative a and is called net flow. PROMTHEE provides a complete ranking of the alternatives from the best to the worst one using the net flows.

4. Optimum Material Selection:



Scenario1	Good Compr...	Higher Fricti...	density	Light Weight	Good Therm...	Optimum Har...	Economically...
Unit	MPa	unit	unit	y/n	unit	unit	unit
Cluster/Group							
Preferences							
Min/Max	min	max	max	max	max	max	min
Weight	2.20	3.20	1.50	0.90	1.00	0.80	0.40
Preference Fn.	Usual	Usual	Usual	Usual	Usual	Usual	Usual
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics							
Minimum	850.00	0.31	4.50	0.00	5.50	34.00	0.00
Maximum	1293.00	0.38	7.20	1.00	7.70	72.00	1.00
Average	1061.25	0.34	5.29	0.75	6.72	45.50	0.25
Standard Dev.	158.29	0.03	1.11	0.43	0.81	15.45	0.43
Evaluations							
Grey Cast Iron	1293.00	0.38	7.20	no	5.50	72.00	yes
Ti-64	850.00	0.34	4.80	yes	7.70	36.00	no
Ti-6242	1080.00	0.32	4.50	yes	7.10	34.00	no
WTiC	1022.00	0.31	4.68	yes	6.57	40.00	no

Fig.03 Optimum material selection

Fig.04

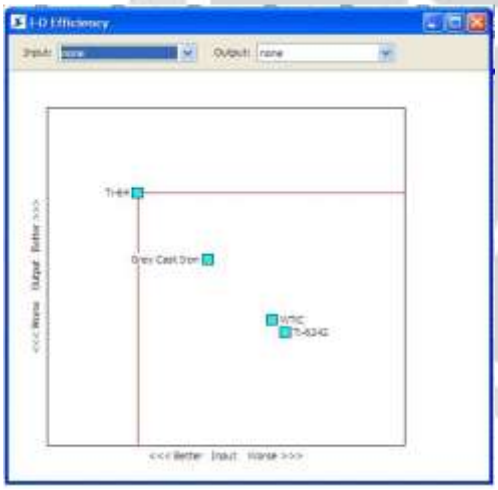


Fig.05

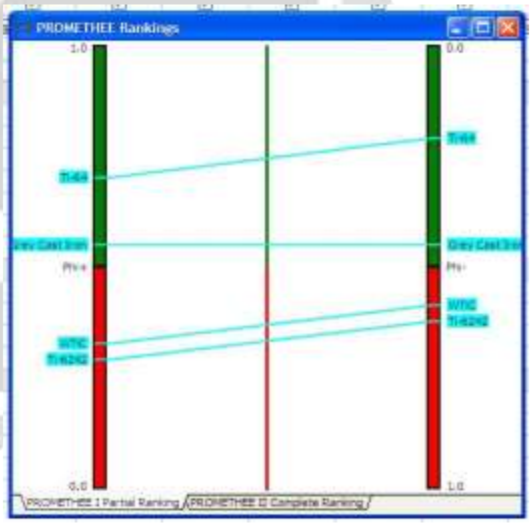
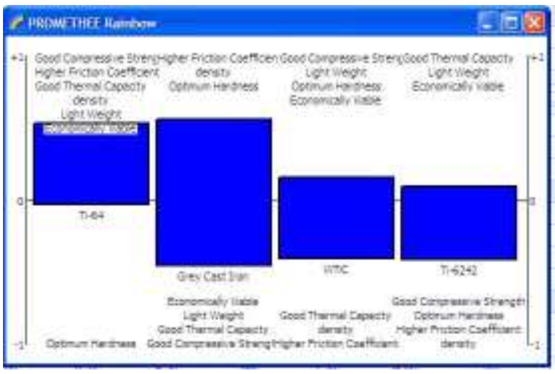


Fig. No. 06

	Input	Output	O/I ratio	Score
Grey Cast	0.1000	0.1000	1.2222	41.47
Ti-64	0.4933	0.4933	2.9474	100.00
Ti-6242	-0.3333	-0.3333	0.5000	16.96
WTiC	-0.2600	-0.2600	0.5873	19.93

Fig.No.07



V. CONCLUSION

The material selection methods for the design and application of automotive brake disc are developed. Functions properties of the brake discs were considered for the initial screening of the optimum material using PROMTHREE (Multi Criteria Decision Making Tool And Techniques). The PROMTHREE method showed highest performance index for Ti-64 material and identified as an optimum material among the Alternative materials for brake disc. The Performance Aggregated Score (Fig.06) for Ti-64 is 100, Grey Cast is 41.47, WTic is 19.93, Ti-6242 is 16.96. The PROMTHREE Rainbow show that (Fig.07) Ti-64 is Superior in Good Compressive Strength Higher Friction Coefficient, Density, Light Weight, Good Thermal Capacity, Economically Viable and lacking in Optimum Hardness. The I/O efficiency show that Ti-64 is better I/O where as Ti-6242 Worse I/O efficiency.

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