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Composite Materials with Complex Compositions used in Vehicle Brake System: a Review

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Abstract: Desirable performance requirements for vehicle brake friction materials that work in normal and especially in heavy-duty conditions should have highly physical, mechanical properties and service characteristics such as: (a) stable and high friction coefficient in various conditions, including high temperatures (b) very good wear resistant material and implicit very good durability in service; (c) good strength at elevated temperatures; (d) high specific heat and thermal conductivity; (e) high corrosion resistance; (f) smooth braking assurance, (g) reduced vibration (judder) and noise, (h) do not damage the counterface (brake disc). The brake friction materials have a complex composition that includes both metallic and non-metallic components. In this paper brake pads composite materials, typically comprising of binders, lubricating components and frictional additives, are reviewed. It is important to note that the research efforts during the years include the development of non-toxic compositions /ingredients of materials used in the transport industry (including vehicle brake system) and, if possible, to minimize their weight, while satisjyng the required characteristics for which they were designed.

Introduction

In the last decade, the worldwide trend was to obtain materials increasingly lighter and suistanable [1] at a cost as low as possible. The environmental policies are focus on products with low impact on environment, by finding solution to increase vehicle fuel efficiency and to lower gas emissions. The efforts include the development of non-toxic compositions /ingredients of materials used in transport industry and, if possible, to minimize their weight (Fig. 1), while they satisfy the required designed characteristics. The researches in this direction include the development of composites materials with complex compositions that can work in safe conditions at high specific loads and speeds [2-7].

The friction parts (brakes, clutches, etc.) from vehicle brake system are composed by a pair of materials in direct contact: the friction materials (brake pads) and the counterparts (brake disc) by which is realized the necessary fretting transmission of torsion or brake moment [4, 8].

The friction materials used in the past were high toxic asbestos or synthetic resin based and as counterparts they still use heavy cast iron disc. Nowadays, as brake friction materials we used composites with metallic (ferrous or non-ferrous base) or carbon composites, as new candidates against the older one synthetic resin based

[2-7]. Also, for reducing fuel consumption of vehicle, for conterface (disc brake) the producers use the lightweight aluminium based composites as A356/25SiCpAl MMC [9, 10] or titanium-based materials [11] and as brake pads composites they use the ferrous (iron and its alloys) and non-ferrous based materials (copper, aluminium) as matrix or ceramic (carbon) composites [2-7].

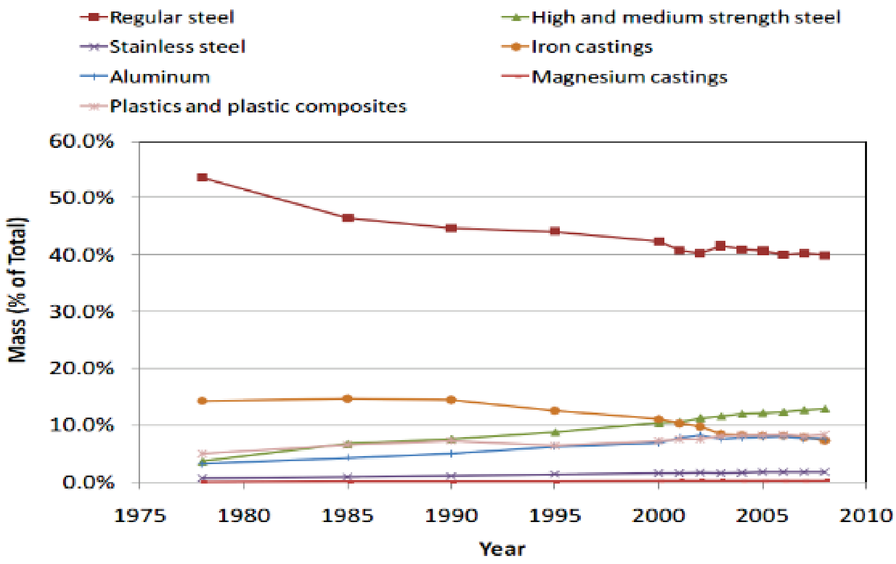

Figure 1. Vehicle Material Composition by Percent Mass [6]

History

The first reference on metal-ceramic (composites) friction materials can be found in the technical literature and belongs to the third decade of this century [3, 4].

Sintered friction materials (SFM) have found practical use until after the Second World War when it was necessary to solve the problem of oversized aircraft landing on small areas of the track, which was coupled with the need beneficial materials to realize the brake linings to withstand high temperatures up to 600-650°C [4,13].

The wider use of these materials and other fields of economic activity reached only after 1945 [3, 4, 13]. In the years 1945-1950 was performed design of a modern tram car at one of braking systems to be located based MFS seal that is produced (with minor changes) and export and currently in a range countries. In other areas of industrial activity such materials have imposed a greater extent during the years '60-'62 when they were introduced in the manufacturing process fundamental types namely: bronze-graphite materials and graphite iron materials.

During 1972-1975, in Romania, at Metallurgical Research Institute of Bucharest was studied and development of iron-based sintered friction materials (SFM) designed for aircraft brake discs, and in 1992-1994 they continuous research, in order to get appropriate new types of SFM requirements [3]. Using this friction type has gradually expanded at heavy braking systems mechanisms, in aircraft and in the electromagnetic coupling, at transmission elements and heavy transport trucks.

Although introduced in industrial production since 1965, first in the US and then in other countries [3,10-13], sintered friction materials are still highly topical, they form the subject of extensive research and patents, with increasing requirements in terms of (i) their ability to absorb and transmit energy, (ii)durability in extreme operating conditions and (iii) expanding their use in military and aerospace equipment [3-17]. Because of the need to protect trade secrets in literature was a gradual reduction in scientific and technical information about SFM, starting with the ‘80-‘85 (in particular concerning the nature of materials components) although clearly there are focused in creating the new generations of SFM with industrial applications [3, 4].

Nowadays [1, 2, 6] the researchers are concerned of the economic efficiency and environmental impact by replacing traditional materials with lightweight materials (light Al /Mg / Ti alloys or light metal or plastic matrix composites). These materials are environmentally friendly and economically efficient simply because it takes less effort (mechanical work) to accelerate / move an lightweight object more easily and therefore decrease the fuel consumption (economic benefit) or decrease gas emissions (CO_2) during life cycling phase of the vehicle. In Fig. 2 are presented a comparison of air pollution impact by replacing the cast iron brake rotors with particle reinforced aluminium matrix composite (PMMC), according with LCA study [2].

We can see that the trends indicates a better environmental performance of the PMMC rotors in comparison with traditional ones.

Materials types used as friction materials for vehicle brake system and the characteristic of their

Desirable performance requirements for vehicle brake friction materials that work in heavy-duty conditions should have highly physical, mechanical properties and service characteristics as : (a) stable and high friction coefficient (according to SAE J899a) in various conditions, including at high temperatures (b) very good wear resistant material and implicit very good durability in service; (c) good strength at elevated temperatures; (d) high specific heat and thermal conductivity; (e) high corrosion resistance; (f) smooth braking assurance (g) reduced vibration (judder) and noise (h) does not damage the counterface (brake disc) [4, 12].

Weighted comparison - air pollution

Activities / Elements	Factor	Processing	Transport	Use	Reproc.	Total
Cast iron brake rotors						
CO	0.0059	0.02	0.02	217.12	0.02	217.17
HC	1.00	0.08	0.06	368.00	0.08	368.22
NO_x	9.89	0.08	0.79	1087.79	0.08	1088.74
CO_2	32.62	0.52			0.52	1.04
PMMC brake rotors						
CO	0.0059	0.0	0.01	216.03	0	216.04
HC	1.00	0.07	0.02	366.00	0	366.04
NO_x	9.89	1.31	0.2	1087.79	0.28	1089.09
CO_2	32.62	153.97			0.39	154.36

Solid waste not included / Pollution from SiC production not included
Transport involves rough estimates

Figure 2. Impact on air pollution by replacing the cast iron brake rotors with PMMC [2].

The brake friction materials have a complex composition that includes both metallic and non-metallic components. Also, brake pads typically comprise the binders, the lubricating components and frictional additives [4, 8]. The purpose of a binder is to maintain the brake pads' structural integrity (to hold the components of a brake pad together) under mechanical and thermal stresses. The binders could be synthetic resins, metallic ingredients or mixture of metallic and organic ingredients. The synthetic resin based friction materials is cheap to produce, but it has as a disadvantage that, in high-energy braking applications (operating up to 370–450◦C) [4] when the induced temperature can be high enough, the material decomposes or breaks down. As a result, the friction coefficient with the brake disc is compromised leading to decreasing road safety [8, 9]. In case of using metallic binders as iron, cooper, aluminum and their alloys, we can improve the wear resistance, thermal diffusivity and strength of the brake friction material. The lubricating components have the objective to: (i) stabilize the developed friction coefficient during braking, particularly at high temperatures, (ii) decrease wear of counterparts and also (iii) increase grippe resistance [2–15].

The frictional additives, determine the frictional properties of the brake pads. Also the frictional components increase and stabilize the friction coefficient values, respectively increase the wear resistance [2–13].

Cooper and Cu alloys are chosen mainly to (i) improve the thermal conductibility at the friction interface (ii) good mechanical strength and (iii) for sustaining the level of the coefficient of friction at elevated temperatures by producing copper oxides at the friction interface [2,9]. Other advantages include very good compressibility and easy to sintering. As copper alloying elements are Sn, Zn, forming solid solutions with copper during sintering process in the presence of liquid phase. Copper powders obtained by electrolysis of aqueous solutions are the most widely used due to their advantages compared to other methods: high purity powder, good technological characteristics associated with good compressibility and sintering behavior. The used dimensions of the copper particles are up to 150 micrometers and the specific shape of electrolytic copper powder is the dendritic ones. Electrolytic copper powder obtained has the dendritic particle form (favorable to the inclusion of non-metallic components with fine grain at homogenization process). The major disadvantage of this material is that it is a poor and expensive material and presents high specific weight.

Aluminum or Al alloys are used in frictional materials or disk brake because of lightweight and good thermal diffusivity [13,17–19]. Both nonferrous Al and Cu composites have high specific capacity, corrosion resistance and compatibility with SiC reinforcements as reinforcements [20, 21] but these composites have been used at low loads (<100N) and low sledding speeds (<4 m/s). At heavy duty conditions, the temperature increase on the surface of the Al or Cu composites, and become soft, and in the extrem case could melt, with undesired consequences on strength speed of the materials, and for thar reasons, these non-ferrous matrix are not proper to use for race cars, trains, trucks or aircraft brakes (in high energy braking applications) [22, 23].

For high speed and load conditions are used ceramic composites as C/C or C/SiC composites, Ti based composites reinforced with hard ceramics materials , respectively iron/steel based composites.

The friction composite materials based on Ti or Titanium alloy has high strength at high temperature, heat resistant , resistance at abrasive wear , a high young modulus and capacity for stable retention of high friction coefficient, but is expensive [24].

The carbon based composites have low density, excellent wear resistance friction stability and high thermal stability, but they have the disadvantage to be high production costs multiple reinfilitration steps, low depositions efficiency and poor oxidation resistance above 450o C , poor surface porosity, extreme sensitivity to the humidity and temperature (implicit instability of friction coefficient), and most important, the carbon composites pollute environment caused by organic brake dust [25].

Composites with iron/steel matrix and ceramic reinforcements used like friction materials bring new possibilities in the production of wear resistant materials because they provide good wear resistance and maintain friction effectiveness at elevated temperature [4, 8, 16], they have a high melting point, high work hardening rate, better strength, weldability, machinability and in comparison for instance with Cu based composites has the low cost. Iron could be alloyed with Cu, Cu–Sn–(Zn), Ni, Mo, Al, Co, Mn, W, Cr, etc. for improving strength of the metallic matrix [4, 8–16]. Thus, at the alloying with the copper or Cu-Sn-(Zn) elements in the course of the sintering process, the liquid phase is formed. This serves to filling the voids (pores) of material and better densification of the sintered material, thereby increasing the material's mechanical characteristics. Secondly, copper contributes to increasing the thermal conductivity of the material, leading to better heat dissipation during braking. The additions of phosphorus (P) formed phosphorous eutectic at 900°C, which allows the rigid joint between the metallic and non-metallic particles at this temperature. Iron powder is obtained by water atomization of melt steel, thermo-chemical treated. The proportion and granulation of these components, was and still is the subject of numerous investigations in various countries in order to achieve the optimal characteristics of brake friction materials.

Lubricating components contribute to a smooth brake, it increases the gripping resistance and decrease wear of the material, in particular of the counterpart.

The characteristics that must accomplish the lubricating components are: (a) high capacity lubrication; (b) does not decompose complete at sintering temperatures and in environments currently used in practice. The disadvantage of using too much lubricant is that they produce decreasing of the friction coefficient of the brake system and decreasing of mechanical properties.

Among the most used solid lubricant components (solid lubricants) are: graphite, molybdenum disulfide, barium sulphate, and bismuth (less used today because it is harmful for human body). There are also used as solid lubricants, barium fluoride, calcium or zinc. Graphite has the following roles: (a) lubricant in the compaction process of powder mixture; (b) reducing any traces of existing oxides on the surface of metal powder particles;(c) basic participant at formation of skeleton of the material (in the case of iron);(d) solid lubricant in the friction process. The quality of the graphite greatly influences the properties of the friction material and the parameters of the sintering process. MoS_2 is used in high temperature solid lubricant. It reacts with oxygen at temperatures above 500°C to form the molybdenum and sulphur trioxide. This makes it suitable as a lubricant instead of graphite, under the same conditions, by chemical reaction with oxygen forming carbon monoxide, a toxic gas, polluting the atmosphere. BaS_x is recommended by some authors [4, 13] as due to its feature to ensure the stability of the friction coefficients and increased wear and gripping resistance due to the formation of a superficial film, which provides a gloss friction surface without a burr. Bismuth has low toxic effects in comparison with lead and has a low melting temperature[4, 10-13].

Friction components may have the following components: (i) high melting and dissociation temperatures; (ii) lack of polymorphic changes in the temperature range from ambient up to the sintering temperature; (iii) good mechanical strength; (iv) wettability properties to the base metal matrix or for the possibility of adhesive bonds creation with it to the consumption of mechanical work at maximum friction separation of hard particles in the metal matrix. Traditional non-metallic materials used for friction role are: SiO_2, Al_2O_3 or others oxides (simple or complex oxides), and also carbides, nitrides, silicides, or borides. SiO is a friction component that meet him in the form of natural quartz sand. Fine particles uniformly distributed SiO_2 and creates areas of discontinuity in the base network, as numerous as SiO_2 density is lower.Al_2O_3 - is a component of friction that you encounter in crystalline powder. It has stability at temperatures above 1000°C to carbon and nitrogen [3-13]

The processing of brake friction materials is realized by a diversity of methods [7, 13, 18-19] including powder metallurgy (P/M) techniques. The brake pads made of a metal matrix composite reinforced with a high content of ceramic particles are not resistant to shock and as a result, require different methods of attachment / joining of steel metal (steel backing) to give it strength [18].

As a result, iron/steel or Ti based composite friction materials has mainly a duplex structure – a sintered friction lining on a steel backing , intended to increase strength of the lining and to facilitate the assembling of the friction elements by welding, riveting or difusion process during pressure sintering , to assure a high quality brazing [18].

Today is still studying the possibility of improving adhesion of composite friction material on steel back plates. Another problem encountered when manufacturing these brake friction composites is to analyze complex phenomena and mechanisms that occur in both, manufacturing process and especially in service, during friction on surface sliding, as a result of adhesion and deformation of roughness. For that reasons, much efforts has been applied to find the mechanism for numerous friction induced phenomena, especially at atomic scale, by measuring the friction force with nanodevices. The analysis of tribological phenomena at the sliding interface becomes more complicated when a composite is involved as a sliding component, due of multiple ingredients [19].

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