

# Is Gasar Brakes Having Future?

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## INTRODUCTION

Quality and reliability of brake components are in many aspects critical for dynamic and technical characteristics and safety of vehicles. Brakes, therefore, have to satisfy very stringent requirements. Brake components operate under heavy-duty conditions (e.g. a variety of weather factors, heavy loads, etc.). At the same time, they should have the attributes of low-noise, light-weight, high friction coefficient and low manufacturing cost.

One of the most promising approaches for meeting the combination of material requirements is the development of composites with high friction properties. However, while the use of composites improves efficiency, their fabrication is difficult and expensive.

In the research, we have proposed the development of new porous composite materials, i.e., gasars to be used as matrices for metal-polymer and metal-ceramic brake components. The general manufacturing process of gasars was established recently [1], and is based on the interaction of hydrogen with metals. The method consists of gas bubble evolution from hydrogen - saturated metal melts simultaneously with the growth of metal crystals under controlled temperature - pressure conditions. By controlling the rate and direction of heat dissipation, hydrogen pressure, and concentration in the melt during crystallization, it is possible to control pore formation and develop porous crystalline materials with predetermined structures.

## BACKGROUND

Brakes are a very important part of a vehicle, which determine the safety and comfort of a driver. Vehicle brakes should be highly reliable and minimally affected by temperature, water, dust, rust or other contamination. A small amount of oil and water (as with tires) increases the lubrication action and deteriorates the brake frictional properties. However, vehicle brakes are required to operate under a wide range of conditions, from hard braking with a heavily loaded vehicle on steep downhill slopes to minimal brake usage on interstate highways. In general, brake effectiveness decreases with increasing speed. The wear and frictional behavior are amazingly complex and are characterized by non-steady-state high temperatures and high pressures.

Contact asperity flash temperatures might range from 1000<sup>o</sup>C to 1100<sup>o</sup>C [2-6]. Brake friction and wear characteristics are sensitive to brake design and lining composition effects as well as temperature, rubbing speed, pressure and prior usage history. The capability of changing vehicle speeds quickly and smoothly is the paramount task for efficient braking system. The problem is that brake components work in especially demanding conditions, i.e., environmental temperatures from – 50<sup>o</sup>C up to + 50<sup>o</sup>C, loading pressures about up to 70 kg/cm<sup>2</sup>, and speeds to 70 m/sec.

This typically results in a short brake lifetime. Improved braking systems require the following:

- high friction coefficient
- high wear resistance
- sufficient durability
- high thermal conductivity
- high resistance to jamming
- high corrosion stability
- high stability in various climatic conditions (variable humidity, high or low air temperatures, and/or aggressive gas, dust or liquids)
- low cost

There are two basic types of brake components linings as described below [2-8]:

**Organic (or molded) linings** consist of a gray-white compound of asbestos, filler materials and powdered resins. These are thoroughly mixed, formed into shape and placed under heat and pressure until a hard slate-like board is formed. The material is cut, formed into individual segments, and attached to brake shoes. Typically, the organic lining is woven from strands of asbestos and threads of other materials, and impregnated with a rubber compound. In some instances, the organic brake lining will also have fine metal wires.

**Metallic brake linings** are made mostly of sintered metals and are composed of finely powdered iron or copper, graphite and lesser amounts of inorganic fillers and friction modifiers. After thorough mixing, lubricating oil is added to prevent segregation of different materials. The mixture is then subjected to a briquetting process and compressed into the desired form.

The organic type brake lining is used almost exclusively for ordinary brake service. Under extreme braking conditions (e.g., in police cars, ambulance and sports cars), the metallic type lining is used exclusively. Under such severe conditions, the frictional characteristics of the metallic lining are more constant than those of the organic lining. However, metallic brake linings have a low initial friction and resultant hard pedal.

Currently, there are many variants of brake components, based on a combination of metal and polymeric composite materials [9-13], each of which has advantages and disadvantages. However, thus far, none meet all of the stated requirements. For example, metal brakes can work under high loads and temperatures, but are prone to wear. On the other hand, polymeric composite braking materials have good frictional properties, but cannot be used at high temperatures. The development of composite materials combining the attributes of metallic and polymeric (or ceramic) properties should result in improved brake performance. However, current braking composites are composed of sintered metal powders (e.g., iron, steel, copper, bronze), ceramic additions (e.g.,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ), and graphite as a lubricant. Such materials have good frictional and other properties, but have not demonstrated sufficient durability, especially under load.

All known technical solutions [2-54] have associated advantages and disadvantages. It would be desirable to provide discs or drums which have a low density, high specific heat, good high temperature properties, high flexural strength, stable coefficient of friction, low wear in all modes of operation, and at low cost.

As a result of the study of the current brake materials, the following essential parameters were considered as basis for the research.

- gray iron has sufficient thermal conductivity, strength, and coefficient of friction combined with high density and low cost
- graphite provides for better frictional properties
- ceramic composites have good coefficients of friction and can operate at high temperatures but are brittle and have low thermal conductivity
- carbon and silicon contribute to higher thermal conductivity
- metal matrix composites have high thermal conductivity, and low density. But, are based predominantly on aluminum or magnesium alloys which have insufficient wear resistance
- drilled designs and cooling rods help to reduce weight and improve heat dissipation
- high-friction non-metallic materials have good coefficient of friction, but low flame and heat resistance
- pores can engulf abrasive particles and improve abrasion resistance

## **EXPERIMENTAL PROCEDURES**

The specific objectives of this work were: (i) to fabricate various types of gasar matrixes for application as brake components, (ii) to study tribological and other operational properties of gasar brake components, and (iii) to show the operational advantages of using brake components in comparison with other materials.

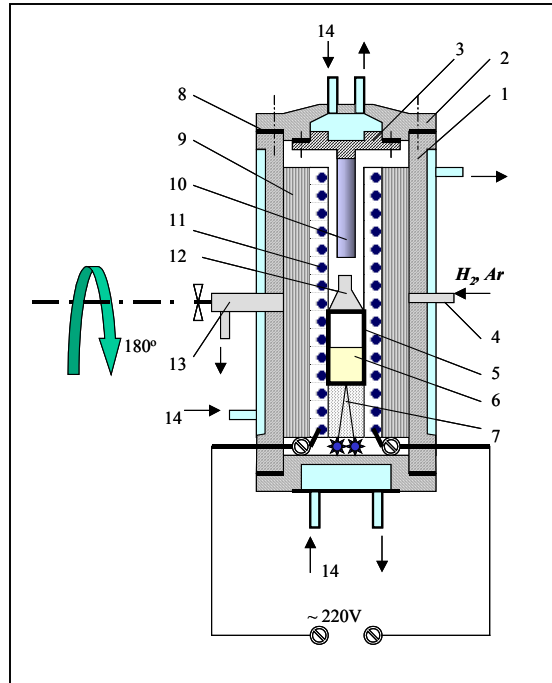
### **Fabrication of Gasar Ingots**

The main focus of the Phase I research was to create new composites for brake components based on the gasar technology. This technology results in innovative composite materials having a monolithic metal matrix and pores with smooth walls [1].

Gasar technology is novel and not known widely. This technology is based on the physical interaction of hydrogen with metals. The basis of this technology is that a metal will absorb more hydrogen in the liquid state than in the solid state. When a hydrogen-charged melt is solidified, the excess hydrogen will evolve in bubbles that may be frozen in the ingot interior. Gas bubbles nucleating at the solidification front provide the pore formation in a gasar. Their number and dimensions depend on the hydrogen content of the melt and on the pressure above the melt surface. A new casting practice was developed that enables the production of gasar porous materials with a unique pore morphology.

The principle design of the setup for producing gasars is described in [55-56]. Several variations of the experimental chamber for gasar synthesis were successfully tested.

Gasar materials can be synthesized in a high-pressure autoclave such as shown in Figure 1.



**Fig. 1 Diagram of the chamber for gasar synthesis:**

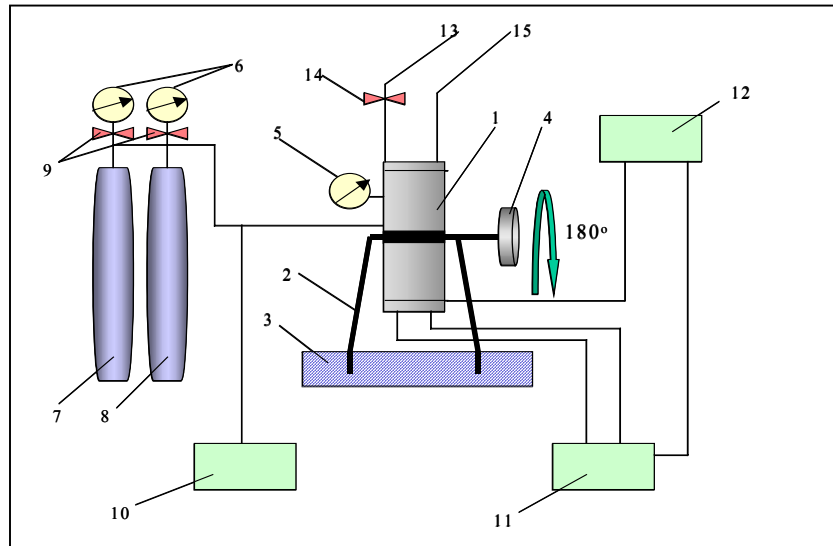
- 1- casing, 2- top cover, 3- mold water-cooled bottom, 4- gas-pressure line, 5- alumina crucible, 6- melt, 7- thermocouple, 8- gas hermetic seal, 9- metal sheets, 10- mold, 11- molybdenum heating element, 12- funnels, 13 - vacuum line, 14- water-line

The apparatus made it possible to melt metals in a crucible and to solidify them in a mold, both pressurized up to 2.5 MPa under strictly controlled proportions of hydrogen and an inert gas. This unit is supplied with several systems: power, water cooling line, vacuum line, gas pressure line, control – measurement equipment (Fig.2).

The experiments involved the use of built-up molds having walls of thin steel sheets with a refractory dressing, and a water-cooled copper chill for the bottom. With this mold design, heat is predominantly transferred from the melt axially via the bottom. Radial heat losses are minimal, for the walls possess a low heat capacity and are surrounded by gas.

The compositions of gray iron (1-3), steel (4) and bronze (5) that were selected for treatment in the gasar process are shown in Table 1. Compositions 1 and 2 are similar to industrial grades (G2500 and G3500) used for heavy-duty brake discs. Compositions 1, 2, and 3 contain nickel as it improves the mechanical properties of the components. However, the associated complicated chemical compositions of the melt hinder the formation of an ordered porous-crystalline

structure. This poses a limitation on the use of materials with complex chemical compositions in the gasar process.



**Fig. 2 Schematic of chamber's supplemental systems**

1 - chamber, 2 - fixing frame, 3 - basis, 4 - turning ring, 5 - manometer, 6 - reductor, 7 - argon high pressure cylinder, 8 - hydrogen high pressure cylinder, 9 - valves, 10 - vacuum line, 11 - power, 12 - control-measured equipment, 13,15 - water line, 14 - water valve.

The mechanism of Gasar structure formation was studied in 350g cylindrical ingots which had diameters of 35 mm. The ingots had an anisotropic structure due to the axial cooling. The experiments focused on the variation of Gasar terminal macrostructures as influenced by two process variables. These were the partial pressure of hydrogen above the melt ( $P_H = 0.5-6.0$  MPa) and the melt temperature prior to pouring ( $T_t = 1300 - 1580^\circ\text{C}$ ). The experiments were carried out in several series, so that one of these factors was varied while the other was maintained constant.

On the basis of preliminary estimations, it was determined that gasars should have a porosity of 30 to 35 percent to prevent degradation of mechanical properties while enhancing frictional properties. For practical investigation of the assumption, porous ingots were obtained under different partial pressures of hydrogen.

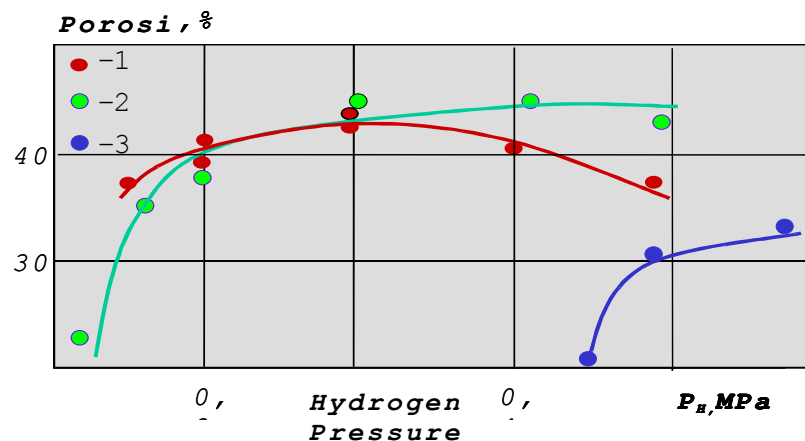
### **Description of the gasar process**

The steps associated with the preparation of porous ingots are given below:

- lumps of metal were put into a crucible
- a cylindrical mould with sheet asbestos lining was mounted on a water-cooled bottom
- funnel was installed

- the top of the chamber with the mould jointed was installed and bolted
- the vacuum line was turned on
- heaters were turned on
- at 200°C the vacuum system was disconnected and the chamber kept air-tight
- hydrogen at required pressures of 0.5 to 6.0 MPa was supplied
- the melt was heated to 1580°C for iron and steel and to 1250°C for bronze
- the melt was held at pouring temperature for 180 seconds
- the chamber was turned by 180 degrees and the melt poured from the crucible into the mould
- the chamber was held in the pouring position for 5 minutes
- heaters turned off
- the chamber cooled to ambient temperature
- the gas pressure in the chamber was dropped

Initially, the porosity of the ingots was measured by hydrostatic weighing in water. Then, all ingots were cut and the cross-sections examined to reveal structural features in the transverse direction. Figure 3 shows the effect of hydrogen pressure ( $P_H$ ) on the porosity of the gray iron-, steel-, bronze-based gasars. As can be seen, with the measured ingot porosity is dependent  $P_H$ , with different behavior observed for different materials.



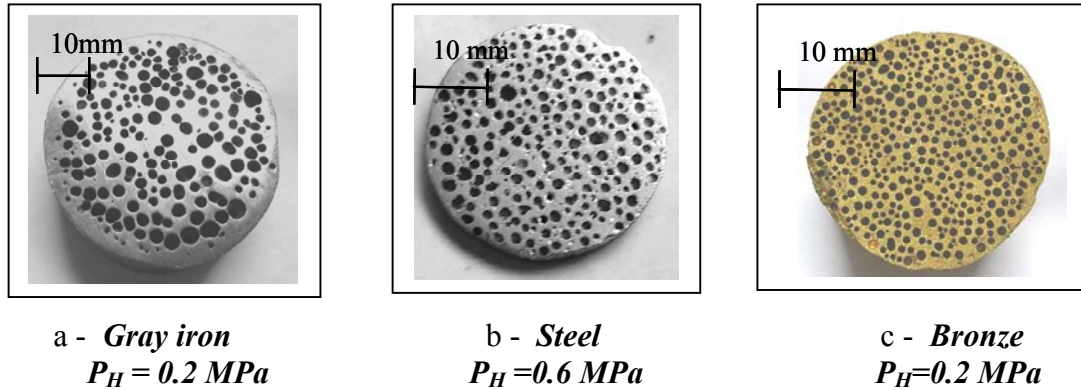
**Fig. 3 Gasar's porosity as a function of hydrogen pressure**  
 1 - iron based; 2 - bronze based; 3 - steel based

To investigate the features of the inner, porous, crystalline structure, the gasar ingots were sectioned transversely 10mm from the bottom of the ingot. The bottom section was examined using metallography techniques, and the following observations were made:

- A gray iron ingot develops porosity at lower temperatures than steel, but the steel gasar structures have a higher homogeneity at the same values of  $P_H$ ;
- A bronze gasar forms uniform porosity at pressures as low as 0.2 MPa, which is much lower than those pressures required to generate porosity in gray iron and steel, though the use of copper-based alloys for brakes is not promising for industrial uses.

The macrostructures of all ingots were investigated, and the most uniform gray iron, steel and bronze materials were selected (Fig.4). The pressures used in the fabrication of these materials

were 0.2, 0.6 and 0.2 MPa, respectively. Of the three gray iron materials produced, composition No. 2 was preferred due to the ease of forming a uniform, porous structure and because it contained sufficient nickel to promote better mechanical properties.



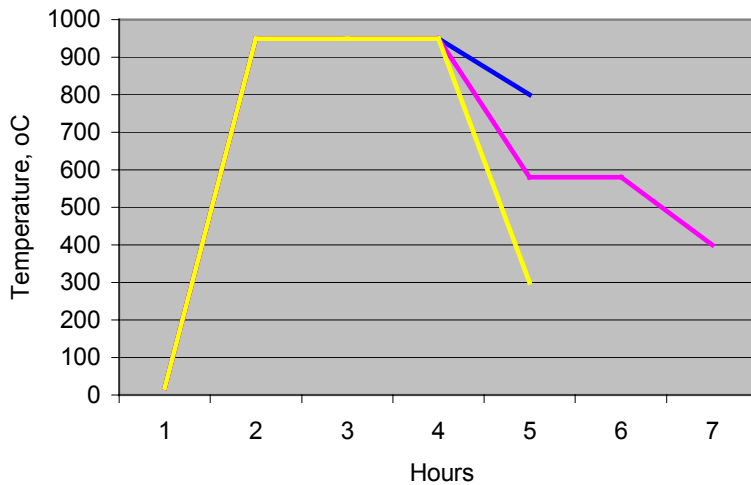
**Fig. 4 The gasar porous macrostructure**

### **Preparation of Gasar Matrixes**

Normally gasar ingots have a monolithic crust on the surface and a porous core. Therefore, to investigate the service properties the ingots were mechanically processed to the dimensions required for mechanical, high temperature or other tests.

Most of the gasar ingots had a high surface hardness which makes them difficult to machine. The high hardness is caused by rapid solidification on the copper water-cooled bottom of the mold. The rapid solidification from the bottom help to control pore formation in the directing of the solidification front. When gray iron is remelted for the gasar processing, gray iron forms cementite and ledeburite. Such grades of gray iron are not recommended for use in brake components and must undergo graphitization to improve tribological properties. Therefore, all of the gasar gray iron ingots were heat treated under the conditions shown in Fig. 5.

After graphitization, the specimens were cut transversely from the bottom and the porous surface examined at different magnifications. It appeared that graphitization was quite extensive in the gray iron gasars, and after a one hour holding time at 950°C, most of the cementite transformed into graphite. After 3 hours, graphitization takes place throughout most of the matrix. The high rate of graphitization is attributed to fine pores in the gasars, which were the sites for graphite nucleation. After annealing for 3 hours, only fine indistinct lamellae of cementite remained, which could be instrumental in enhancing wear resistance.



**Fig. 5 Modes of heat treatment of gray iron gasar samples**

Yellow line – Uncontrolled cooling in air results in a graphite + ferrite structure; lilac line – cooling with intermediate endurance results in graphite + sorbite structure; blue line – controlled cooling in a furnace results in a troostite structure.

The air-cooled specimens had a matrix with a micro hardness of about 320 – 340 HRB corresponding to troostite, while samples held at 580°C had a hardness of about 270 – 290 HRB corresponding to sorbite. Troostite and sorbite structures are known for high wear resistance, which makes them promising for use in brake components.

### Filling of Gasar Matrices with Friction Substance

The properties of the gasar-based composites are greatly dependent on the type and properties of the filler in their pores. In this program, MER investigated the ability of materials with different compositions to fill the pores, and the effect on the friction coefficient and ability to withstand high loads. The two filler compositions utilized for this purpose are described in Table I below:

**Table I. Compositions of the tested filler materials (weight percent)**

Composition 1	Composition 2
• 10% curing polystyrol pyridine	• 25% powder Al <sub>2</sub> O <sub>3</sub>
• 10% graphite	• 25% alumina
• 2% carbon black	• 15 % powder graphite
• 30% cupper fibers	• 15% powder copper
• 1% zirconium silicate	• 20% liquid SiO <sub>2</sub>
• 3% talc	
• 5% magnesia	
• 25% iron powder	
• 14% barytes	

The filling of pores using materials with *composition 1* was achieved using a press capable of developing static pressures up to 1.0 MPa and temperatures up to 300°C and able to maintain these parameters for several hours.

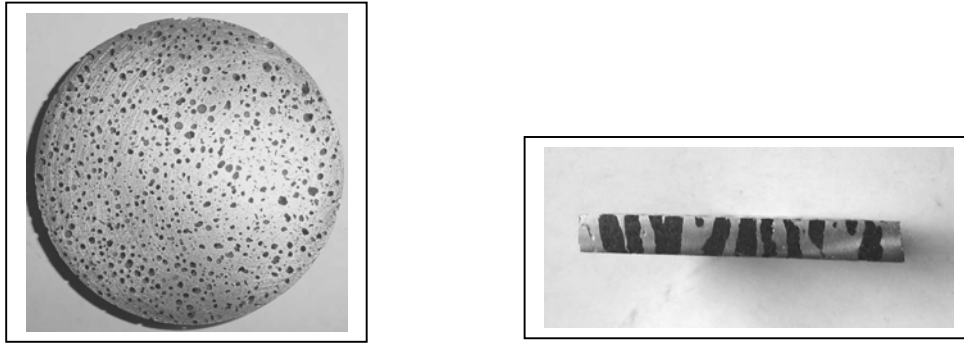
The following steps were utilized in the fabrication of the composites:

- a specified amount of the pore-filling powder was placed on the bottom of a mold in the form of heavy walled metal cylinder;
- a porous matrix gasar block was placed into the layer of powder in the mold with its pores at the top surface;
- more of the pore-filling powder was poured on top of the gasar specimen;
- the mold was closed with a piston and positioned between the heated platens of the press;
- a pressure of about 0.5 MPa was applied;
- the temperature was raised to 130°C;
- the pressure and temperature were maintained for 80 minutes;
- the pressure was released and specimens removed from the mold.

Composites utilizing filler with *composition 2* were prepared by using gasar ingots cut out into discs with pores on both sides. The process of material preparation is described below:

- powder components were mixed;
- liquid SiO<sub>2</sub> was added
- a porous sample made as a disc with open pores was connected to a vacuum pump via special gaskets
- the specimen was immersed into the solution
- the vacuum pump was turned on
- the solution impregnated the pores due to the pressure differential
- the pump was turned off
- the specimen was disconnected
- the impregnated matrix was positioned between steel discs
- the specimen was placed in a furnace for 30 minutes
- on extraction from the furnace, the steel discs were removed
- the sample was placed into a furnace again, and heated to 1100 °C for 2.5 hours for final sintering

These procedures were successfully used in the fabrication of porous gasar discs with a thickness of 10mm and pores of more than 50 µm in diameter. Metallography examination of the cross section of the matrices showed that the filler completely filled the pores and withstands subsequent machining and testing (Fig. 6)



**Fig. 6 Gasar friction composite filled with the *composition 1* filler**  
Left- cross section; right transverse section

To verify other approaches to pore filling, the above scheme was supplemented by ultrasonic treatment of the mold with powder in it prior to specimen positioning and other steps.

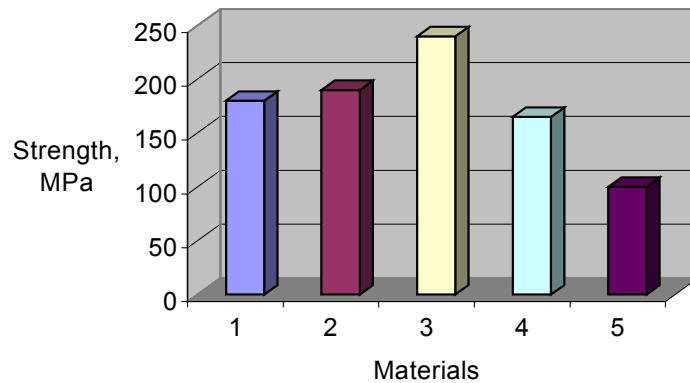
Alternatively, the filler powder was dissolved in a water-based  $\text{SiO}_2$  to form a colloidal solution, which was poured into the mold. The specimen was immersed into the solution and the mold cover closed. As shown by the experiments, none of these additional steps resulted in a noticeable improvement in pore filling.

### **Tests of Operational Gasar Composite's Properties**

The strength of porous materials is known to diminish as the density of the materials decreases. In addition, the shapes of the pores and surface roughness have a significant influence on material behavior under load. Typical pores formed in sintered and foamed materials are irregular and have a great number of acute angles acting as stress promoters.

As a result, porous materials break up easily and can not be used for construction purposes. On the other hand, most of the naturally occurring porous materials such as bone, wood and honeycomb have a high specific strength and can withstand considerable alternating loads. Structurally, gasars are very similar to their natural analogues yet are different due to the monolithic metallic matrix and pores of regular geometrical shape with smooth surfaces. For these reasons, gasars exhibit good mechanical properties even with considerable porosity.

To determine the mechanical properties of specimens of gray iron gasars with 38 – 40% porosity, the sorbite, ferrite and troostite matrices, with pores filled with composition 1 filler, were tested under a compressive load. The method and equipment used were standard for compression tests. The results were compared with the strength of a monolithic cast iron specimen of the same composition and an organic lining (Fig. 7).



**Fig. 7 Strength of friction materials under compression load:**

1- gray iron monolithic; 2 - gray iron gasar composite with sorbite metal matrix; 3 - gray iron gasar composite with troostite metal matrix; 4 - ceramic –metal-composite; 5 - organic lining

As can be seen from the graph, the specific strength of the cast iron composites with the sorbite matrix structure is comparable with that of monolithic cast iron. The strength of composites having a troostite matrix is even higher.

Normally gasars have a monolithic crust on their surface. The crust has a beneficial effect on the strength properties of the composites as the monolithic layer strengthens or reinforces the porous body. This was verified during the compression test of a specimen taken from the ingot bottom with the solid crust removed from it. The specimen had a porosity of 36%, a monolithic 1.5 mm thick crust layer on one side, and the pores were filled with composition 1 on the other side. As shown in Fig. 7, this composition nearly equals that of monolithic gray iron, however, the specific strength exceeds that of gray iron because of the lower density of the gasar material. High strengths are achieved by eliminating the inherent porosity of the composite through infiltration of the filler material, which together with the solid crust, acts as a reinforcing agent.

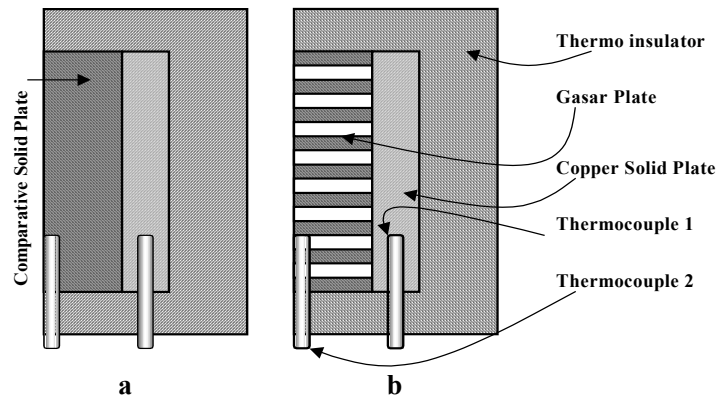
These tests have shown that gasars with 30- 40% porosity retain high specific strength, which surpasses that of the organic linings and ceramic-metal composites, and, therefore, can be used for heavy-duty components such as brake elements.

The temperature distribution of disc brakes cannot be explained by mere heat dissipation. This is a much more complicated process in that heat is generated only in the very narrow zone of contact of the pad with the disc. The temperatures experienced in the disc and the pad are considered separately below.

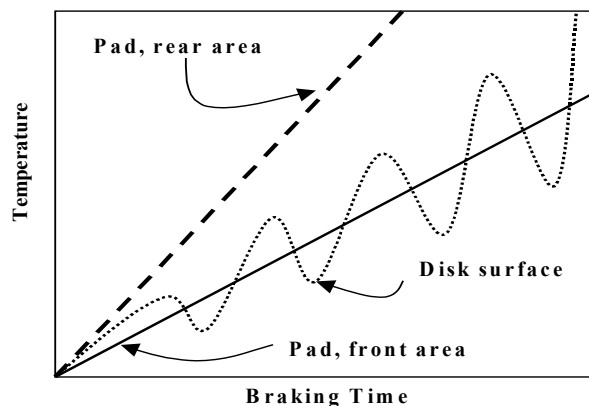
The surface of the pad lining operates unevenly due to predominantly one direction of wheel rotation. Those areas, which are the first to experience the friction forces (front or leading), contact a relatively cold surface of the disc while the trailing parts contact a much hotter surface. Thus, the temperature at the trailing edge of the pad lining is always much higher than at its leading edge. Thus, this should be taken into account while simulating pad heating and cooling.

Also, heating of the lining depends on the braking time and the force. Heat is removed from the lining to the bulk of the pad and finally to the brake mechanism. This heat removal is slow due to the low thermal conductivity of the friction material, which results in most of the heat being absorbed by the disc. Accordingly, the lining surface generally experiences non-uniform heating.

The surface of the disc also operates under uneven heating conditions, which differ from those experienced by the lining. Only a small part of the disc surface contacts the lining, which begins to cool immediately after the contact ends. The cooling time is inversely proportional to the rotational speed of the disc. The cooling rate depends on a number of factors including the disc material, its design and rotational speed of the wheel. With regard to this complicated operational mode of brakes, simplified tests were performed to determine whether a brake disc or brake lining made of gasar composites improves heat dissipation in comparison to known materials. Discs and linings were tested in two separate experiments. The test with the gasar disc is shown schematically in Fig. 8. In this test, the disc surface is subjected to cyclic heating and cooling while monitoring the increase in temperature (Fig. 9).



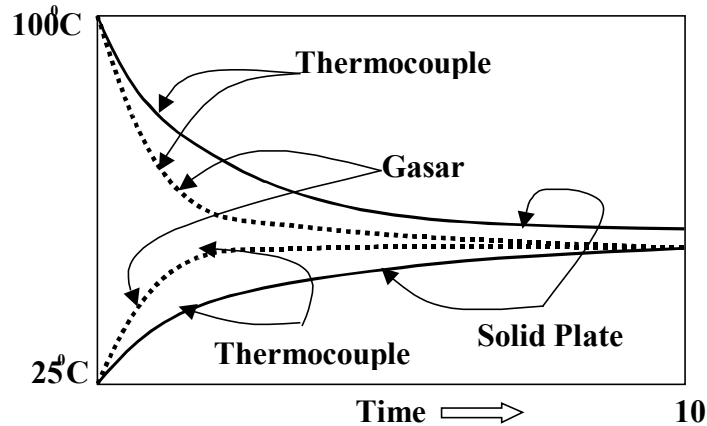
**Fig. 18 Evaluation of heat dissipation in a gasar disc in comparison with that of monolithic material.**



**Fig. 9 Heating of disc and pad lining surfaces for one brake cycle vs time.**

A monolithic copper disc of 28 mm diameter and 10 mm thickness was heated in boiling water and placed into a heat insulating case. A gasar plate or a monolithic plate of the same

composition was then put onto it. The gasar plate and the reference plate both had an initial temperature of 25°C. The gasar plate had a porosity of 33 % and an average pore diameter of 1.5 mm. Temperature measurements were taken by two thermocouples, inserted, respectively, into the copper disc and the gasar or reference plate. The test results averaged for 20 test runs are shown in Fig. 10.



**Fig. 10 Plate temperature vs time**

As shown in the graphs, the copper disc conducts heat to the gasar plate much faster (about 1.5 times) than to the monolithic plate.

The second test run was carried out to evaluate heat dissipation in the brake lining made of a gasar plate with its pores filled with a friction material. Plate porosity prior to filling was 32 % and the average pore diameter was 1.5 mm.

According to the experimental results, the gasar friction composite accepts heat more readily than the monolithic metal plate fabricated from the friction material only. Such test results could be expected because the friction material has a lower thermal conductivity than the gasar metal matrix.

### **Wear resistance**

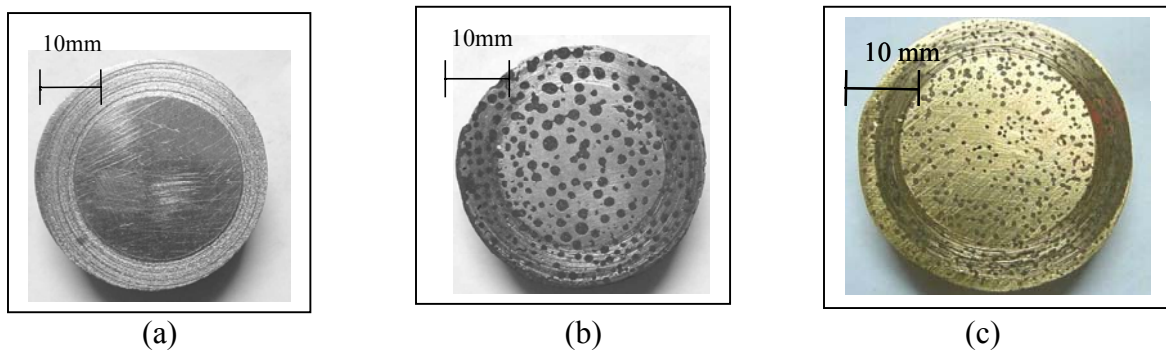
The quality of brake components is characterized by a number of parameters, such that their operational properties are normally tested using finished articles, as the operation conditions are difficult to simulate. Gasars and their fabrication techniques were studied in this program, and the feasibility of using gasar-based composites in industrial applications was investigated. To identify and prove the advantages of these new materials in comparison to existing ones, their friction properties were investigated using specimens 28 mm in diameter and 7 mm in height. Similar tests were performed on monolithic samples of the same chemical composition. Based on analysis of the test results, the properties of the gasars-based materials were compared with those of monolithic specimens.

A number of porous specimens were produced, machined, heat treated and filled one of the two types of fillers. The specimens had porosities of 32 –35 % and pore sizes between 0.7 and 2.5

mm. All specimens were weighed prior to testing using an electronic balance and the results recorded up to the fourth decimal digit.

Friction tests were performed using the machine, which is equipped with two half-axles, one of which has a fixture with a sample attached and the other, which has a counter-body made of a hard steel ring. The half-axle was connected to a membrane pump, which produced pressure on the half-axle with the counter-body. When starting the machine, the sample starts to rotate and the half-axle with the ring starts moving towards the fixed sample. At the moment of contact a torque is generated, which is transformed into an electric signal by means of transducers. The instruments in the measuring units record this torque. The wear rate of the sample and the temperature in the contact zone increases with the speed of rotation and the axial load.

Linear velocities of the counter-body up to 5 m/sec and pressures up to 50.0 MPa were used with a test duration of 20 minutes. Simultaneously, the coefficient of friction was recorded and the temperature was plotted vs time. After the test the machine was switched off. Then the sample was removed from the fixture and weighed. Similar test runs were made using monolithic cast iron samples, bronze and steel, and the resulting surfaces are shown in Fig. 11.

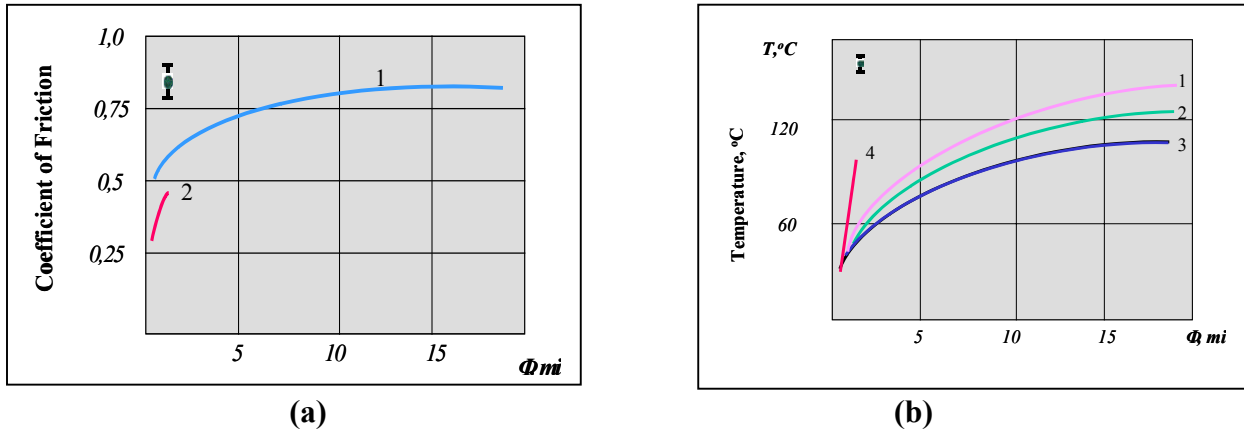


**Fig. 11 The sample's view after frictional tests:**

a - monolithic cast iron after 1 min, b - cast iron based gasar composite after 20 min,  
c - bronze based gasar composite after 20 min

The results of the friction coefficient measurements are shown in Fig 12a. It can be seen that the value of the friction coefficient is between 0.5 – 0.85 for all tested composites. The sample fabricated using monolithic cast iron could not operate at all due to high noise, high temperature and high deterioration. Its coefficient of friction was only about 0.3 – 0.5.

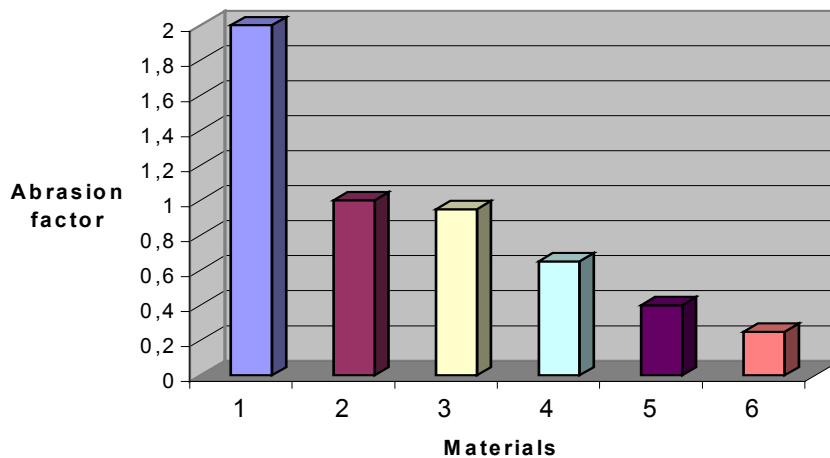
The temperatures experienced in the composite are shown in Fig. 12b. Three variants of impregnation, differing by the graphite content, were tested. It was revealed that the composite's operational temperature can be lowered by increasing the graphite content in the pores.



**Fig. 12 Coefficient of friction (a) and operational temperature (b) of the cast iron based gasar composite vs time:**

- (a): 1 - frictional coefficient of gray iron gasar composites, 2 - monolithic gray iron;  
 (b): 1,2,3 - differ with graphite contents as 1.0:1.5: 2.0. 4 - monolithic gray iron

The wear properties of the samples are shown in Fig. 13. As can be seen from the plots, gasar composites are more efficient under friction and heat conditions. Cast iron with troostite matrix and steel with ceramic filler have the best friction properties with wear much lower than that of monolithic gray iron. This is probably due to the formation of a protective film on the metal surface. The film generated by the filler material acts as a lubricant uniformly distributed over the contact surfaces, thus, assuring a higher number of brake cycles by the gasar-based composites under high temperature conditions.



**Fig. 13 Abrasion factor of friction materials:**

- 1 - organic lining; 2 - gray iron monolithic; 3 - gasar –gray iron - composite with ferrite structure; 3 - gasar – gray iron - composite with sorbite structure; 5 - gasar– gray iron composite with troostite structure; 6 - gasar –steel – composite  
 (Abrasive factor = Ratio of weight loss of sample to weight loss of cast gray iron sample)

The deterioration of gasar materials are lower than that of the monolithic metal. It is believed that this is due to the presence of a frictional substance in the pores, which covered the metal with a thin film, thus protecting the metal body. The presence of the filler in the pores also results in an improvement in friction properties during the heating accompanying brake operation. Similar properties were shown by bronze-based gasar composites.

To confirm this observation, the cast iron gasar-based material without impregnation was tested. The behavior of this sample was similar to that of the monolithic sample. This test has unequivocally proven the advantages of gasar-based composites.

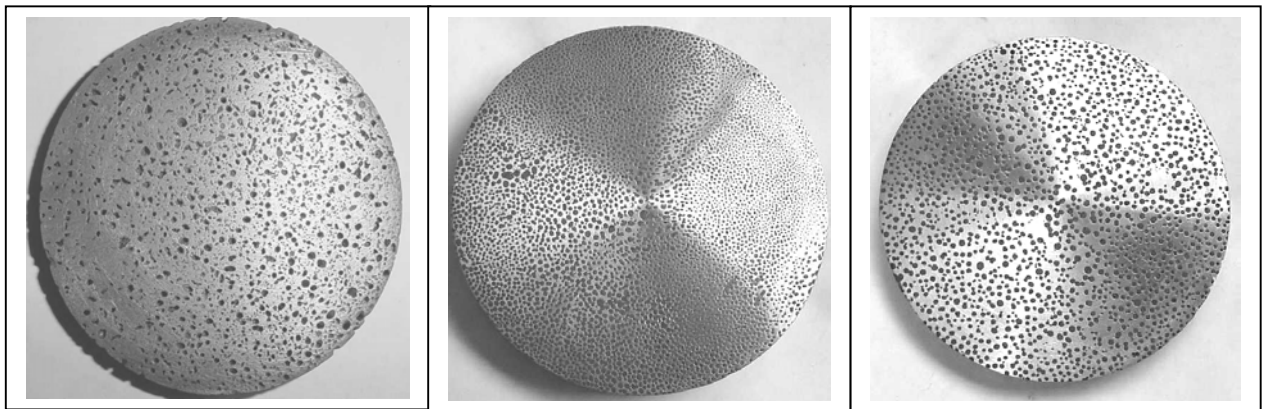
The effect of pore size on wear resistance was also studied. It was determined that the presence of pores resulted in a reduction in deterioration without a noticeable dependence on the pore sizes. It is believed that the wear resistance mostly depends on overall porosity and the filler content.

The results of the tests conducted suggest that the gasar-based composites with their specific macrostructure are characterized by unique friction properties. Namely, they exhibit high friction coefficient and stability and low wear.

The advantages of utilizing gasar -matrices as brake components are the following:

- increased braking performance;
- reduced deterioration;
- increased thermal conductivity;
- increased chemical stability; and
- increased safety, durability and reliability.

Gasar technology provides way to design matrices with open porosities from 10% to 60 % and to control the braking abilities of composites after filling pores with abrasives. To demonstrate the capabilities of the gasar technology, gasar brake materials compared to the typically used of cast iron, bronze and steel based samples were prepared as shown in Figure 14.



Cast iron

Steel

Bronze

**Fig. 14 View of demonstrational gasar-composite brake materials**

## CONCLUSIONS

Gasar materials have a unique porous structure featuring pores of cylindrical, spherical or ellipsoidal shape in monolithic metal matrices. The dimensions, number, shape and orientation of the pores can be controlled. This imparts to the gasar excellent frictional and damping properties as well as high strength, stiffness, and rigidity as compared to other porous metals. In addition, it is possible to design new metal-ceramic or metal-polymer composites using this technology.

*The primary objective of the research was to study the technical feasibility of using the proposed gasar matrices for the development of high performance brake components. The feasibility study included synthesis and characterization of the gasar matrices, fabrication of brake composites and demonstration of the improvement in performance over present, state-of-the-art brake components.*

The following conclusions can be made.

1. The possibility of using the gasar technique for obtaining porous gasar materials with predetermined porosity in a one-stage process has been demonstrated. The basic features and potential of the new technique along with its simplicity and environmental safety have been shown. Experimental and demonstration samples of cast iron-, bronze- and steel-based gasars have been produced.
2. Gasars have been shown to be able to undergo machining and heat treatment similar to monolithic materials of the same chemical composition. This can be used to select the structure of the metal matrices and provides another tool for controlling their properties.
3. Filling the gasar pores with different compositional substances has proved efficient in terms of improving their friction properties. Samples of cast iron-, bronze- and steel-based friction composites have been produced.
4. Tests of friction properties of advanced gasar composites have been carried out and demonstrated 10 times higher wear resistance and 1.5 to 2 times higher friction coefficient as compared to monolithic materials of the same composition (i.e., cast iron or bronze) without any adverse effect on specific strength. In addition, heat dissipation is 1.5 times higher.
5. An advantage of the new gasar process is its flexibility in varying the chemical composition to obtain steel- or even stainless steel-based brake components with high anti-corrosion properties. This is possible because the performance of the gasar material is not critically dependent on the composition, as evidenced by the wide variety of compositions successfully utilized. In addition, during remelt of waste materials, it is possible to remove undesirable components if required.

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