Sintered ferrous takes path of **most** resistance

Until now, high duty applications have centred on the incorporation of discrete wear resistant phases in a sintered ferrous microstructure. But British researchers have examined the emergence of a novel sintered ferrous material, containing hard particle additions, that may influence the development of wear resistant parts...

A novel sintered ferrous material has been developed that incorporates a wear-resistant hard particle addition. These hard particles contain high levels of iron, chromium and tungsten that combine to generate very fine carbide species within the hard particles. The hard particles can be admixed into a wide variety of ferrous matrices, and sintered articles can be readily produced under normal processing conditions. It has been found that a particularly useful sintered material can be produced when hard particles are incorporated into a low alloy ferrous matrix (3% chromium, 0.5% molybdenum, 1% carbon) and then infiltrated with copper during the sintering process. This particular sintered material has been identified as being suitable for high duty applications that require a high degree of wear resistance, such as automotive valve seat inserts. The excellent performance of this material has been demonstrated in both rig and engine testing.

Table 1: Chemical composition of selected hard particle powder.

Fe/%	Cr/%	W/%	Ni/%	Co/%	C/%	Others
36.9	29.7	21.5	4.6	5.1	2.1	⇠1% total

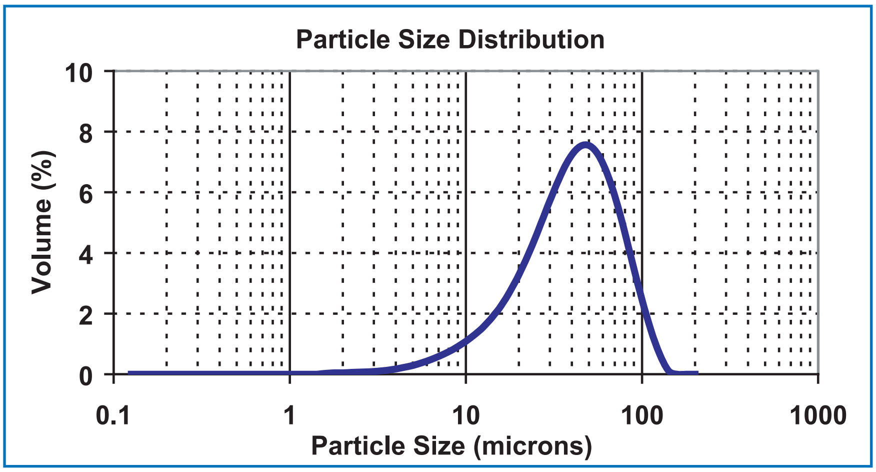

Figure 1. Particle size distribution, determined by laser technique.

Alloy powders

One of the many strengths of ferrous powder metallurgy is its ability to produce microstructures that aren't achievable by conventional casting techniques. In particular it is possible to create heterogeneous materials in which different species can be incorporated to confer various properties such as wear resistance, machinability and lubrication.

For automotive valve seat applications, the primary requirement is for wear resistance, and to this end, attention has often focused on the incorporation of discrete wear resistant phases in a sintered ferrous microstructure. These wear resistant phases have included many candidates such as ceramic particles (e.g. carbides, nitrides, oxides) [1,2], ferro alloys (e.g. ferro-molybdenum, ferro-tungsten) [3], and various alloy powders (typically based on iron, cobalt, or nickel) [4,5,6]. In terms of commercialisation, it has been found that the alloy powders have been the most successful. Such alloy powders can give good intergranular bonding in the sintered ferrous matrix, to produce high integrity materials with enhanced wear resistance. It is found that these alloy powders often contain high levels of molybdenum, since molybdenum not only confers a high degree of wear resistance, but is also particularly effective in intergranular bonding due its combination of diffusion mobility and its

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low affinity for oxygen during the sintering process [7].

In this novel sintered material, a new wear-resistant alloy powder composition has been identified with high levels of chromium, tungsten, and pre-alloyed carbon. It is known that chromium and tungsten will both readily form carbide type compounds that are hard, and hence wear resistant. When this style of wear-resistant alloy powder is incorporated into a sintered ferrous matrix, it is often described as a "hard particle addition". In this article the development of a compatible ferrous matrix is also described, to give a final wear resistant sintered material that is particularly suitable for automotive valve seat applications.

Table 2: Comparison of basic mechanical properties of sintered materials.

	No added copper	**2% admixed copper powder**	**Copper infiltration during sintering**
	7.08	7.06	8.10
Hardness /HRA	63	65	72
Matrix Microhardness /Hv200g	340	370	350
Hard Phase Microhardness /Hv100g	1030	990	1050
Radial Crushing Strength /MPa (MPIF method [9])	380	420	1180

Hard phase formation

The hard particle powder was prepared by conventional gas atomisation in nitrogen gas. The chemical composition of the selected hard particle powder is shown in Table 1.

The particle size distribution, seen in Figure 1, was determined by the laser technique using a Malvern Instruments Mastersizer 2000.

For the ferrous matrix, a range of commercial powders were initially evaluated using a basic formulation incorporating 20 mass% of the hard particle powder. On the basis of the sintered properties and microstructure, it was decided to focus on an atomised grade pre-alloyed with 3%Cr and 0.5%Mo (Höganäs "Astaloy CrM"). This iron powder is known to be compressible, and the pre-alloyed chromium and molybdenum can confer high sintered strength and hardness. It was also decided to incorporate a standard graphite powder addition of 1% with respect to the ferrous matrix, in order to promote the formation of a highly alloyed bainitic microstructure within the ferrous matrix.

In order to achieve the maximum possible degree of wear resistance, it is necessary to have a high level of the hard particle phase in the sintered microstructure. Unfortunately the hard particle powder has low compressibility, and excessive levels of addition lead to low pressed strength

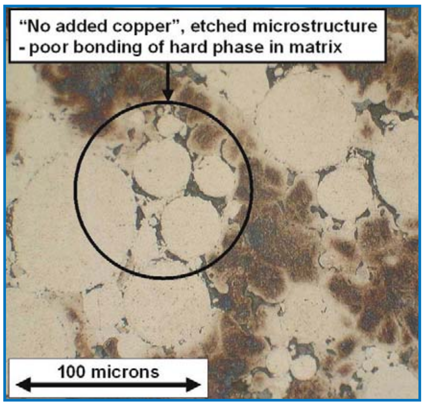

Figure 2. Poor bonding of hard particles in ferrous matrix with no copper infiltration.

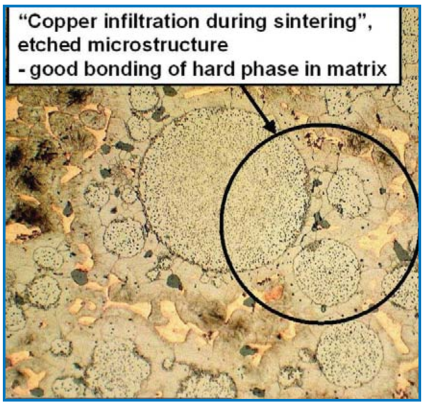

Figure 3. Copper infiltrated material shows hard phase as well bonded.

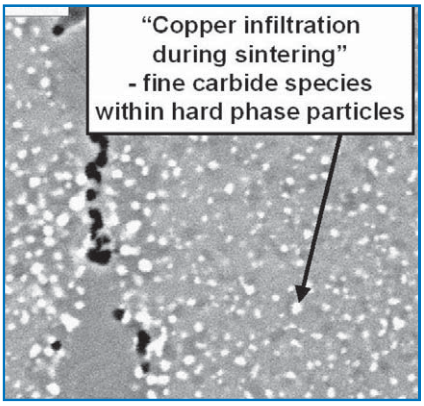

Figure 4. Copper infiltration is demonstrated to give three-fold increase in property.

and pressing difficulties such as ejection cracks. The preferred level of hard particle powder addition was established by preparing mixes with a range of hard particle levels, and measuring the resultant pressed (green) strengths using the MPIF method [8]. On the basis of previous experience in the production of automotive valve seat inserts, the level of hard particle addition was consequently set at 30%.

Three variants around the basic 30% hard phase formulation were then studied further:

1. No added copper:
   30% hard particle addition
   0.75% pressing wax
   0.5% MnS machining aid
   balance = ferrous matrix (99% "Astaloy CrM", 1% graphite powder)
2. 2% admixed copper powder:
   30% hard particle addition
   0.75% pressing wax
   0.5% MnS machining aid,
   2% admixed fine copper powder
   balance = ferrous matrix (99% "Astaloy CrM", 1% fine graphite powder)
3. Copper infiltration during sintering:
   30% hard particle addition
   0.75% pressing wax
   0.5% MnS machining aid
   balance = ferrous matrix (99% "Astaloy CrM", 1% graphite powder)

Here the pressed compact was sintered in contact with a pressed copper compact made from a standard copper alloy infiltrant powder. The copper melts during sintering and penetrates the iron compact to give a fully dense copper infiltrated structure. This is an established technique for the production of high duty automotive valve seat inserts.

All compacts were pressed at 770 MPa into simple ring-shaped specimens, and then sintered in a conventional mesh belt furnace at 1110°C in a N_2/H_2 atmosphere. The basic mechanical properties of the sintered materials were then measured and compared, as displayed in Table 2.

Examination of the sintered microstructures showed that there was generally poor bonding of the hard particles in the ferrous matrix when there was no copper infiltration. This is indicated in Figure 2.

But in the copper infiltrated material, the hard phase was well bonded in the ferrous matrix, as displayed in Figure 3.

The difference in the extent of the hard phase bonding is also particularly evident in the radial crushing strength, where it can be seen that the use of copper infiltration during sintering gave a three-fold increase in this property, seen in Figure 4.

Scanning electron microscopy of the copper infiltrated material confirmed the presence of the anticipated fine carbide species within the hard phase particles.

The copper infiltrated variant "3" was judged to be of a very high quality, with the hard phase particles well bonded in a low alloy ferrous matrix. Further samples of this grade were then prepared in the form

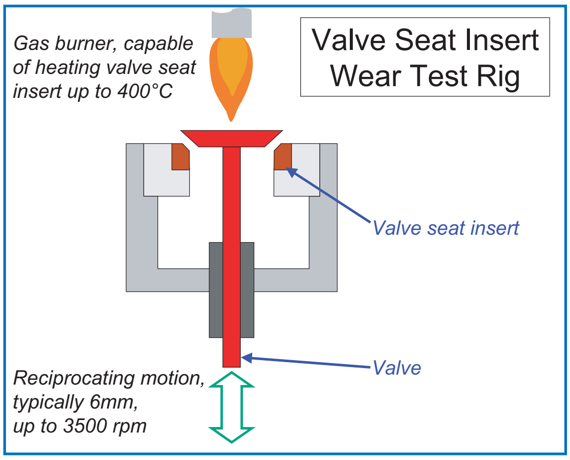

Figure 5. Diagram illustrating method of Wear Rig Testing.

of valve seat inserts in order to compare the wear resistance against some commercial automotive valve seat insert materials.

Wear rig testing

In this test, a valve seat insert is tested against a reciprocating valve. The assembly is heated by a gas burner. The wear of both the valve and valve seat insert is then measured. The method is illustrated in Figure 5.

For this testing, a temperature of 250°C was selected, with the valve reciprocating with 6mm of travel at 3000 rpm for five hours. A diesel exhaust valve with a hard facing of a Fe/Cr/Co/Ni/W/Mn alloy was used. Two commercial automotive valve seat insert materials were also tested for comparison. The results may be seen in Figure 6.

On the basis of results obtained from this simple rig test, it was judged that the new material could have a wear resistance similar to the commercial high speed tool steel type material 1, and even appeared to be superior to the commercial high density bainite type material 2. The new material was considered sufficiently promising to progress to a full engine test.

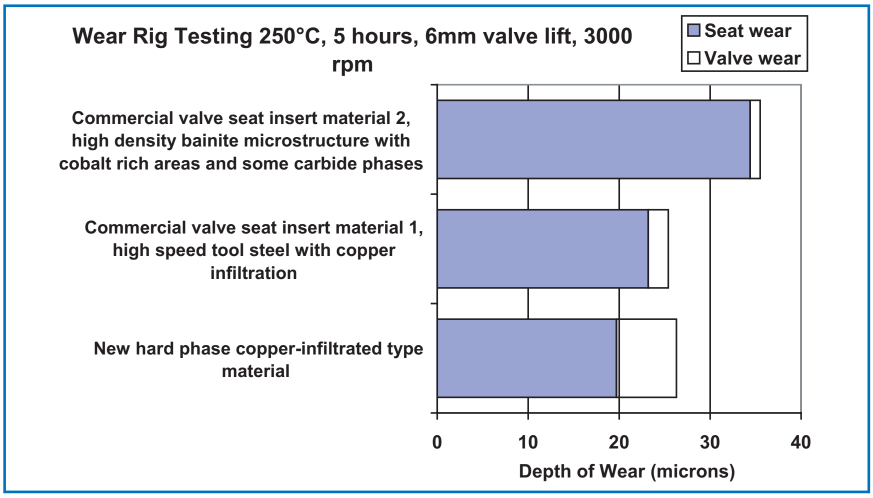

Figure 6. Results of Wear Rig Testing of hard phase copper-infiltrated type material compared with two commercial automotive valve seat insert materials.

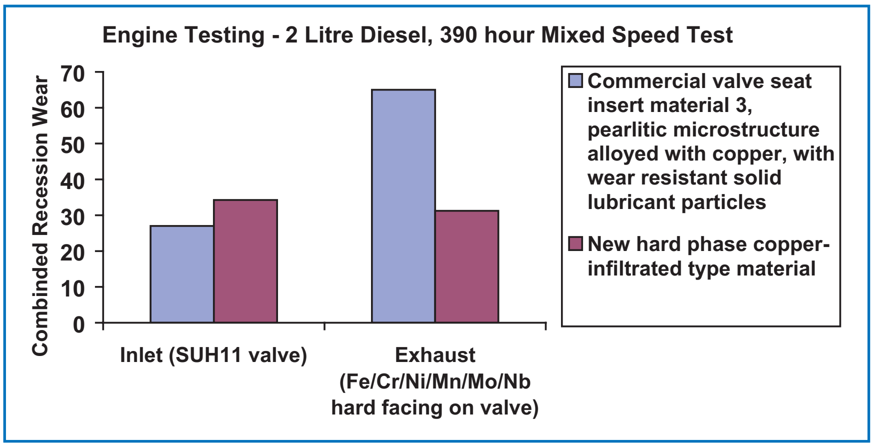

Figure 7. Results of Engine Testing of commercial valve seat insert and new hard phase copper-infiltrated type material.

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Engine testing

A two litre diesel engine was used for the testing. Half of the fitted valve seat inserts were removed and replaced by parts made in the new hard phase copper infiltrated type material. The engine was run for 390 hours under a general mixed speed cycle. The wear was determined by measuring the valve recession. This recession value represents the combined wear of the valve seat insert and the valve. The results are shown in Figure 7.

On the basis of these results, it was judged that the new material is suitable for use as an automotive valve seat insert. The results for the exhaust valve seat inserts was particularly impressive, where the new material gave around half the recession wear of the valve seat insert material currently fitted in this engine.

The Authors

This article is based on *A novel sintered ferrous material containing hard particle additions, suitable for wear resistant applications*, a paper by Les Farthing and Iain Whitaker of Federal-Mogul sintered products limited, which was given at Euro PM 2007 in Toulouse.