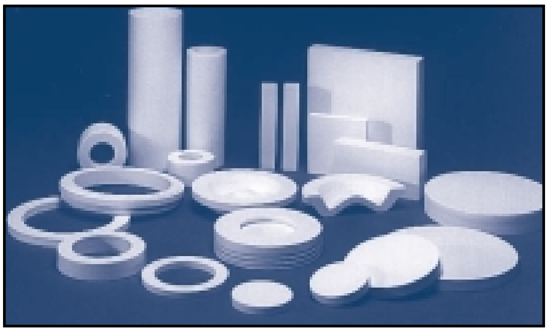
AUTOMOTIVE
Data Sheet

SAFFIL

PROPERTIES OF METAL MATRIX COMPOSITES

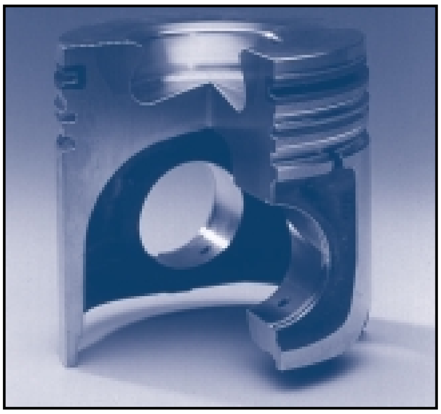
Overview

Saffil has been actively involved in the development of metal matrix composite (MMC) applications since 1980, producing grades of Saffil fibre tailored to meet the stringent technical requirements of reinforced aluminum components such as pistons and engine blocks.



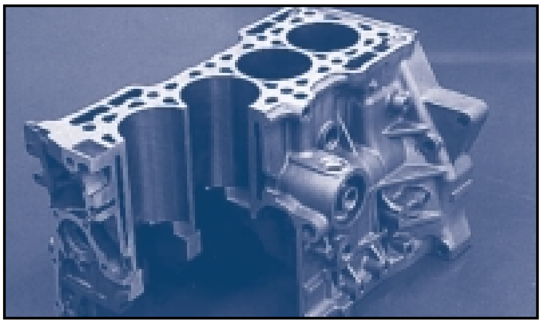
The driving force behind new engine work is the need to build lightweight units capable of delivering higher performance, improved fuel economy, lower emissions and reduced noise levels.

For more than a decade, Kolben Schmidt, Mahle, AE and Toyota have pioneered the use of Saffil fibre reinforced pistons for diesel engines, while Honda Motor Company focused on the reinforcement of engine blocks.



In 1990, Honda launched a new generation of aluminum engine blocks with fibre reinforced cylinder walls replacing traditional cast iron liners. The first model selected for production was the Prelude Si, a 16 valve in-line 4-cylinder engine, using a new casting process to incorporate the Saffil - carbon fibre hybrid preforms.

Elimination of the cast iron liner using MMC technology allows a reduction in material thickness between the adjacent bores. Tightening the cylinder spacing in this way results in reduction in the overall length of the engine and a weight saving on the block of around 4.5kg.



Honda has since expanded the use of MMC engine blocks and include models of the Accord, Ascot Innova and the S2000.

Honda has also developed a high pressure die casting (HPDC) process for manufacturing the MMC engine blocks which reduces process costs and enables widely available equipment to be employed (See tables 8 and 9)

KS Aluminum-Technologie AG is also using Saffil fibres with silicon particles (LOKASIL) in engine blocks and at 17% loading to reinforce the cylinder head in a turbo charged, 4-valve diesel engine. The cylinder head is produced by squeeze casting.

Figs. 1 to 6 and tables 2 to 4 show data for composites based on typical piston alloys. In all cases, the Saffil fibre was incorporated in an approximately random planar orientation.

At 300°C, the presence of the fibre has improved the ultimate tensile strength (fig. 1) by a factor of 4. It also extends the maximum use limit of the alloy to around 500°C, a peak temperature which is sometimes approached in the combustion bowl rim of diesel engine pistons.

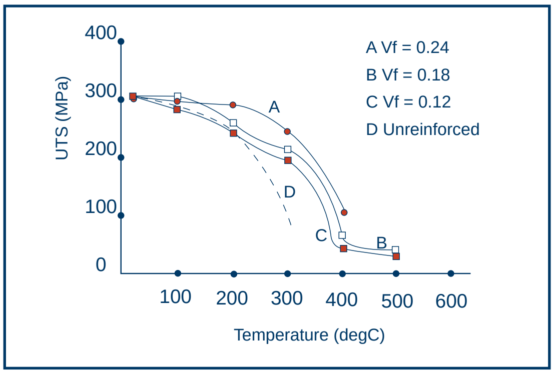


Figure 1 Tensile strength of composites made from Saffil fibre RF grade in AC8B (T6) alloy.

Useful improvements in high temperature fatigue strength are demonstrated by the data in table 2 and fig. 2. The scatter displayed by the pure alloy is almost eliminated by adding the fibre. The modulus has been increased to values in excess of those predicted by theory for a random planar array of fibres. This indicates strong fibre - matrix bonding and also the effect of modified matrix microstructure. At 300ºC, the composites containing 18% and 24% fibre have a higher modulus than the unreinforced alloy at 25ºC (fig. 3).

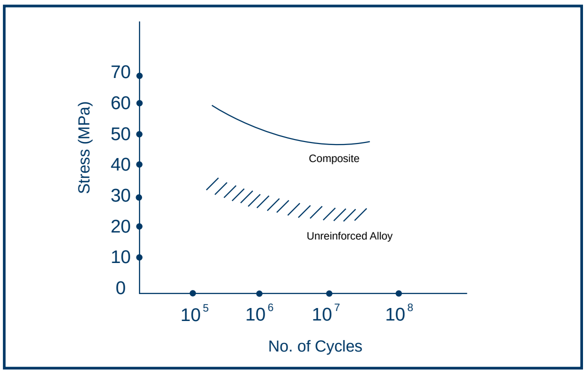


Figure 2 Fatigue test data at 350ºC for LM13 alloy reinforced with 20% v/v Saffil fibre measured after 100h pre-soak at 350ºC.

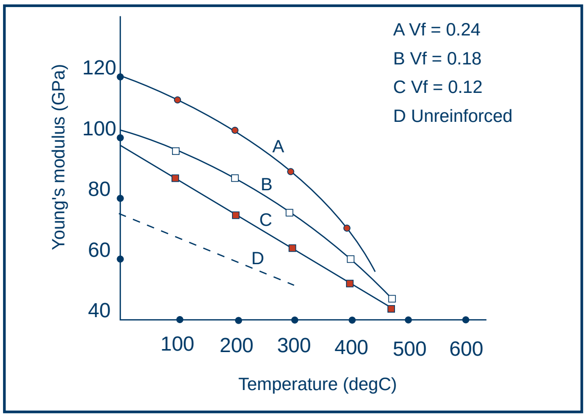


Figure 3 Modulus of composites made from Saffil fibre RF Grade in AC8B (T6) alloy.

The coefficients of thermal expansion are lower than in the pure alloy (table 2) and the difference increases with the volume fraction of fibre.

The thermal conductivity is lower than for the unreinforced metal and decreases as the fibre level rises (fig. 4). It is higher in the direction parallel to fibre orientation planes than in the normal direction, but in all cases, is much higher than for Niresist iron which is frequently used for piston inserts.

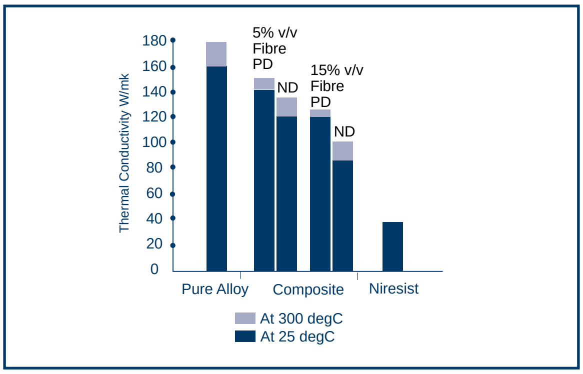


Figure 4 Thermal conductivity of composites containing 5% and 15% v/v Saffil fibre in AA332 alloy measured in Parallel Direction (PD) and Normal Direction (ND) with respect to fibre orientation planes.

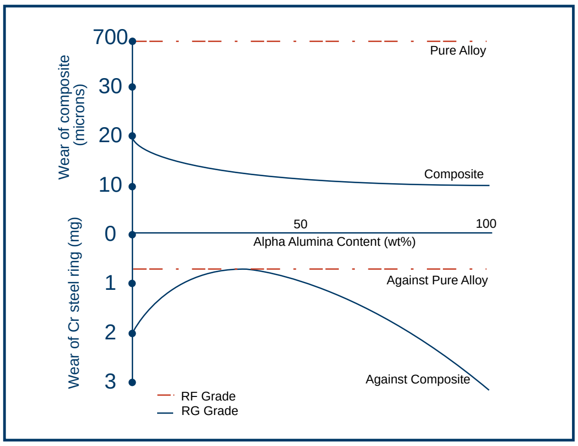


Figure 5 Wear of composite (4.4% v/v Saffil fibre in AC8A (T7) alloy) and mating surface (Cr steel ring).

The wear resistance of the alloy is greatly improved by including only a small volume fraction of fibre. Fig 5 shows data for 4.4% v/v addition of RG grade Saffil fibre. Wear of the mating component, in this case Cr-steel, might be increased by contact with the reinforced alloy, but can be avoided by using RG grade fibre with the appropriate alpha alumina level. Additional wear data giving results for a higher fibre loading and also a comparison with Niresist are shown in Fig. 6.

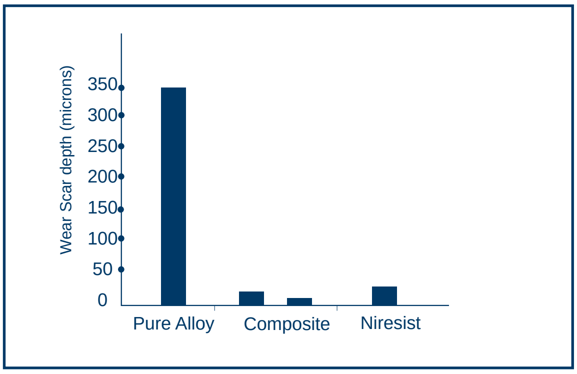


Figure 6 Wear of composites (5% and 15% v/v Saffil fibre RF grade in AA332 (T5) alloy) against modular cast iron ar 190°C.

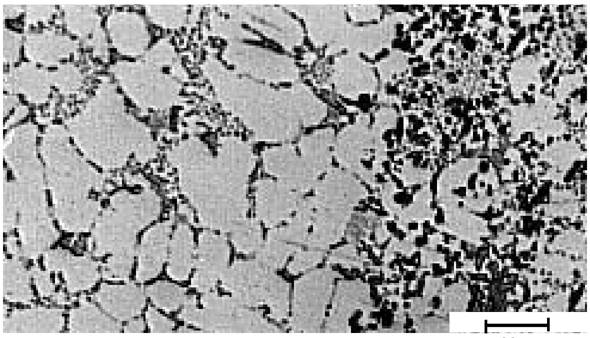


Figure 8 Optical micrograph of interface between reinforced and unreinforced regions of AC8B (T6) alloy showing uniform distribution of Saffil fibre at 0.24 volume fraction.

The hardness at 25°C increases linearly with increasing volume fraction of fibre to a value over 60% greater than the unreinforced alloy for a volume fraction of 0.24 (table 4). As expected the composites also display much greater hardness than the pure alloy at elevated temperatures (table 2).

Other Alloys

All the preceding composites data refer to alloys commonly used in pistons. Composites based on other alloys show enhanced ultimate tensile strength even at room temperature. For example, (fig 7). Such composites usually show higher strain to failure than those based on piston alloys (table 5). The presence of the fibre in aluminum alloys generally results in modified microstructure. (fig 8) and in particular, in a reduced grain size.

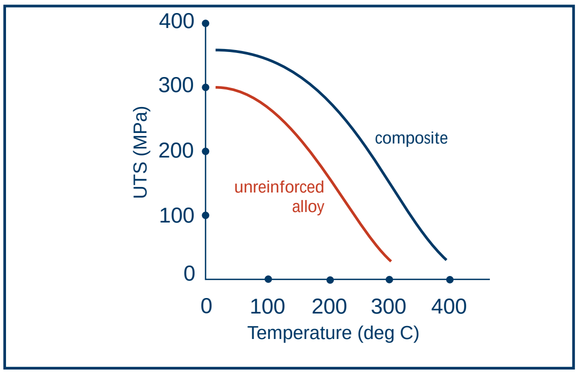


Figure 7 Tensile strength of composite made from 20% v/v Saffil fibre RF Grade in A1-6061 (T6) alloy.

Table 2 Fatigue Strength and hardness of Saffil fibre/SAE 339 alloy composites

Volume fraction (Vf)	Fatigue strength at 10^7 cycles (Mpa) at				Hardness (Rockwell E) of fatigue tested specimens at		
	22°C	204°C	288°C	343°C	204°C	288°C	343°C
0	130.5	106.0	80.9	40.5	77-90	75-87	58-72
0.10	-	119.2	89.3	-	99-109	88-97	-
0.20	-	120.0	85.0	67.6	103-110	97-99	95-97

Table 3 Coefficient of thermal expansion of composites containing Saffil fibre in AA332 (T5) alloy measured parallel and normal to planes of fibre orientation.

Volume Fraction (Vf)	∞(in plane) (10^{-5} °C^{-1})	∞(normal) (10^{-5} °C^{-1})
0	2.45	2.45
0.05	2.39	2.36
0.15	1.89	2.23

Table 4 Hardness at 25°C of AC8B (T6) alloy reinforced with Saffil fibre RG Grade

Volume Fraction (Vf)	Vickers hardness number (HV 10)
0	131
0.12	179
0.18	190
0.24	212

Table 5 UTS and strain to failure for composites made from various alloys with Saffil fibre RF Grade

Matrix	Volume Fraction (Vf)	UTS (Mpa)	Strain to failure(%)
Al	0.20	188	4.0
Al-2.5Mg	0.20	196	3.3
Al-10Mg	0.20	280	1.3
Al-6061	0.20	425	1.2
AC8B	0.18	325	0.6

Table 6 Compositions of alloys referred to in these datasheets

	Si	Fe	Cu	Mg	Zn	Ni
SAE339	12.0	<1.2	2.25	1.0	<1.0	1.0
AA332	9.5	<1.2	3.0	1.0	1.0	-
AC8A	12.5	0.8	1.1	0.9	0.02	1.57
AC8B	8.5-10.5	<1.0	2.0-4.0	0.5-1.5	<0.5	0.5-1.5
LM13	10.0-13.0	<1.0	0.7-1.5	0.8-1.5	<0.5	<1.5
6061	0.4-0.8	0.7	0.15-0.4	0.8-1.2	0.25	-

Table 7 Tensile data at 25°C for Al 6061 (T6) alloy reinforced with 20% v/v Saffil fibre produced by powder metallurgy route.

Direction	Modulus (GPa)	0.2% Proof Stress(MPa)	UTS (MPa)	Strain to failure (%)
Longitudinal	94	383	475	1.9
Transverse	91	378	434	1.5

Table 8

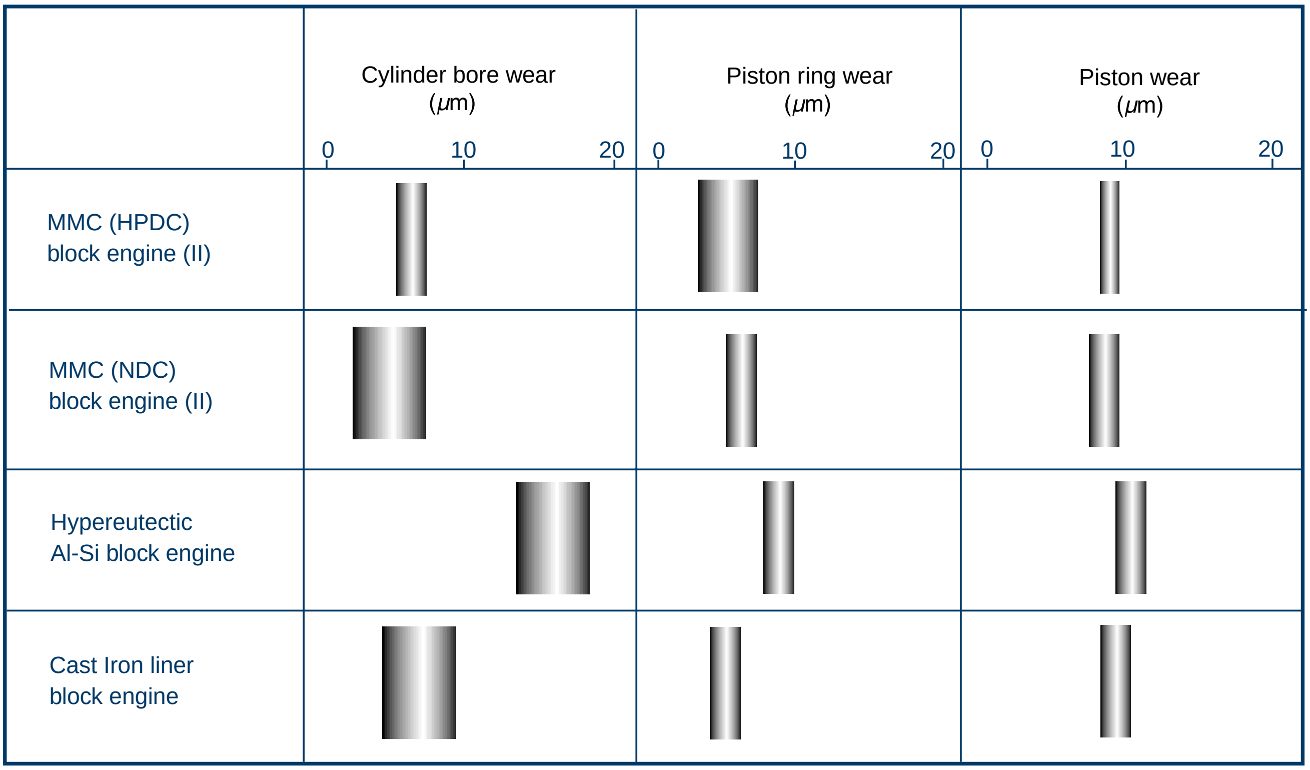
Evaluation of Cylinder Block Types

Items \ Cylinder Block Types			HPDC				NDC	LPDC/GDC		
			With Liner			Liner-Less				
			Cast-iron liner	One piese Cast-iron liner	A1 liner MMC,PM	MMC Type - II	Plating (Ni-SiC)	Plating (Ni-SiC)	Hyper-eutectic Al-Si	Cast Iron (mono)
ENGINE FUNCTIONS	Weight Reduction		—	—~○	○	◎	◎	◎	◎	×
	Compactness		—	○~◎	—~○	◎	◎	◎	◎	◎
	Engine Performance	Max Power	—	—	○	◎	◎	◎	◎	×
		Max Torque	—	—	—~○	◎	◎	◎	◎	◎
	Fuel consumption (10-15 mode)		—	—	—~○	◎	◎	◎	◎	×
	Drivability (0-100km/hr)		—	—	—~○	◎	◎	◎	◎	◎
	SUMMARY		—	—~○	—~○	◎	◎	◎	◎	—
PRODUCTION PROCESS/COST	Cost		—	△~—	△	△~—	△	×	×	○
	Investent in equipment		—	△~—	△~—	△~—	△	×	×	×
	Production process		—	—	—	△~—	△	×	×	×
	LCA		—	△~—	△~—	○	△	×	△	×
	SUMMARY		—	△~—	△~—	—	△	×	×~△	△
TOTAL SUMMARY			—	—	—	○	—~○	—	—	△~—

good ← ◎ ○ — △ × bad

Table 9

Effect of cylinder bore material on wear (50,000-mile fleet durability test)



Data in tables 8 and 9 courtesy of Honda Motor Co.