DEVELOPMENT AND TESTING OF CARBON PISTONS

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INTRODUCTION

The research department of Daimler-Benz has been developing carbon pistons for combustion engines for about 3 1/2 years. In this context "carbon" means graphite without the addition of reinforcing fibres.

Although the development of the material would itself without doubt be an essential topic, this paper is restricted to the application of the material and treats the matter from the view of a mechanical engineer.

The project "Development of Carbon Pistons" is a joint project in which several partners and sub-contractors are working together and is sponsored by the German Ministry for Research and Technology.

REASONS FOR THE DEVELOPMENT OF CARBON PISTONS

Today, aluminum alloy is generally used for mass produced pistons. However, graphite has several advantages in comparison with aluminum. The most important differences are shown in Fig. 1.

The density of graphite is much lower than that of aluminum alloy. other favorable properties of graphite are the lower coefficient of thermal expansion and the higher resistance to heat. Unfavorable is that the tensile strength of graphite at room temperature is comparatively low. However, considering the tensile strength as a function of temperature, as shown in Fig. 2, you see that the strength of aluminum alloy drops at temperatures above 160 °C. In contrast to this the tensile strength of graphite even increases slightly with temperature.

On the basis of these graphite material properties the following advantages can be expected if the material is applied to pistons:

- a reduced piston weight because of the lower material density,
- a smaller piston clearance because of the low coefficient of thermal expansion.
- Furthermore, it can be expected that the carbon piston transmits less noise because of the material's damping capacity.
- Another advantage of graphite are the excellent emergency frictional properties, which make piston scuffing impossible.

These were the advantages which triggered our development of carbon pistons. As we will see later on, the carbon piston lived up to our expectations, and showed even more improvements.

DESIGN AND FABRICATION

A carbon piston was designed and built to fit into an existing production engine. As a test bed, the engine of the Mercedes-Benz model 190 E was chosen. This engine is a 4-stroke-4-cylinder-gasoline engine with a displacement of 2 litres and a bore of 89 mm.

Carbon pistons were manufactured by turning and milling from the solid with the aid of numerically controlled machines. The material for the pistons came from Poco Graphite, Inc., Decatur, Texas, which had the highest strength of all standard grades in the market.

TESTS OF FUNCTIONALITY AND DURABILITY

After the first carbon pistons were built, their functional test followed. At first, only one carbon piston was installed in the 4-cylinder engine, which was mentioned before, together with 3 standard pistons. The carbon piston was equipped with standard piston rings and a normal connecting rod but with a ceramic piston pin of silicon nitride. The engine was tested on a simple engine bench. This bench was used employing a moderate test program with alternating loads.

After 56 hours on the bench the engine was dismantled for inspection. The carbon piston and the ceramic piston pin were in an excellent condition.

At the beginning of 1989 an engine was equipped for the first time with 4 carbon pistons and 4 ceramic piston pins. The carbon pistons and the ceramic piston pins had thicker walls than the conventional metallic parts to compensate for the inferior strength. In spite of this fact the total weight of the carbon pistons and the ceramic piston pins was 20 % less than that of the corresponding metallic production parts.

This first engine, which was completely furnished with carbon pistons, was tested for 120 hours on the bench according to a rather severe test program, where almost 40 % of the running time the engine was at full load. In this program the engine was under much more load than in normal road traffic. After 120 hours the engine was disassembled and the carbon pistons and the ceramic piston pins were inspected. All components were in an excellent condition, and could be used again.

Thus the engine was reassembled and installed in a test car - a Mercedes-Benz model 190 E. In this car the engine with carbon pistons accumulated more than 15 000 miles without any trouble. The car was used by all colleagues of our department on public roads - i. e. in city - and long distance traffic. In consideration of the safety of the driver, the engine speed was restricted not to exceed

4 000 rpm. This was the only restriction.

During the road test the engine performed very well all the time. Compression graphs, which were taken before and after a distance of 15 000 miles, indicated no difference and thus a continuing good engine condition. Fig. 3 shows a carbon after 120 hours on the engine bench and 15 000 miles in the test car.

COMPARISON MEASUREMENT

After the function and a sufficient service life of the engine with carbon pistons had been established, exact measurements could be started. With the aid of these tests the expected and possible other advantages of carbon pistons in comparison to today's production pistons should be evaluated.

For the comparison measurements only one engine was used to avoid the influence by tolerances of different engines. So at first all tests were performed with carbon pistons. Then the carbon pistons and the ceramic pins were replaced by their series counterparts.

The evaluations concerned mainly the following items:

- fuel consumption
- oil consumption, and
- exhaust emissions

Fuel consumption and exhaust emissions were determined in an official test program, which is called 14-points-CVS-test. This test corresponds to city traffic.

The oil consumption was measured in a special trial run. In this test, the engine continuously ran for three hours under full load conditions at an engine speed of 4500 rpm.

The most important results of the comparison measurements are compiled in Fig. 4. All data are relative and related to the production engine with aluminum pistons. This figure indicated that the engine with carbon pistons performed better in all points than the production engine. Concerning exhaust emissions the improvements with the engine using carbon pistons were 20 % with respect to hydrocarbons (HC), 30 % concerning carbon monoxide (CO), and 3 % concerning nitrogen oxides (NO_x). A slight improvement of 3 % was also achieved with respect to fuel consumption. The largest improvement, however, was observed in oil consumption. The carbon piston engine consumed only 44 % of the lubricating oil which the standard engine needed.

CONCLUSIONS

With the use of top quality graphites, which are available on the market, it was possible to reduce the piston weight by 10 %. Another weight reduction of 10 % was realized by the application of a ceramic piston pin. Thus in a first approach the weight of the piston/piston pin assembly was already 20 % less than with the corresponding production parts.

Function and service life could be demonstrated up to a maximum engine speed of 5 100 rpm.

Comparative tests so far revealed no disadvantages for the engine with carbon pistons. Slight improvements - in the order of 3 % - were measured with respect to power output and fuel consumption. However, one must bear in mind that all improvements were attained by a simple replacement of successful production components. Up to now, no optimization has been undertaken - neither of the carbon piston nor of the engine with respect to the special properties of graphite.

The engine with carbon pistons showed very important and clear improvements concerning exhaust gas emissions and oil consumption. Therefore, the application of carbon pistons could help to reduce environmental pollution, and to extend the useful life of the catalyst. The improvement regarding the emission of hydrocarbons is especially essential, because this constituent is difficult to diminish when the catalyst is not yet at operating temperature.

Before the carbon piston will be suitable for mass production there are at least two pre-requisites which have to be accomplished: Firstly, the tensile strength of the graphite must be improved. This is necessary to allow at the same time a further weight reduction of the piston, and to meet the requirements of full engine speed.

Secondly, economic production methods must exist which are suitable for series production.

			Aluminum alloy	Graphite
Density	ρ	g/cm^3	2.70	1.83
Coefficient of linear expansion	α	1/K	$21 \cdot 10^{-6}$	$6 \cdot 10^{-6}$
Modulus of elasticity	E	GPa	80	11
Thermal conductivity	λ	W/mK	150	80
Maximum temperature	t	°C	380	460
Tensile strength	σ_B	MPa	225	70

Figure 1. Material Data of Aluminum Alloy and Graphite

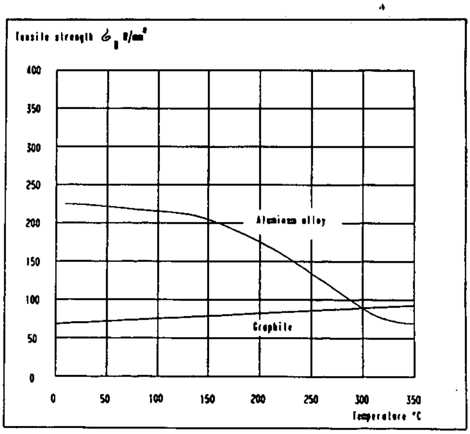

Figure 2. Tensile Strength of Aluminum Alloy and Graphite

Figure 3. Carbon Piston after 120 hours on Engine Bench and 15000 miles in Test Car.

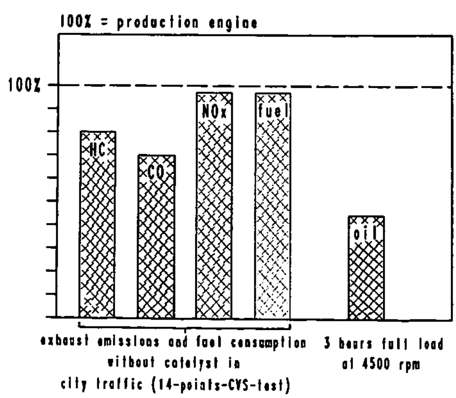

Figure 4. Engine with Carbon Pistons compared to Production Engine.