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Carbon-Carbon Piston Development

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Summary

Pistons for internal combustion engines have been made of such materials as cast iron, steel and aluminum. Most pistons manufactured today are made of aluminum. However, aluminum has low strength and stiffness at elevated temperatures, and aluminum has a large coefficient of thermal expansion. A new piston concept, made of carbon-carbon refractory-composite material, has been developed that overcomes a number of the shortcomings of aluminum pistons. Carbon-carbon material, developed in the early 1960's, is lighter weight than aluminum, has higher strength and stiffness than aluminum and maintains these properties at temperatures over 2500°F. In addition, a low coefficient of thermal expansion and a high thermal conductivity give carbon-carbon material excellent resistance to thermal shock. An effort, called the Advanced Carbon-Carbon Piston Program was started in 1986 to develop and test carbon-carbon pistons for use in two-stroke-cycle and four-stroke-cycle engines. The carbon-carbon pistons developed under this program were designed to be replacements for existing aluminum pistons, use standard piston pin assemblies and use standard ring sets. The purpose of the engine tests was to show that pistons made of carbon-carbon material could be successfully operated in a two-stroke-cycle engine and a four-stroke-cycle engine.

Carbon-carbon pistons can potentially enable engines to be more reliable, to be more efficient (lower hydrocarbon emissions, greater fuel efficiency), and to have greater power output. By utilizing the unique characteristics of carbon-carbon material — very low expansion rate, low weight, high strength and stiffness at elevated temperatures, and high thermal conductivity — a carbon-carbon piston can (1) have greater resistance to structural damage caused by overheating, lean air-fuel mixture conditions and detonation, (2) be designed to be lighter-weight than an aluminum piston thus, reducing the reciprocating mass of an engine, and (3) be operated in a higher combustion temperature environment without failure.

Evolution of the Engine

The first commercially successful internal combustion engine was patented by a French inventor named Jean Joseph Etienne Lenoir in 1860 (ref. 1). In 1876 the four-stroke-cycle, spark-ignition engine was introduced by Nickolaus Otto. The introduction of the gasoline-powered automobile by Charles and Frank Duryea in 1895 and the gasoline-powered airplane by Orville and Wilbur Wright in 1903 created a worldwide market for the engine. The early spark-ignition engines that powered these vehicles had weight-power ratios of approximately 15.0 lb/bhp (ref. 2). These engines used compression ratios of only 4-to-1 because the gasolines available during this period had low-octane values and poor anti-knock (autoignition) qualities. In 1908 Henry Ford introduced his first Model T Ford automobile, and within three years more than a half-million automobiles had been sold (ref. 1). By 1918 the airplane had evolved from a novelty to a vehicle that was designed to meet specific military needs. Improvements in the design of the engine, advancements in the processing of fuels, and refinements in the production of metals led to substantial reductions in the weight-power ratio of the internal combustion engine. By the mid 1930's aircraft such as the DC-3 were powered by high performance piston engines such as the Wright Cyclone engine that produced 1000 horsepower and the Pratt & Whitney R-1830 engine that produced 1200 horsepower (ref. 3).

In the late 1950's compact automotive V-8 engines made of cast iron were introduced with aluminum alloy pistons as standard production parts. Aluminum alloy pistons had significant advantages as compared to cast iron and steel pistons; the aluminum pistons were much lighter and could dissipate heat more rapidly. In the 1970's and 1980's, government regulations and rising fuel costs prompted automobile manufacturers to build vehicles that had lower exhaust emissions and greater fuel economy. The manufacturers responded by building engines and auxiliary components that dramatically reduced exhaust emissions; by building vehicles with lower aerodynamic drag; and by building body, chassis, and engine components made of lighter weight materials such as high strength steels, aluminum alloys, and composite materials. During this period the popularity of motorcycles, snowmobiles and outboard engines for boats steadily increased which, in turn, fostered the development of two-stroke-cycle engines with low weight-power ratios. Today, new types of weight sensitive vehicles such as personal watercraft (jet skis), ultralight aircraft and light hovercraft have become generally available because of the development of two-stroke-cycle engines with low weight-power ratios.

The development of the internal combustion engine has historically been an evolutionary process that has been driven by the conflicting requirements of performance, economics and a concern for the environment. The quest for higher performance has been, by far, the strongest driver in this evolutionary process. The introduction of new materials and improvements in the processing of existing materials have created many opportunities for significant advances in the performance of the engine. High performance spark-ignition engines available today have weight-power ratios of less than 1.0 lb/bhp.

Aluminum Pistons

The piston is one of the most important components in the internal combustion engine. The piston must perform many functions simultaneously while operating in a very hostile environment; the piston must withstand rapidly changing pressure loads, dynamic forces, and thermal conditions. Today, most pistons are made of aluminum which is relatively light weight, easy to manufacture and low in cost. The use of aluminum as a piston material does, however, have disadvantages. The strength and stiffness of aluminum rapidly decrease above 350°F; the melting temperature of aluminum is approximately 1100°F; and the coefficient of thermal expansion (CTE) of aluminum is relatively large (refs. 4 and 5).

Aluminum pistons used in low and medium performance engines are very reliable and operate for extended periods without maintenance. However, aluminum pistons used in high performance engines have lower reliability and require more frequent maintenance. High performance engines are generally designed to have low weight and high power output. These engines are usually setup to operate at moderately high power output levels for extended periods or at maximum power output levels for short periods. These types of operational envelopes subject the piston to high temperatures and high pressure loads at a time when the mechanical properties of the aluminum alloy are low. In addition, because the pistons are exposed to a wide range of operating temperatures they must be designed with relatively large clearances between the skirt and the cylinder wall to allow for thermal expansion.

Engines typically operate with exhaust gas temperatures between 1100°F and 1250°F. Engines operating with lower exhaust gas temperatures are inefficient and may have problems with spark plug fouling. High performance engines operate with exhaust gas temperatures at about 1275°F. If exhaust gas temperatures exceed 1350°F because of lean air-fuel mixture conditions or if pressure loads dramatically increase because of detonation, piston failure is likely. Local melting of the crown of the piston is a typical failure mode. In severe cases, a hole can be blown through the crown of the piston. Another common failure, piston seizure, occurs when a piston expands to the diameter of the cylinder causing metal-to-metal contact between the piston and the cylinder wall. Because of these and other problems, the operation of a high performance engine must be constrained to a range such that the aluminum pistons can maintain their structural integrity.

Carbon-Carbon Pistons

Piston Concept

A new piston concept has been developed that overcomes a number of the shortcomings of aluminum pistons. The new piston concept is made of carbon-carbon refractory composite material [refs. 6-11]. The carbon-carbon (c-c) piston was developed as a replacement for an aluminum piston used in a two-stroke-cycle engine. The engine was used to power a U.S. Army remotely piloted vehicle. The aluminum piston and its carbon-carbon piston replacement are shown in figure 1. A cooperative effort, called the Advanced Carbon-Carbon Piston Program, was started in 1986 involving NASA Langley Research Center and the U.S. Army, Fort Eustis, Virginia. The first objective was to develop and test an all-carbon-carbon piston for use in the two-stroke-cycle engine. The second objective was to transfer the carbon-carbon piston technology to engines used in light aircraft, automobiles and other types of transport vehicles, i.e., four-stroke-cycle engines.

Material

Carbon-carbon refractory-composite material was developed in the early 1960's for use on the nose cone and in the rocket nozzle of missiles. Today, this unique high-temperature material is also used on the nose cone and wing leading edges of the Space Shuttle, on the brakes of large commercial aircraft, and on the clutches and brakes of Formula 1 racing cars. Carbon-carbon material is lighter in weight than aluminum, has higher strength and stiffness than aluminum and maintains these properties at temperatures over 2500°F as shown in figure 2. In addition, a low coefficient of thermal expansion and a high thermal conductivity give carbon-carbon material excellent resistance to thermal shock [refs. 12, 13 and 14]. Properties of aluminum and carbon-carbon piston materials are given in table 1. The physical properties of carbon-carbon material, like most other composite materials, can be tailored to meet specific requirements. Properties such as modulus of elasticity, thermal conductivity and tensile strength can be increased or decreased significantly depending upon precursor materials and processing [12]. Because the mechanical properties of carbon-carbon material do not decrease at elevated temperatures, an engine, using c-c pistons, can be operated in a manor not normally possible for an engine with aluminum pistons. An engine can be operated with exhaust gas temperatures greater than 1350°F without piston failure, with leaner air-fuel ratios to obtain greater fuel economy and lower exhaust gas emissions, and with greater reliability at high power output levels.

Two types of carbon-carbon pistons have been developed under the Advanced Carbon-Carbon Piston Program. These pistons are shown in figure 3. Pistons labeled 1 and 2 are designed for use in a four-stroke-cycle engine, and pistons labeled 3 and 4 are designed for use in a two-stroke-cycle engine.

Design

The carbon-carbon pistons shown in figure 3 are facsimiles of their respective original aluminum pistons. These refractory composite pistons were designed to be interchangeable with the original aluminum pistons, and use the same sealing rings, piston pin and circlips as used on the aluminum pistons. The carbon-carbon pistons tested in the two-stroke-cycle engine use a slipper skirt design, two compression rings, and a full floating piston pin that is restrained in the pin bore by a circlip and a machined shoulder. The three-ring carbon-carbon piston tested in the four-stroke-cycle engine uses a full skirt design, two compression rings and an oil control ring, and a full floating piston pin that is restrained by two circlips. The two-ring carbon-carbon piston tested in the four-stroke-cycle engine uses a full skirt design, two compression rings, and a full floating piston pin that is restrained in the pin bore by a circlip and a machined shoulder.

Manufacture of Carbon-Carbon Pistons

Fabrication Techniques

Four fabrication techniques have been examined in an effort to develop a low-cost, high-volume process for manufacturing pistons made of carbon-carbon refractory-composite material. The first set of pistons were fabricated by machining a piston from a solid billet of carbon-carbon material. However, this billet machining process was not an economical method of manufacture — a piston manufactured using this technique cost approximately $2000 in 1990. A second fabrication technique involved the use of a knitted preform and a ceramic mold. Although no pistons were fabricated using this technique, molding could potentially be a low-cost method of manufacture. A third fabrication technique involved the use of a carbon-carbon crown insert and an aluminum piston body. The fabrication of two pistons has been attempted using this technique; however, this technique has not been fully developed. A fourth fabrication technique involved the use of a number of preformed parts assembled by conventional composite hand lay-up methods. This technique has been a successful means of fabricating pistons in small quantities. Under the Advanced Carbon-Carbon Piston Program, a total of 24 carbon-carbon pistons have been fabricated; 6 pistons were machined from billet material, and 18 pistons were fabricated using woven carbon-fiber material and the hand lay-up method.

Processing

The pistons shown in figure 3 were manufactured using the conventional composite hand lay-up method. A schematic drawing illustrating this construction method, the most economical method of fabrication to date, is shown in figure 4. A piston is assembled from four parts: a crown, a thin-wall cylinder and two shoulder inserts. Each part is fabricated using woven carbon-fiber cloth and phenolic resin. The crown and shoulder inserts are premolded and cured to near-net-shape. A tapered shoulder is machined around the perimeter of the crown, and one side of each insert is machined to form an arc. The crown and shoulder inserts are positioned together, then woven carbon-fiber material is wrapped around the crown and the two inserts to form a skirt. The assembly is inserted into a vacuum bag, placed into an autoclave, and co-cured at approximately 350°F. After the initial cure cycle has been completed, the assembly is subjected to a series of carbonization and densification steps. This high-temperature processing is necessary to form the carbon-carbon material. The processing takes place in a nitrogen atmosphere furnace with a typical temperature profile consisting of slowly heating a part to 1600°F, holding at this temperature for approximately two hours followed by a slow cool down sequence to room temperature. The part is removed from the furnace, re-impregnated with phenolic resin, cured, and placed back in the furnace for re-carbonization. The part is subjected to four densification and carbonization cycles to form a carbon-carbon refractory composite material called ACC-4.

After the densification processing has been completed, the piston is machined to size, then the crown region is coated with an oxidation barrier. The piston is first machined to the required diameter, grooves for the ring lands are machined into the side of the crown, then a hole for the piston pin is machined through the skirt and shoulder inserts. All of the machining is completed using standard techniques, conventional cutting and drilling bits (high speed steel and carbide bits), and slow feed rates. The cutting and drilling bits did, however, require frequent resharpening; diamond burrs were found to be very effective for milling operations. After the rough machining had been completed, the piston was subjected to an additional high-temperature processing step to form a silicon carbide (Si/C) conversion coating. The coating encapsulates the crown and the first ring land area of the piston. This barrier coating protects the crown of the carbon-carbon piston from oxidizing, especially in regions close to an exhaust port or exhaust valve. Unprotected carbon-carbon material will react with high-temperature oxygen at temperatures over 800°F and decompose. The high-temperature oxygen is a by-product of the combustion process during normal engine operation. The Si/C conversion coating process produces a coating thickness of approximately 0.014 inches. The process used to create the Si/C conversion coating is similar to the carburizing of steel. After formation of the conversion coating, the piston is machined to final size (ring lands, piston diameter and piston pin bore). Diamond cutting tools were necessary in these machining operations because of the high hardness of the silicon carbide coating.

The repetitive nature of the densification and carbonization cycles, and the high temperature processing required for these cycles contribute greatly to the expense of fabricating a piston. The cost of an experimental 2.6-in.-diameter, 5.466-ounce mass piston (170 grams), made in quantities of ten using conventional composite hand lay-up methods, is approximately $200 per piston in 1993.

Testing of Pistons

Two-Stroke-Cycle Engine

The first type of engine used to test the carbon-carbon pistons was a commercially available two-stroke-cycle, 090 Stihl chain saw engine. This one-cylinder, air-cooled engine had a displacement of 8.36 cubic inches. The engine was equiped with a specially impregnated aluminum cylinder wall; the piston was equiped with two cast iron compression rings. The engine test apparatus consisted of the 090 Stihl chain saw engine (the handle and blade assembly were removed) connected to a water brake dynamometer with a centrifugal clutch and flexible coupling. The engine was instrumented with four thermocouples to sense temperatures — exhaust gas temperature, spark plug temperature, cylinder head temperature and ambient air temperature. The dynamometer was instrumented with a load cell to sense torque loads from the engine and a magnetic pick-up assembly to sense crankshaft rpm. Once the engine was started it was controlled by a remotely located throttle and operated within the manufacturer's specifications for normal use.

Four-Stroke-Cycle Engine

The second type of engine used to test the carbon-carbon pistons was a commercially available four-stroke-cycle, 5 hp Briggs and Stratton industrial engine. This one-cylinder, air-cooled engine had a displacement of 12.57 cubic inches. The engine was equiped with a cast iron cylinder liner; the piston was equiped with two compression rings and an oil control ring. The first compression ring was made of chrome-plated cast iron, the second ring was made of cast iron, and the oil control ring was comprised of two thin chrome-plated steel rings separated by a stamped steel cage. The dynamometer and instrumentation setup used for these tests was similar to the setup used for the two-stroke-cycle engine. However, an additional thermocouple probe, which penetrated the side of the engine crankcase, was used to monitor oil temperature. Once the engine was started it was controlled by a remotely located throttle and operated within the manufacturer's specifications for normal use.

Results and Discussion

Engine Testing

The purpose of the engine tests was to demonstrate that pistons made of carbon-carbon material could be successfully operated in a two-stroke-cycle engine and a four-stroke-cycle engine. For each type of engine, the c-c pistons were designed and fabricated to resemble closely their aluminum counterparts. However, because of compromises made during the development of the pistons, and during the fabrication of the carbon-carbon material, differences in piston mass and geometry were difficult to avoid. None of the advantages of the carbon-carbon material were utilized in the design of these pistons. In addition, no attempts were made to enhance the performance of either engine.

Testing began with the operation of an aluminum piston in the two-stroke-cycle engine. This piston was used to establish an operating range for the various temperature and torque measurements. Next, the aluminum piston was removed from the engine, the carbon-carbon piston was installed, and the test was repeated. The same process was followed for the testing of the pistons in the four-stroke-cycle engine. The temperature measurements were made to ensure that the aluminum and c-c pistons were tested under comparable conditions. The torque measurements were taken to determine the relative performance of the aluminum and c-c pistons. Torque output, as a function of crankshaft rpm, for the two-stroke-cycle engine and for the four-stroke-cycle engine are shown in figures 5 and 6, respectively. The variations in torque output were most likely a result of differences between the experimental carbon-carbon pistons and the production aluminum pistons. Factors such as compression ratio, cylinder wall finish, carburetion, and ignition timing were not changed from test to test, only the piston assembly (piston, rings, circlips, piston pin, and needle bearing in the case of the two-stroke-cycle engine) was changed.

Two-Stroke-Cycle Engine

The differences in performance between the carbon-carbon piston and aluminum piston tested in the two-stroke-cycle engine were most likely related to variations in piston mass and geometry. The c-c piston (4.630 ounce mass, 144 grams) had a mass 23% less than its aluminum counterpart (6.044 ounce mass, 188 grams). Although the c-c piston was originally designed to have approximately the same mass as the aluminum piston, significant amounts of c-c material were removed from the skirt area around each pin boss. This material was removed in an effort to match the transfer port geometry that was molded into the side of the aluminum piston. See figure 1. In addition, the c-c piston was machined such that it would have a sliding fit inside the cylinder (approximately 0.0015 in. clearance at room temperature).

Another factor that may have affected engine performance was the fit of the two compression rings. The rings were considered to have an acceptable fit in their respective ring lands, however, the fit of each ring with the locating pins was less than desirable. A 1/32-in.-diameter rolled steel pin, positioned in the center of each ring land, was used as a locating pin. The rolled pin was held in place by a light press fit; the ends of each ring were modified to have a close fit around the pins. A rolled pin, as opposed to a conventional solid pin, was considered necessary because of the press fit used to retain the pin, and the differences in CTE between c-c and steel. A solid pin with a light press fit would most likely cause the carbon-carbon material to fracture, at operating temperature, due to the thermal expansion of the steel.

When the c-c piston was tested in the engine it did not seize, or produce any audible or visual abnormalities (slapping noise, excess smoke) as compared to that generated by the aluminum piston. These qualitative observations indicate that there was an acceptable clearance between the c-c piston and the cylinder wall. The difference in piston mass may be the most significant factor that contributed to a shift in the torque output measurements. The carbon-carbon piston used in the two-stroke-cycle engine was tested for approximately 1 hour.

Four-Stroke-Cycle Engine

The variations in performance between the carbon-carbon pistons and the aluminum piston tested in the four-stroke-cycle engine were most likely related to piston geometry. The two-ring c-c piston was equiped with only two compression rings and no oil control ring. This piston was designed and tested before the three-ring piston, and was fabricated with only two rings because of tooling restrictions. The piston was machined to have the same diameter and ring land dimensions as the aluminum piston. Using this piston, the four-stroke-cycle engine produced an acceptable level of torque output, however, the engine would operate for only 15 minutes then, it would stop — 7 ounces of motor oil would be consumed during testing and the spark plug would foul. There was a significant amount of oil smoke mixed with the exhaust stream during engine operation. The two-ring c-c piston was tested for approximately 1/2 hour (two 15-minute tests).

The three-ring c-c piston, fabricated using new tooling, was designed to overcome the oil consumption problem experienced with the two-ring piston, and to address the sensitive area of ring land geometry. The height of the two compression ring lands machined into the three-ring c-c piston was greater than the height used on the aluminum piston. This modification was made to compensate for the expansion of the cast iron rings. Cast iron has a coefficient of thermal expansion approximately three times greater than that of carbon-carbon whereas cast iron has a coefficient of thermal expansion approximately one-half that of aluminum [refs 4 and 15]. This ring land height was most likely not an optimum for the material combination of carbon-carbon and cast iron.

Another factor related to piston geometry was the fit of the piston in the cylinder. The three-ring c-c piston was machined to have the same exterior dimensions as its aluminum counterpart. The clearance between the cylinder wall and the piston, at room temperature, was 0.004 in. When the c-c piston was tested in the engine, at operating temperature, it produced an audible slapping noise that was not present during the testing of the aluminum piston. The occurrence of this noise indicates that the c-c piston had a larger clearance between it and the cylinder wall than did the aluminum piston. There was no observable smoke in the exhaust stream during engine operation nor was there a reduction in the oil level in the crankcase after the engine test. In the case of this three-ring c-c piston, the piston/cylinder wall clearance and ring land clearance may have contributed to poor sealing of the combustion chamber causing the engine to produce a lower level of torque output, as shown in figure 6. The three-ring c-c piston used in the four-stroke-cycle engine was tested for approximately 2 hours.

The mass difference of the carbon-carbon and aluminum pistons was also an area of investigation. The two-ring c-c piston (4.115 ounce mass, 128 grams) had a mass 9% less than the aluminum piston (4.533 ounce mass, 141 grams); in addition, this piston did not use an oil control ring (0.289 ounce mass, 9 grams) and had only one circlip (0.013 ounce mass, 0.4 grams). The three-ring c-c piston (4.308 ounce mass, 134 grams) had a mass 5% less than the aluminum piston. In both cases, the mass difference was probably not a significant factor.

Conclusions

The development and testing that has taken place under the Advanced Carbon-Carbon Piston Program has shown that pistons can be manufactured from carbon-carbon refractory-composite materials and that a carbon-carbon piston can be successfully operated in an internal combustion engine. A total of eight pistons have been successfully operated in two types of engines; five pistons in a two-stroke-cycle engine and three pistons in a four-stroke-cycle engine.

Carbon-carbon material has many unique characteristics that can be utilized in the design of pistons. Carbon-carbon material has a lower density than aluminum; has higher strength and stiffness than aluminum and maintains these properties at temperatures over 2500°F; has a low coefficient of thermal expansion; has high thermal conductivity; and has excellent resistance to thermal shock. Carbon-carbon pistons can be designed to replace existing aluminum pistons, and use standard sealing ring and piston pin assemblies. By utilizing all of the physical properties of carbon-carbon refractory-composite material, pistons can be made lighter-weight to reduce the reciprocating mass of an engine; pistons can be made to have improved structural reliability when used under the same operating conditions as aluminum pistons; and pistons can be made to have a lower piston-to-cylinder wall clearance.

Carbon-carbon pistons can potentially enable high-performance engines to be more efficient, be more reliable, and have greater power output. An engine equiped with c-c pistons can operate using leaner air-fuel mixtures because these pistons can function in higher combustion temperature environments without failure. An engine using leaner air-fuel mixtures can potentially produce more power, have fewer hydrocarbon emissions and/or have greater fuel efficiency. In addition, because c-c material retains its strength and stiffness at high temperatures, carbon-carbon pistons have greater resistance to structural damage caused by overheating, lean air-fuel mixture conditions, and high cylinder pressures that result from detonation.

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Table 1. Properties of aluminum piston casting alloy F332.1 T5 and carbon-carbon refractory-composite material ACC-4

Property (@77 °F)	Aluminum (F332.1 T5)	Carbon-Carbon (ACC-4)	
density	0.100 lb/in^3	0.058 lb/in^3	
coef. of therm. expan. ($\times 10^{-6}$)	11.7 in/in/°F	1.0 in/in/°F [a],	3.0 in/in/°F [b]
thermal conductivity	60.4 Btu/ft-h-°F	28.6 Btu/ft-h-°F [a],	2.8 Btu/ft-h-°F [b]
modulus of elasticity	10.6×10^6 psi	13×10^6 psi	
tensile strength	36×10^3 psi	40×10^3 psi	

a fiber direction
b perpendicular to fiber direction

ORIGINAL PAGE
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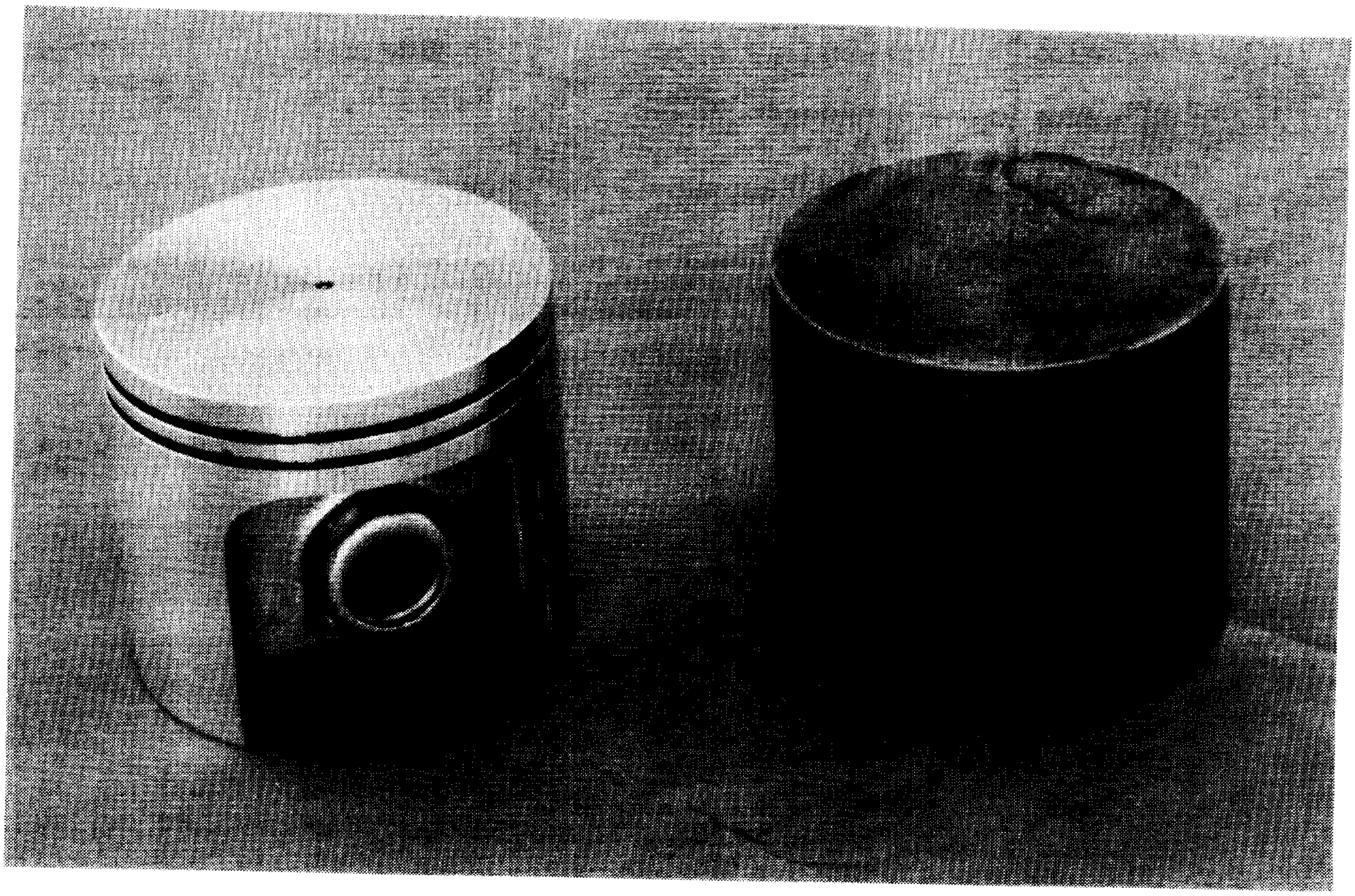

Aluminum piston

Carbon-carbon piston

Figure 1. Carbon-carbon piston and aluminum piston designed for use in a U. S. Army two-stroke-cycle, remotely-piloted vehicle engine.

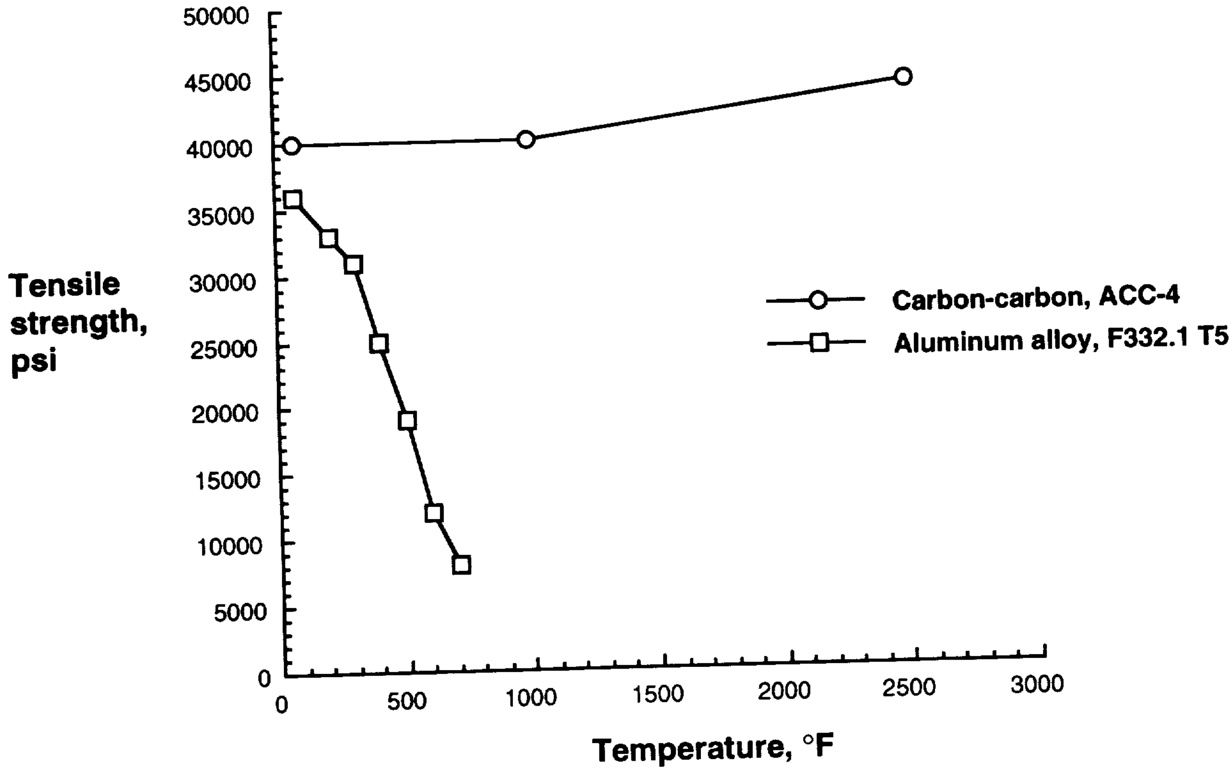

Figure 2. Tensile strength of carbon-carbon material ACC-4 and aluminum alloy F332.1 T5 as a function of temperature.

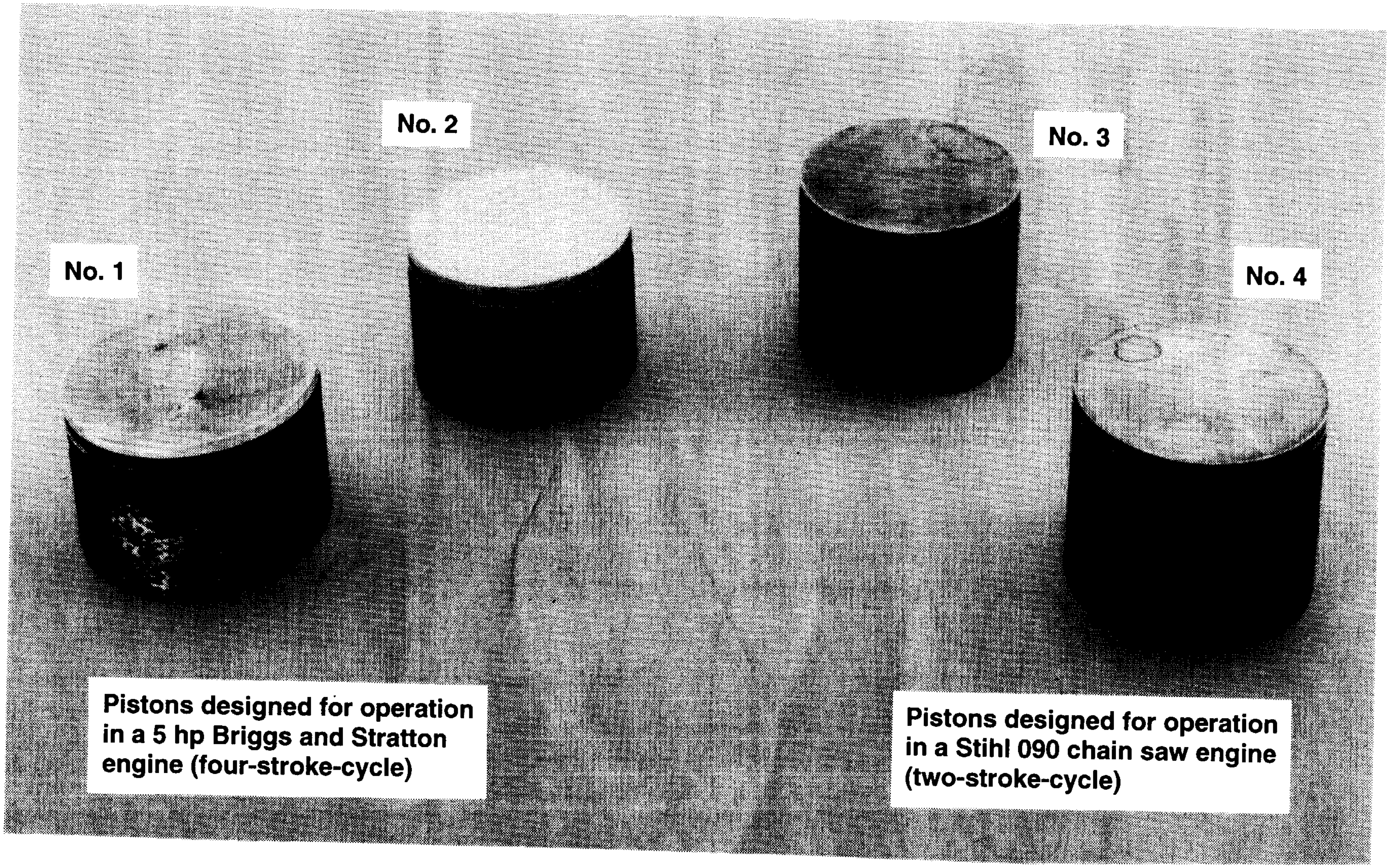

Figure 3. Carbon-carbon pistons.

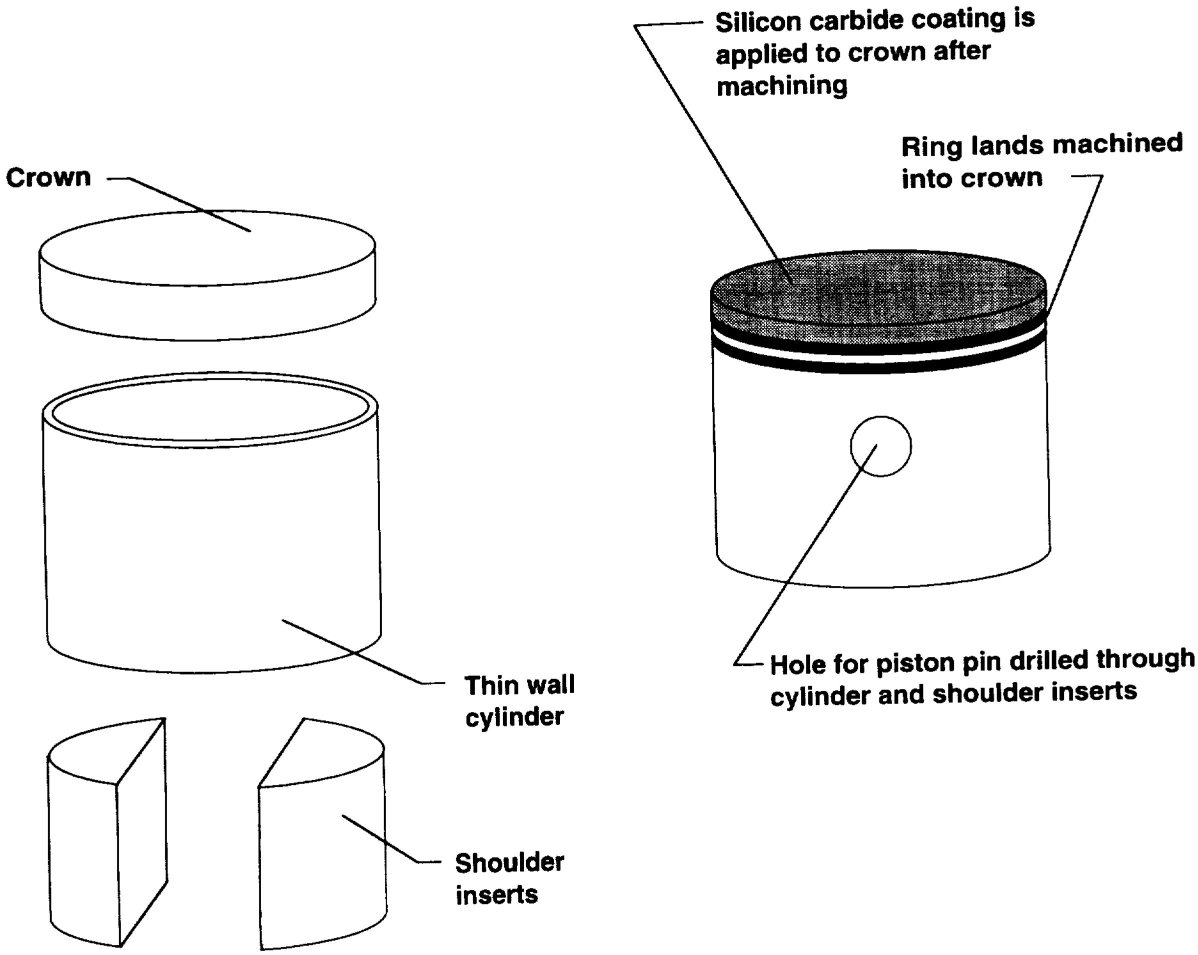

Figure 4. Carbon-carbon piston fabrication using conventional composite-material hand lay-up method.

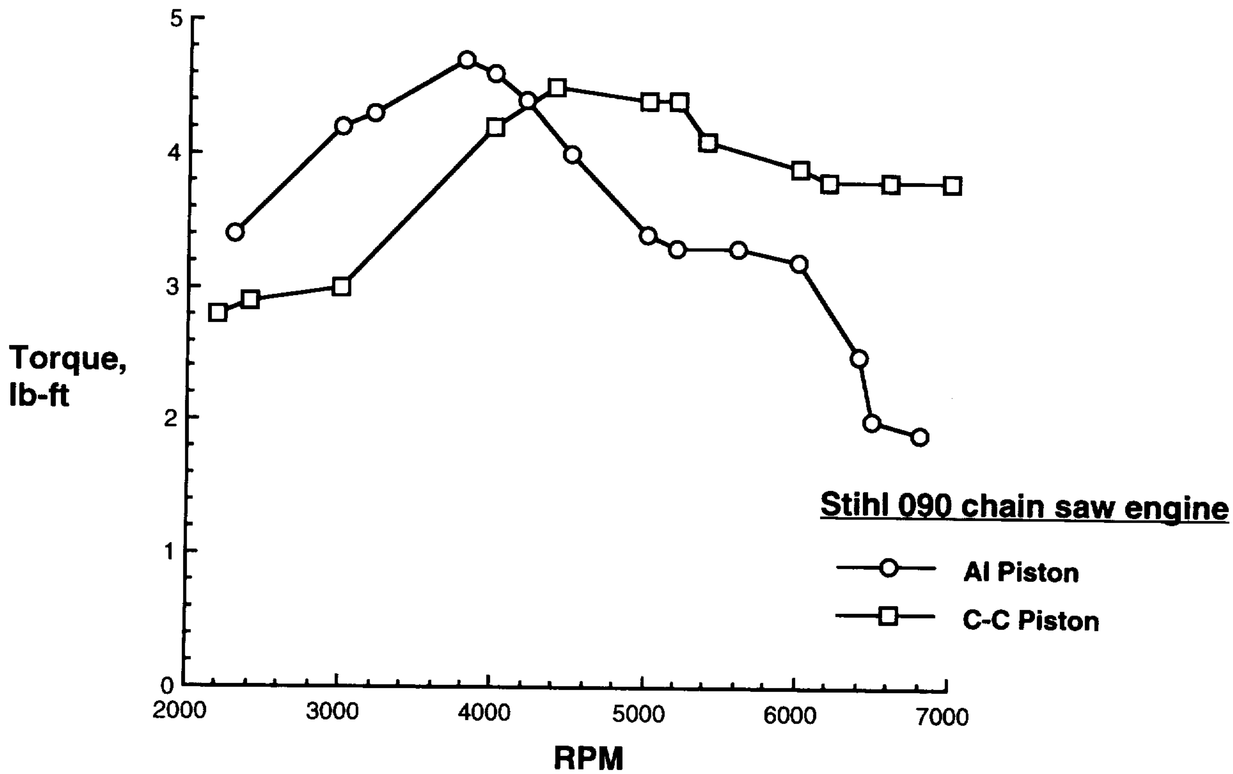

Figure 5. Two-stroke-cycle engine torque output as a function of crankshaft RPM.

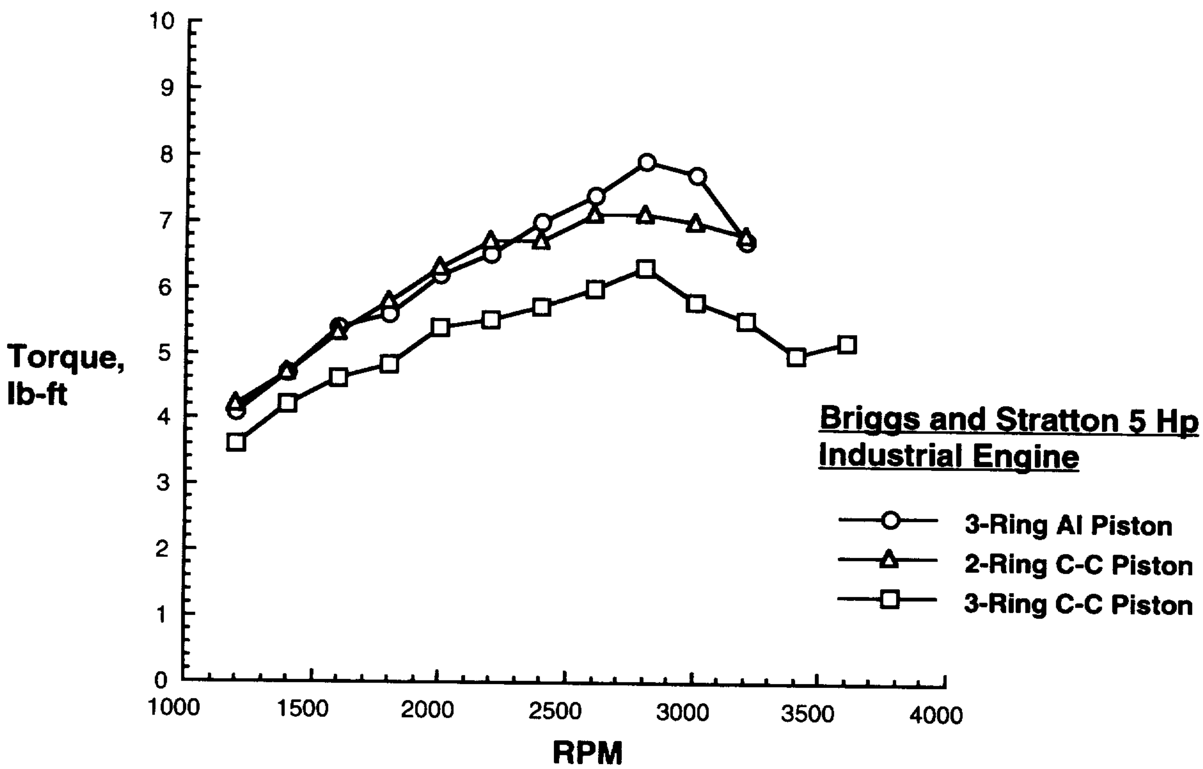

Figure 6. Four-stroke-cycle engine torque output as a function of crankshaft RPM.

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13. ABSTRACT *(Maximum 200 words)*

A new piston concept, made of carbon-carbon refractory-composite material, has been developed that overcomes a number of the shortcomings of aluminum pistons. Carbon-carbon material, developed in the early 1960's, is lighter in weight than aluminum, has higher strength and stiffnes than aluminum and maintans these properties at temperatures over 2500°F. In addition, carbon-carbon material has a low coefficient of thermal expansion and excellent resistance to thermal shock. An effort, called the Advanced Carbon-Carbon Piston Program was started in 1986 to develop and test carbon-carbon pistons for use in spark ignition engines. The carbon-carbon pistons were designed to be replacements for existing aluminum pistons, using standard piston pin assemblies and using standard rings.
Carbon-carbon pistons can potentially enable engines to be more reliable, more efficient and have greater power output. By utilizing the unique characteristics of carbon-carbon material a piston can (1) have greater resistance to structural damage caused by overheating, lean air-fuel mixture conditions and detonation, (2) be designed to be lighter in weight than an aluminum piston thus, reducing the reciprocating mass of an engine, and (3) be operated in a higher combustion temperature environment without failure.

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