Development of NASA High Strength Aluminum Alloy for Use in the Evinrude ETEC Outboard Engine.

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ABSTRACT

Reduced exhaust gas emissions for outboard engines has become a primary concern over the last 10 years. This paper discusses development of a high strength aluminum piston alloy specifically engineered to meet the unique requirements of a direct injected two stroke outboard engine with world class emissions levels.

PROBLEM DESCRIPTION

The two-stroke internal combustion gasoline engine has been a fixture in the outboard engine industry for nearly a century. This engine, when properly designed, is a mechanically simple, powerful, lightweight and low maintenance engine. In the mid-1990's, pending emissions legislation threatened to eliminate the carbureted two-stroke outboard engine from the market. Developments in direct injection (DI) technology re-invented the two-stroke outboard and in 1997 the first direct injected outboard engine was sold under the Evinrude and Johnson brand names.

As direct injection systems evolved and emissions requirements increased (see chart 1) so did engine piston temperatures. At the same time the outboard engine market was demanding higher and higher levels of power output per cylinder which increased piston loads from mechanical motion and combustion pressure. The combination of emissions legislation and market demands were causing piston loads to approach the fatigue strength limit of the material at high temperatures. A leap in the technology of aluminum piston alloys was required to meet the world's toughest emissions legislation.

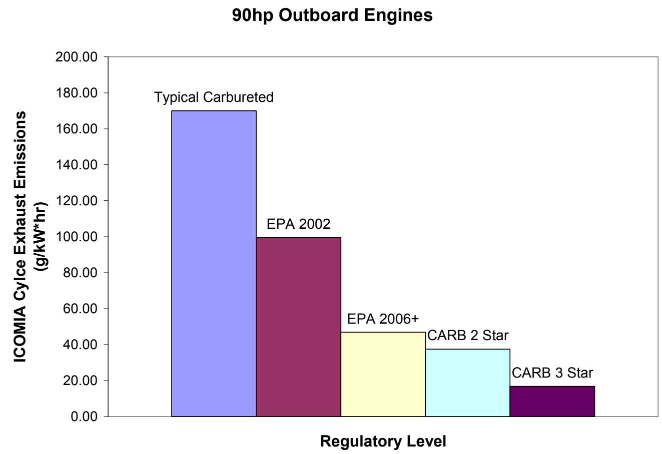


Figure 1: Outboard Engine Emissions Legislation

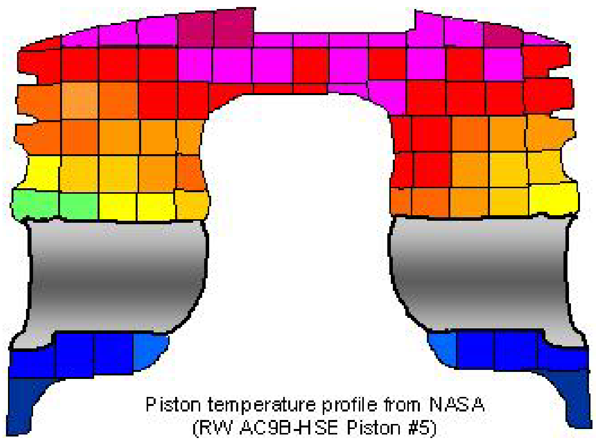
RESEARCH, IMPLEMENTATION & EVALUATION

One of the Bombardier Recreational Products (BRP) Evinrude outboard engine material laboratory technicians was searching the Internet for material properties and discovered an article on a new aluminum alloy being developed by NASA.

Evinrude engineering did not have the expertise in house to design a piston alloy that would meet the temperature requirements of an Ultra Low Emissions outboard engine. At the start of the project Evinrude engineering was skeptical about the claims made by NASA. Most of the engineering staff was concerned about dealing with a large, potentially slow, government agency like NASA. Additionally NASA is viewed by the public as an agency who's technology does not apply to daily life.

The first meeting between NASA and Evinrude engineers on April 1, 2002 proved the skeptics wrong. NASA scientists Jonathan Lee and Po-Shou Chen impressed the Evinrude engineers with their knowledge of all aspects of a hyper-eutectic aluminum piston alloy. The NASA scientists, in addition to understanding the metallurgy behind a hyper-eutectic alloy, also understood the processing requirements, quality standards and cost sensitivity of a commercial product such as an outboard engine or an automobile.

One of the first questions the NASA scientists had for the Evinrude engineers was did our application really require a high temperature piston material. NASA had previously worked with the automotive industry and determined that their piston temperatures did not warrant the use of this new technology. A two stroke engine has a power stroke (where heat from combustion is generated) every engine revolution, where as a four stroke engine has a power stroke every other engine revolution. This is the primary reason why two stroke engines inherently make more power then their four stroke counterparts, but this is also why a two stroke engine is more demanding on the engine's pistons.



Temp (F)	350	400	450	500	550	600	650	700	750
HRB									
Color Key	58	51	45	39	32	26	20	14	8

Figure 2: Temperature profile of a direct injected two-stroke engine.

The temperature profile showed a large region of the piston was above 500 degrees Fahrenheit. In the NASA scientists opinion the piston temperature would need to exceed 500 ºF in order to utilize the maximum benefits of the new high strength piston alloy.

Implementation:

Now that Evinrude engineering and NASA both agreed that the new alloy would be beneficial to outboard engines it was time to cast the first set of pistons. NASA provided the initial target alloy composition (approximate date of 7-2002). The laboratory analysis of the trial 1 pistons examined the four key areas listed below.

1. Overall casting integrity
2. Primary AL grain size
3. Primary SI grain size
4. Alloy composition

The last category examined was the all important alloy composition. The key to the NASA alloy is the addition of several trace elements that stabilize the microstructure. This allows the piston to retain much more of its original strength when subjected to high temperatures. Overall three casting trials were run to finalize the alloy specifications for use in a direct injected two-stroke outboard engine. For an in depth technical review of these trials refer to the 2004 ICES paper # 2004-01-2588.

Evaluation:

Tensile tests performed at Westmoreland Mechanical Testing and Research (per ASTM E21-92 1998) showed that the trial three NASA piston alloy was almost 2.5x stronger then our previous vendor supplied piston alloy. (Figure 3)

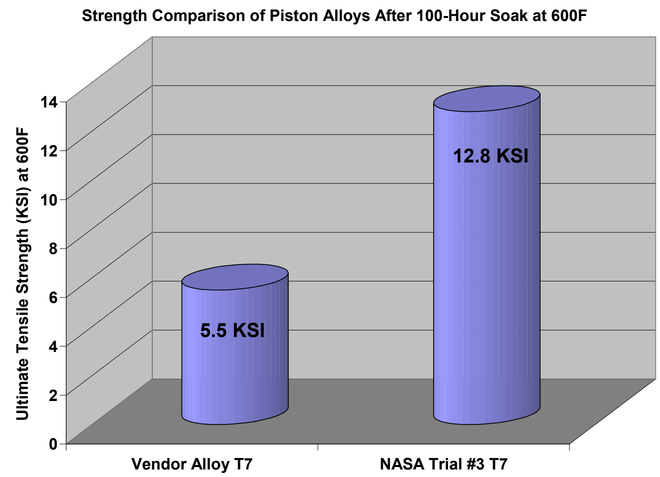


Figure 3: Tensile test results.

With the successful completion of the trial 3 piston testing NASA and Evinrude engineering had custom tailored the original NASA alloy to meet the unique requirements of a Direct Injected 2-stroke outboard engine. The new alloy allowed the development of emissions strategies for the Evinrude ETEC engine line that helped these engines meet the world's most stringent exhaust emissions standards while maintaining world class levels of durability. Without this new alloy piston temperatures would have exceeded their practical limit.

Environmental Impact & Value:

Outboard engines are emissions tested on a five mode test cycle known as the ICOMIA cycle; this cycle is based on the average boaters RPM and engine load under typical operating conditions. The regulated components of outboard engine exhaust are hydrocarbons (HC's) and oxides of Nitrogen (NOx). Carbon Monoxide (CO) is reported but not currently regulated. To evaluate the environmental impact of this new alloy you have to examine the impact of the Evinrude ETEC engine. The new high temperature alloy did not create a low emissions engine, but it did allow for combustion and calibration strategies that would not have been possible without the new piston alloy.

Some basic assumptions have to be made in order to put some hard numbers on the Environmental impact. All information uses ICOMIA cycle test results as reported to the EPA and CARB during the emissions certification process.

1. The engines "lifetime" will be assumed at the end of the CARB emissions degradation test of

350 hours. This is by no means the end of the useful life of an outboard engine, and represents approximately 10 years of recreational boating.
2. Reduction calculations assume that each ETEC engine sold replaced what would have been the cleanest technology manufactured by BRP in the horsepower category analyzed.
3. Each ETEC engine family and the previous technology family will use the highest horsepower available for calculation purposes. The ETEC engine and the previous engine will both use matching horsepower models.

The environmental impact calculations were performed as follows

(Lifetime hours)*(Units produced)*(specific emissions reduction g/kW*hr)*(power kW)*(.207 Icomia cycle weighting factor for power) = Emissions reduction in grams.

An example calculation for the 250hp ETEC vs. the 250hp FFI engine is listed below.

250hp FFI HC Certification Level = 23.07 g/kW*hr

250hp ETEC HC Certification Level = 6.65 g.kW*hr

Specific HC Emissions Reduction = 16.42 g/kW*hr

Units built to date = 3744

Calculation:
(350hours)*(3744units)*(16.42g/kW*hr)*(186.4kW)*.207 =
830222000grams.

This calculation was repeated using EPA certification data for the 50hp two cylinder ETEC, the 90hp three cylinder ETEC and the 250hp V6 ETEC. The final emissions reduction realized over the lifetime of these ETEC engines is:

37,776 kg of NOx

5,515,837 kg of HC's

Full calculation data can be provided on request.

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