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Applications and Features of Titanium for Automotive Industry




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Abstract

In the field of automobiles, titanium found its first application to the engine parts of racing cars early in the 1980s. Since then, the application range of titanium has expanded, including the application to the muffler systems of super sport-type bikes and limited models of high-grade cars. This paper describes the study being made on titanium applications to automotive components which is a new prospective field of application, and the problems involved in titanium application to high-grade mass-produced cars.

1. Introduction

At the Third Meeting of the Conference of Parties to the UN Framework Convention on Climate Change (COP3), held in Kyoto in December 1997, Japan proposed to reduce its carbon dioxide emissions in 2010 by 6% of the total carbon dioxide emissions from the developed countries as compared with 1990.

According to this proposal, the Japanese automobile industry studied the measures to improve fuel economy by 8.5% of the 1990 level by 2000 and by 20% of the 1995 level by 2010.

At the 1999 Tokyo Motor Show were prominently exhibited concept cars, new cars, and new engines using aluminum, magnesium, and titanium as materials for weight reduction against the background of environmental issues, instead of material substitution for visual appearance in the past.

Titanium has been traditionally used as lightweight, highly strong, and exceedingly corrosion-resistant material in aircraft, electric power plants, seawater desalination plants, and heat exchangers. More recently, it has found increasing applications in consumer products, sporting goods, and information technology (IT) equipment by making use of its aesthetic surface appearance and luxurious feeling.

This article introduces the present application of titanium to automobile parts as important themes for developing new markets for titanium, and describes the problems to be solved for further expansion of the automotive titanium market.

2. Target of Weight Reduction (Improvement in Fuel Economy)

The relationship between the weight and fuel economy of automobiles is shown in **Fig. 1**. As can be seen from Fig. 1, 1% of weight reduction improves fuel economy by about 0.7%. Fuel economy is the most important factor for achieving the goal of carbon dioxide emission reduction. The above-mentioned 20% fuel economy improvement of gasoline cars calls for 30% of weight reduction.

Example: Car A weight reduction program: 1,300 kg in 1998 to 1,000 kg (–20%) in 2003 to 900 kg (–30%) in 2008

About 20% of weight reduction is considered to be capable of being achieved by the following material measures, but it still does not reach the goal.

1) Use of high-strength steel: Application of smallest possible thickness to each part (40 kg-class to 60 kg-class to 80 kg class)

2) Use of aluminum and plastics: Application to large-deformation load bearing parts (not rigid)

The rest of the weight reduction may be achieved by improve-

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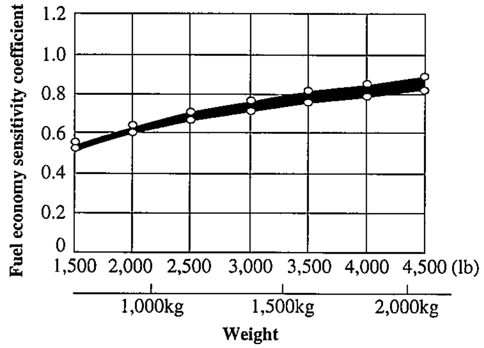


Fig. 1 Weight and fuel economy of automobiles

ment in engine combustion (e.g., direct injection) and hybridization, among other measures. Use of the light metals titanium and magnesium is being studied concurrently.

3. Characteristics of Titanium and Possibility of Titanium Application to Automobiles

The materials used in automobiles are shown as compared with titanium in **Table 1** and **Fig. 2**. Titanium is higher in specific gravity than aluminum alloys and magnesium alloys, but far higher in strength, so that its specific strength is located above that of aluminum alloys. Especially in the medium-temperature region of up to about 600°C, the advantage of titanium is conspicuous. In terms of specific toughness (toughness/specific gravity) and specific fatigue strength (fatigue strength/specific gravity), two important indexes for titanium application to automobiles, titanium is advantageous over steel and aluminum alloys.

Table 1 Property comparison of titanium with other metals

	Specific gravity	Young's modulus (GPa)	Tensile strength (MPa)	High-temperature oxidation	Corrosion resistance
Steel	7.85	205	400-800	◎	×
Stainless steel (SUS304)	7.95	200	600	◎	○
Commercially pure titanium (Grade 2)	4.51	106	450	○	◎
Titanium alloy (6Al4V)	4.43	114	900	◎	◎
Aluminum alloy	2.70	70	250	×	×
Magnesium alloy	1.70	45	200	×	×
Plastic (SMC)	1.90	10	300	×	○

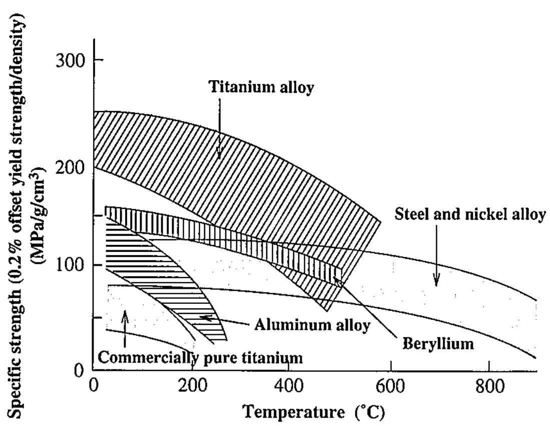
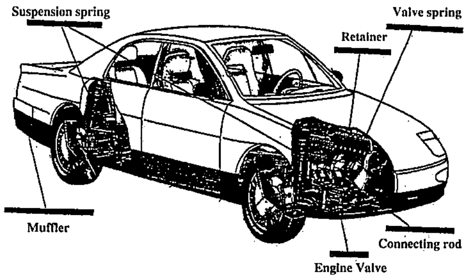


Fig. 2 Relationship between specific strength and temperature of metals[1)]

Corrosion resistance becomes a problem in applications to outer panels and trimmings. Titanium displays unparalleled corrosion resistance to salt and seawater environments. In the United States and Europe, deicing salt is spread on roads to prevent freezing in winter. Use of titanium is also expected in automobiles for protection against this deicing salt. When titanium is used in springs, the number of turns can be reduced because Young's modulus of titanium is about 50% of that of steel. Titanium is thus considered to be helpful in not only weight reduction but also size reduction.

Given the above-mentioned properties of titanium, the automobile parts to which titanium may be applied and the expected weight savings are shown in **Fig. 3**. The engine valve or reciprocating engine parts has the highest possibility of being converted to titanium. The next candidates are the connecting rod or rotating engine part and the suspension spring and exhaust pipe and muffler with large weight reduction expected.



Part		Weight reduction
Engine	Valve	0.3kg/40%
	Valve spring	0.7kg/55%
	Retainer	0.2kg/40%
	Connecting rod	0.7kg/20%
Suspension spring, and		5.3kg/50%
exhaust pipe and muffler		6.0kg/40%

Fig. 3 Candidate parts for titanium application and weight reduction expected[2)]

4. Titanium Applications in Automobiles[3)]

The application of titanium in the automobile industry begun with F-1 racing cars in the early 1980s. Since high output, fast rotation and high response were required of racing cars, high-strength titanium was used in their engine parts. Here are introduced examples of titanium applications to present mass-production cars.

4.1 Engine parts

Mitsubishi Motors adopted the Ti-22V-4Al alloy with excellent cold forgeability in the AMG engine retainers of the Gallant in 1989, and Honda Motors adopted the free-cutting titanium alloy Ti-3Al-2.5V+S+REM in the connecting rods of the sports car NSX in 1990. In 1998, Toyota Motor adopted the sintered titanium alloys Ti-6Al-4V/TiB and Ti-Al-Zr-Sn-Nb-Mo-Si/TiB in the engine intake and exhaust engine valves, respectively, for the Altezza. The Altezza uses eight each of the inlet and exhaust valves. Their combined weight is 408 g/car, which means a 40% weight reduction from steel valve weight of 677 g/car. The adoption of the titanium valves helped to reduce the valve spring weight from 43 g to 36 g. In 2000, Nissan Motor adopted the titanium alloys Ti-6Al-4V and Ti-6Al-2Sn-4Zr-2Mo-Si in the engine inlet and exhaust valves for the CIMA, respectively.

4.2 Suspension springs

The LCB (low-cost beta) titanium alloy Ti-4.5Fe-6.8Mo-1.5Al was adopted in the suspension springs for the Volkswagen Lupo FSI in 2001. This material is TIMET's new grade with a weight reduction of about 50% from the Beta-C alloy Ti-3Al-8V-6Cr-4Mo-4Zr used in racing cars. The weight of the titanium springs is 1.36 kg and is about one-third of that of steel springs. Use of titanium achieved a total weight savings of 81.6 kg, including the load under the springs.

4.3 Exhaust pipes and mufflers

Titanium exhaust pipes and mufflers were initially produced mainly for aftermarket use. In 1988, Kawasaki Heavy Industries adopted titanium in the muffler of the large sports-type motorcycle ZX-9R. Starting with this case, titanium has been used to fabricate the mufflers of the Honda CBR900RR, the Yamaha YZF-R1, and Suzuki GSX-R1000 in the past two years. More recently, this titanium application has expanded to cover motocross motorcycles, and the motorcycle exhaust system titanium market has rapidly grown to about 500 tons per year. For cars, titanium mufflers are still mainly intended for aftermarket use, but the consumption of titanium in this application is gradually increasing. General Motors of the United States adopted titanium in the dual mufflers of the Corvette Z06 for the first time for a volume production car in 2001. The weigh reduction achieved is 41% to 11.7 kg from 19.8 kg of comparable steel mufflers.

4.4 Others

As trimmings, titanium is used in the shift knobs of the Honda S2000 Roadstar and Integra Type R. Colored titanium is used in the scuff plate of Toyota's Crown Majesta. For high-performance sports cars, titanium is available as option for the strut tower bar in the engine room.

5. Issues for Expansion of Titanium Applications to Automobile Parts

Lowering the material cost is the largest issue when using titanium in automobile parts. The low-cost titanium materials developed by Nippon Steel (including introduction of TIMET technology) are described below.

The most widely used titanium material in the automobile industry is the Ti-6Al-4V alloy. Nippon Steel developed the Super-TIX series that has expensive vanadium replaced by iron and covers a tensile strength range of 800 to 1,000 MPa (see **Fig. 4**). There are two main composition systems: Ti-Fe-O-N (tensile strength of 800 to 900 MPa) and Ti-Al-Fe-O (tensile strength of 1,000 MPa). Since

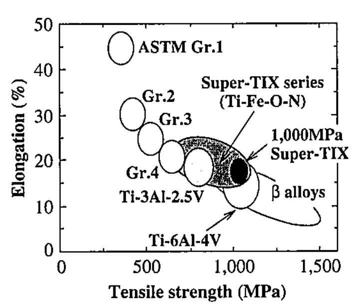


Fig. 4 Mechanical properties of Super-TIX[4]

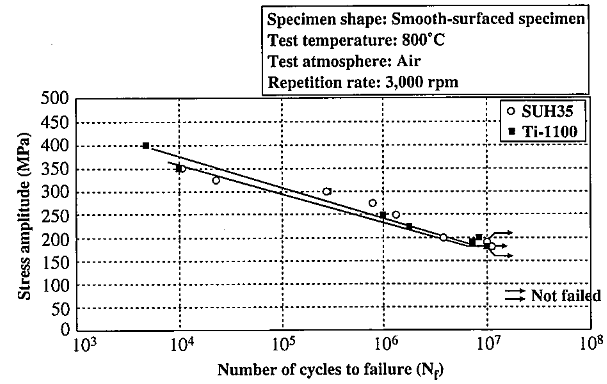


Fig. 5 Rotating bending fatigue properties of Timetal® 1100 at 800°C

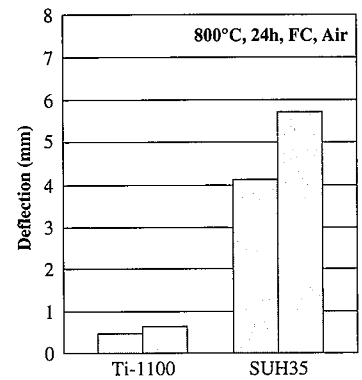


Fig. 6 High-temperature test results of Timetal® 1100

the Super-TIX performs as well as the Ti-6Al-4V alloy, its application to connecting rods, fasteners, and frames can be expected.

Beta alloys have been conventionally used in springs from the standpoints of workability and fatigue strength. The aforementioned LCB alloy is available as a low-cost version. This alloy similarly has expensive vanadium replaced by the lower-cost beta stabilizing elements iron and molybdenum.

Another issue with titanium alloys is expanding their operating limits at medium and high temperatures. The maximum operating temperature is about 600°C for titanium alloys. Exhaust valves are heated to about 800°C and were thus considered to be difficult to make from titanium alloys. TIMET developed the alloy Timetal® 1100 with excellent high-temperature properties. The performance evaluation results of the alloy as compared with the conventional exhaust valve steel SUH35 are shown in **Figs. 5 and 6**. The Timetal® 1100 has the same strength and rotating bending fatigue strength as those of the SUH35, but its high-temperature deflection is about 0.5 mm and one-tenth of that of the SUH35.

The weight reduction of the valve train is highly demanded from the standpoints of higher fuel economy, more quietness, and greater output, and is expected to lead to the adoption of new titanium alloys.

6. Conclusions

Weight reduction is an everlasting issue for the automobile industry. The use of titanium in automobile parts started with F-1 racing cars in the 1980s by making the most of the excellent properties (high specific strength, corrosion resistance and springiness). Since then, titanium applications have steadily increased and now cover high-class volume production cars and motorcycles.

If titanium is to find increasing usage in mufflers, engine valves and springs, among other applications, it is indispensable that its material cost should be reduced by a maximum of 30% by proposal of low-cost titanium alloys, for example. Automobile manufacturers and automobile part manufacturers who process titanium materials should be encouraged to simplify titanium processing steps jointly with titanium manufacturers. For automobile manufacturers, the development of design technology to make the most of titanium's merits will assume ever-increasing importance.

We are convinced that the titanium applications in the automobile industry will be able to expand further with the concerted cost reduction and optimum design efforts of titanium manufacturers, automobile part manufacturers, and automobile manufacturers.

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