

Lightweight and high performance titanium exhaust systems for Porsche sports cars

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ABSTRACT

Automotive applications of titanium follow logically from the high strength, high temperature durability and unique density of titanium and its alloys, and their excellent resistance to corrosion and wear. Exhaust systems represent an attractive entry point for titanium into the automotive market. There has been a significant growth in the application of titanium and its alloys to automotive exhaust systems over the last years. However, the use of titanium has been limited to racing cars and a few top-of-the-range road models, mainly because of cost and temperature capability. But with the recent improvements of high-temperature properties of titanium with alloy modifications, the application of titanium and its alloys to original-equipment manufacturers' (OEM) automotive exhaust systems will be able to grow dramatically in the next years. This paper presents an example of the commercial challenges of working with a new OEM automotive company not familiar with titanium.

INTRODUCTION

One of the most important reasons for using titanium in exhaust systems is weight reduction, which brings better results both in the vehicle performance and fuel efficiency. The application of titanium and its alloys to automotive and motorcycle parts has grown dramatically in the last years. Exhaust system applications, including mufflers and exhaust pipes, have been a main target for titanium in cars and motorcycles. In addition to weight savings, the visual appearance of titanium as well as performance with titanium attracts customers.

Although weight savings are attractive, the oxidation resistance and strength of commercially pure titanium at elevated temperatures limit its application only to certain exhaust parts. No major steps forward need to be taken when titanium sheets and pipes are utilized in those exhaust parts that are not exposed to

temperatures higher than about 600°C. However, if the temperature of titanium parts exceed 700°C in an air environment, the oxidation resistance and strength of commercially pure titanium (like Gr. 2) are insufficient, which leads to a cracking problem in the exhaust system. Insufficient temperature capability and high price were thus apparent obstacles to the application of titanium in mass-produced automotive exhaust systems.

Therefore, there was a strong requirement of titanium alloys having higher performance at elevated temperature with keeping good formability from the viewpoint of rising operation temperature and manufacturing cost. To properly respond to this tough issue, there has been notable progress in material side from the titanium manufacturers worldwide as well.

Properties of titanium alloys required especially for automotive exhaust systems can be summarized as follows:

- High strength at elevated temperature is required especially at temperatures above 600°C, and small degradation during long term use is also needed.
- High oxidation resistance, specifically small thickness loss during long term use at high temperature especially above 700°C is required.
- Good formability, i.e. bendability, stretch-expansion formability, drawability, etc. that are equivalent to or better than those of Gr.2 commercially pure titanium are of crucial importance.

Several new alloys targeting application in automotive exhaust systems have been reported. Amongst them are also the following titanium alloys used in Akrapovic automotive exhaust systems:

- Exhaust XT (TIMET)
- Ti-1.2ASN (KOBELITE)
- Ti-1Cu-0.5Nb (NIPPON STEEL)

AKRAPOVIC CAR EXHAUST TECHNOLOGY

COMPANY EXPERIENCE

Akrapovic Exhaust Systems Technology is a manufacturer of top-quality exhaust systems for motorcycles, sports cars and carbon parts. Amongst other materials for exhaust systems, the company uses more than 300 tons of titanium material per year, and has excellent experience and technologies for forming, welding, and piping using several kinds of titanium alloys.

A car exhaust system looks simple at first glance. But a closer look shows that it is a complex system that has a significant effect on the performance of a racing or a regular sports car. Successful design of a titanium exhaust system commences with considering the conditions to which a particular exhaust components are to be exposed. The titanium alloy should be selected according to the operating conditions, especially the maximum operating temperature under upset conditions. In turn, the physical and mechanical characteristics of the alloy selected can dictate some design features. The ductility of an alloy, for instance, limits the minimum bend radius which is feasible for sheet, plate or tubing. Titanium's excellent corrosion resistance often permits a zero corrosion allowance to be specified. Consequently, wall thicknesses for tubes, mufflers and other exhaust components are usually smaller than would be required for other materials.

Successful application of the titanium alloys for exhaust systems demands a thorough consideration of titanium's unique properties at the design stage as well as during fabrication. Factors such as titanium's high strength to weight ratio, low elastic modulus, corrosion and erosion resistance, its tendency toward galling, and its reactivity at high temperatures need to be considered in order to optimize exhaust designs in titanium. It is necessary to emphasize some of the unique properties of titanium that are very important for proper planning and better understanding of the forming processes during the exhaust components manufacturing:

- The room temperature ductility of titanium and its alloys, as measured by uniform elongation, is generally less than that of other common structural metals. That is to say, titanium might require more generous bend radii and has lower stretch formability. It may demand hot forming for severe bending or stretch forming operations.
- The modulus of elasticity of titanium is about half that of steel. Consequently, a significant spring back is made after forming titanium.

That is why some compensation must be made.

- The galling tendency of titanium is greater than that of stainless steel. This means that special attention must be paid to lubrication in any forming operation in which titanium is in moving contact with metal dies or other forming equipment.

The welding process is also very important. Titanium and most its alloys are readily weldable, and several welding processes can be applied. Titanium and its alloys are most often welded with the tungsten inert gas (TIG) welding. Compared to other high-performance materials, such as stainless steels or nickel-base alloys, titanium, however, demands a greater attention to cleanliness and to the use of auxiliary inert gas shielding than these materials.

When designing and fabricating exhaust systems, it is generally best to start fresh, i.e. bearing only titanium's properties in mind, instead of trying to simply substitute titanium for other materials that were previously used.

CAR EXHAUST SYSTEM EXAMPLES

Before entering the new market, a detailed tuning market analysis of the car segment was conducted. Some of the findings are written in continuation:

- The car tuning market is growing constantly and independently of economic situation.
- Exhaust systems are one of the biggest tuning parts.
- The bigger the car engine, the more likely that the car is tuned and the more important is the performance achieved.
- Exhaust systems are the most important tuning part for sports cars (willingness > 60%).

Based on the analysis mentioned and on the current company experiences with motorcycle exhaust market, the company's weaknesses, strengths, opportunities and threats on a new market were specified. The most important opportunities for our company can be summarized as follows:

- Titanium is becoming fashionable.
- Sports cars segment and tuning market are growing.
- There exists a big market potential.
- Sports car drivers spend more for tuning than ordinary car drivers.
- Car tuning traders are open to new things and eager to experiment.

According to the tuning market analysis Akrapovic decided to tackle the car exhaust system manufacturing in two ways, firstly as an OEM supplier and secondly as an independent aftermarket supplier distributing products to car tuning stores. In both

cases the company tends to be ranked as a high or premium class manufacturer. Putting theory into practice, Akrapovic utilized titanium to produce several car exhaust systems, some of them also for mass-produced vehicles. In response to the Porsche criteria, Akrapovic recognized an optimal new Porsche 911 GT2 exhaust systems could be made from titanium (see Fig. 1). The Akrapovic design addresses the differences between titanium and stainless steel, including characteristics such as spring back, vibration and resonance frequency. New muffler components were custom developed for titanium fabrication, and a unique acoustic tone to meet customer sound and car performance requirements.



Fig. 1. Porsche 911 GT2 – first Porsche fitted with titanium exhaust system homologated for road use



Fig. 2. Porsche 911 GT2 titanium muffler and tailpipe

The new 911 GT2 is the first Porsche homologated for road use to be fitted as standard with an exhaust system featuring a titanium rear-end muffler and titanium tailpipes (see Fig. 2). Compared with corresponding exhaust components made of stainless

steel, titanium reduces the weight of the entire system by approximately 50 per cent, i.e. by 9 kilograms. This reduces the load across the rear axle, thereby improving driving dynamics. Lightweighting is one of the keys to this car's high speed and pinpoint-accurate handling.

Another example is a complete titanium exhaust system for Porsche 911 Turbo model, including headers, catalytic converter housing, tubes, muffler and tailpipes (see Fig. 3). Supporting the metallic or ceramic catalytic converter in the titanium exhaust system was a most challenging task. The so called mats are used to hold catalytic converters in place and prevent damaging the often fragile ceramic or metallic substrate. The canning operation with which the substrate and the mat are inserted into the titanium housing was also patented by Akrapovic.



Fig. 3. Porsche 911 Turbo complete titanium exhaust system



Fig. 4. Performance test of the Porsche 911 Turbo on a car dynamometer

Exhaust and noise regulations have to be achieved while obtaining the highest performance at the lightest weight possible for cars that are also valid in regular street use in everyday traffic. It is our job to show our

clients that improvements are possible. A lot of efforts have to be made to achieve good results, for example a huge number of runs with different exhaust configurations on a car dynamometer is needed (see Fig.4).

Since racing exhaust systems are the obvious and best proof of the quality of our products that the public can get, exhaust systems for some of the top racing cars were also developed. The company's efforts were rewarded at one of the hardest 24-hour endurance races in the world where the Porsche 997 RSR car equipped with a titanium Akrapovic exhaust system achieved a resounding victory (see Fig. 5).

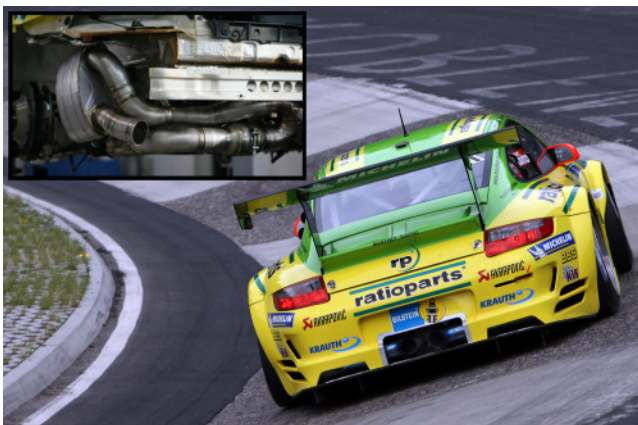


Fig. 5. Porsche 997 RSR on a track

If you want to win a race you sometimes have to make adjustments in the right place. In this case it was to save on the weight and make adjustments to the rear suspension – a reduction of 12 kg was made to the exhaust (see Fig.6). The Manthey-Racing Porsche 997 RSR Team, which uses this car in the hardest endurance race, does not leave anything to chance, most notably not their choice of the exhaust system.

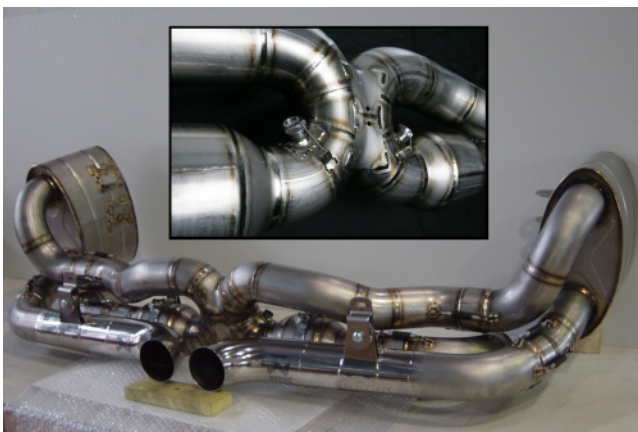


Fig. 6. Porsche 997 RSR complete titanium exhaust system

CONCLUSION

There has been a significant growth in the application of titanium and its alloys to automotive and motorcycle exhaust systems over the last decade. When titanium emerged as the solution for car exhaust systems, the manufacturing technology to produce them in mass-market quantities did not exist. Working with titanium manufacturers to optimize an exhaust grade of titanium and the experience in producing motorcycle titanium exhaust systems that was acquired over many years, Akrapovic successfully adapted its stamping, bending, cold forming and welding methods for specific titanium properties.

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ABOUT AKRAPOVIC

- **Akrapovic is a manufacturer of top-quality titanium exhaust systems for motorcycles and sports cars.**
- **The company uses more than 200 tons of titanium alloys per year.**
- **The company has excellent experience and technologies for forming, welding, and piping using several kinds of titanium alloys.**

TITANIUM FOR CAR EXHAUST SYSTEMS

- **Insufficient temperature capability and high price were apparent obstacles to the application of titanium.**
- **Titanium manufacturers have made notable progress in material side.**
- **Required properties of titanium alloys:**
 - **High strength at elevated temperature especially above 600°C**
 - **High oxidation resistance at elevated temperature**
 - **Good formability**

ANALYSIS FINDINGS

- **The car tuning market is growing constantly and independently of economic situation.**
- **Exhaust systems are one of the biggest tuning parts.**
- **The bigger the car engine:**
 - the more likely that the car is tuned,
 - the more important is the performance achieved.
- **Exhaust systems are the most important tuning part for sports cars (willingness >60%).**

PORSCHE 911 GT2 EXHAUST SYSTEM



- **OEM titanium exhaust system.**
- **The first Porsche homologated for road use to be fitted as standard with titanium exhaust system:**
 - Compared with stainless steel version, titanium reduces the weight of the entire system by approximately 50 per cent (9kg).
 - This reduces the load across the rear axle, thereby improving driving dynamics.



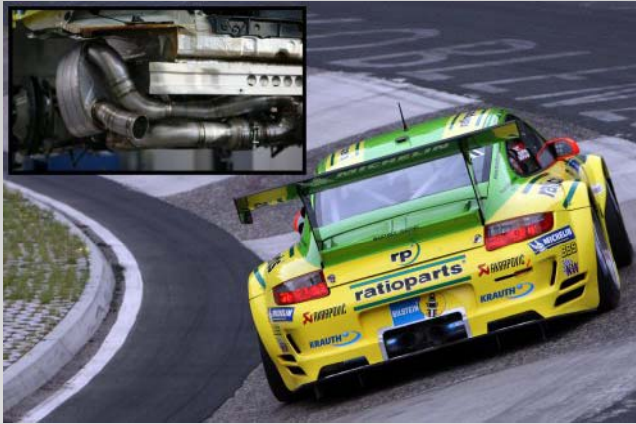
PORSCHE 911 TURBO EXHAUST SYSTEM



- **Complete titanium exhaust system:**
 - Including headers, catalytic converter, connecting tubes, muffler and tailpipes.
 - Patented solution for supporting the metallic or ceramic catalytic converter in the titanium exhaust system.
- **During the development process a lot of testing on a car dynamometer has to be made to achieve good results.**



PORSCHÉ 997 RSR EXHAUST SYSTEM



- **Complete titanium exhaust system for top race car.**
- **A reduction of 12 kg was made to the exhaust compared with stainless steel version.**
- **The company's efforts were rewarded with resounding victory of this car at one of the hardest 24-hour endurance races.**

SUMMARY

- **Using titanium in exhaust systems means weight reduction \Rightarrow better results both in the vehicle performance and fuel efficiency.**
- **Recent improvements of titanium properties \Rightarrow the application of titanium to car exhaust systems will be able to grow considerably.**
- **Titanium alloys used in Akrapovic automotive exhaust systems:**
 - Exhaust XT (TIMET)
 - Ti-1.2ASN (KOBE STEEL)
 - Ti-1Cu-0.5Nb (NIPPON STEEL)

THANK YOU FOR YOUR ATTENTION