NEW HIGH PERFORMANCE TITANIUM FOR EXHAUST SYSTEMS

Further Study

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Titanium exhaust systems for motorbikes and cars

More than 1000 metric tons of Gr.2 are used for motorbike exhaust systems per year throughout the world.

Reason: Light weight, High class image, Characteristic titanium color

However, titanium exhaust systems have not been used for mass-produced cars.

One of the reasons: Car exhaust systems are exposed to higher temperatures than motorbike exhaust systems.

▶ These higher temperatures lead to a cracking problem in the exhaust systems
  - Insufficient high temperature oxidation resistance of Gr.2
  - Insufficient high temperature strength of Gr.2.

In motorbikes, the exhaust gas temperature also tends to increase.

Reason: Increase of demand of higher power engine, Use of catalyzer

▶ Cracking problem has also been considered recently.
KOBE STEEL’s new titanium alloy series for exhaust systems

Ti-1.5Al (Gr.37)
- The first mass-produced titanium alloy for exhaust systems in the world
- Mainly for motorbikes with higher exhaust gas temperatures
- Being mass-produced
- Registered in ASTM as Gr.37

Ti-1.2ASNEX
- Mainly for cars and motorbikes with much higher exhaust gas temperatures
- Superior performance to Ti-1.5Al
- Already produced mass-produced cold coils (6 metric tons)
## Alloy design concepts

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Ti-1.5Al (Gr.37)</th>
<th>Ti-1.2ASNEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formability</td>
<td>The same level as Gr.2</td>
<td>The same level as Gr.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strength</th>
<th>Room temp.</th>
<th>High temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The same level as Gr.2</td>
<td>2 to 3 times higher than Gr.2</td>
</tr>
</tbody>
</table>

- **Good formability equivalent to Gr.2**
- **Weight reduction by reducing thickness**

<table>
<thead>
<tr>
<th>High temp. oxidation resistance</th>
<th>Applicable temp.</th>
<th>Potential applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gr.2 &lt;600°C</td>
<td>600-700°C</td>
</tr>
<tr>
<td>Higher than Gr.2</td>
<td>Higher than Ti-1.5Al</td>
<td>Replacement of parts made of Gr.2</td>
</tr>
</tbody>
</table>
SUZUKI GSX-R1000

Photo: Courtesy of Suzuki Motor Corporation

Ti-1.5Al has already been used for mass-produced motorbikes.
Akrapovic in Slovenia is one of the most famous motorbike exhaust systems makers in the world.

They are the greatest user of Ti-1.5Al.

They use Ti-1.5Al for exhaust systems as a standard material instead of Gr.2.

More than 150 metric tons of Ti-1.5Al have been produced for their exhaust systems.
Evaluation results of Ti-1.5Al exhaust system after endurance test

Investigated cross section of Ti-1.5Al exhaust system after endurance test

Ti-1.5Al
- Depression of grain growth
- No surface cracks because of excellent oxidation resistance
- High-endurance is expected
- No cracks

Gr.2
- Remarkable grain growth
- Many surface cracks due to embrittlement by oxidation
- Breakage is possible in an early stage
- Cracks

KOBE STEEL, LTD Proprietary Information
**Weight gain due to high temperature oxidation**

**High temperature oxidation resistance**

- **Ti-1.2ASNEX > Ti-1.5Al > Gr.2**
- **Excellent!**

Weight gains of these materials are almost the same.

Weight gain of Gr.2 is twice as large as that of Ti-1.2ASNEX.

Only Ti-1.2ASNEX shows a dramatically small weight gain.
Cross sectional microstructures before and after exposure in air at 800°C for 100hrs

<table>
<thead>
<tr>
<th>Material</th>
<th>Before test</th>
<th>After 800°C, 100hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr.2</td>
<td><img src="image1" alt="Cross section microstructure" /></td>
<td><img src="image2" alt="Cross section microstructure" /></td>
</tr>
<tr>
<td>Ti-1.5Al</td>
<td><img src="image3" alt="Cross section microstructure" /></td>
<td><img src="image4" alt="Cross section microstructure" /></td>
</tr>
<tr>
<td>Ti-1.2ASNEX</td>
<td><img src="image5" alt="Cross section microstructure" /></td>
<td><img src="image6" alt="Cross section microstructure" /></td>
</tr>
</tbody>
</table>

**Remarkable Thickness reduction and grain growth**

- Large thickness reduction leads to a decrease of strength.
- Too much grain growth leads to low fatigue strength.

- Ti-1.2ASNEX is the most advantageous material in respect of less deterioration of strength and high fatigue strength.

- Level of thickness reduction and grain growth is not as much as with Gr.2

- Almost no thickness reduction and no grain growth
Embrittlement resistance

Welded tubes (O.D. 38.1x1.5\textsuperscript{t})

$\rightarrow$ 800\textdegree C, 100hrs in air $\rightarrow$ Flattening until cracking

Gr.2

Brittly cracked

Flat ratio (%) $\rightarrow$ 13

Flat ratio $= (38.1 - d) / 38.1 \times 100$

Ti-1.5Al

Brittly cracked

23

800\textdegree C is too high for Ti-1.5Al.

Ti-1.2ASNEX

Not brittly cracked

21

Ti-1.2ASNEX has superior embrittlement resistance.
Ti-1.2ASNEX exhaust system made by Akrapovic

After endurance test

Several parts of exhaust systems made of Ti-1.2ASNEX

Ti-1.2ASNEX has sufficient formability for making exhaust systems.

Photo: Courtesy of Akrapovic Company
Ti-1.2ASNEX exhaust system made by Akrapovic after endurance test

Test conditions
- HONDA CRF450
- Tested by Jaka Moze
  - MX3 world motocross championship rider
- Total 30hrs, Max temperature approx. 800°C
  - Gr.2 exhaust systems surely crack in this condition.
Detailed appearance of Ti-1.2ASNEX exhaust system made by Akrapovic after endurance test.

Ti-1.2ASNEX exhaust system does not show any damages.
Inside of Ti-1.2ASNEX exhaust system made by Akrapovic after endurance test

Inside of exhaust system does not show any damages.
Microstructure of Ti-1.2ASNEX exhaust system made by Akrapovic after endurance test

Investigated cross section

Approx. 800°C

Cross sectional microstructure

Total elongations of tensile test pieces sampled from exhaust systems before and after endurance test

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Before endurance test</td>
<td>37.5%</td>
</tr>
<tr>
<td>After endurance test</td>
<td>37.2%</td>
</tr>
</tbody>
</table>

Tested test piece sampled from exhaust system after endurance test

Inner surface of exhaust pipe

- Microstructure of exhaust system does not show any damages.
- Fine grains are maintained.

No decrease of total elongation ➔ No embrittlement

Long life of exhaust systems is expected by using Ti-1.2ASNEX.
Conclusions

Ti-1.5Al
(Gr.37)

- The first mass-produced titanium alloy for exhaust systems in the world
- Mainly for motorbikes with higher exhaust gas temperatures
- High performance and reliability are obtained without much additional cost.

Ti-1.2ASNEX

- Mainly for cars and motorbikes with higher exhaust gas temperatures
- Vastly improved high temp. oxidation resistance compared with Ti-1.5Al
- This alloy can be used for parts for which titanium cannot be used due to excessive temperatures.
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