AN INNOVATIVE PROCESS
TO MANUFACTURE TAILOR-MADE TITANIUM PRODUCTS

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ABSTRACT

Present processes to manufacture titanium long products are hindered by a long supply-chain implying plants often located far apart and are practically limited to the use of standard specifications and alloys which are available in relatively large lots of at least a few tonnes.

A group of European companies has conducted a research project aimed at developing a “fast track” supply chain with high flexibility allowing to manufacture small quantities of tailor made alloys in record time (down to a few weeks) and at strongly reduced costs.

The process has been developed for the production of extruded tubing and profiles, which the involved companies can deliver machined and bent to customers’ specifications.

-Patents are pending and trial orders have already been manufactured on industrial equipments.

The originality is both in the process itself which is being patented, but also in the cooperative R&D performed between nearby companies belonging to 2 industrial groups.

-PFW Aerospace AG in Speyer Germany: a tier-one supplier of Tubing, Ducting, Cargo Loading Systems and Structure elements to Airbus, Boeing and other aerospace cosntructors. PFW is a subsidiary of Safeguard International.

-GFE Metalle und Materialien GmbH in Nuremberg Germany, a manufacturer of Master Alloys and other special products. GFE belongs to AMG Advanced Metallurgical Group NV of which Safeguard International sis a major shareholder.

-Cefival in Persan (France), a specialist of the hot extrusion of titanium tubing and profiles with a long experience of supplying the aerospace industry and other titanium consuming industries. Cefival is controlled by the Italian Calvi Group.

-The key idea behind this new process is that “small is beautiful” in all respects: lead-time, cost and even metallurgical properties.

1. INTRODUCTION

Titanium industry can be compared, to a certain degree, to the steel industry: due to the fact that the fastest growing volumes are in flat products, the leitmotiv is “big is beautiful”.

The reasons are both economical and technical.

As for steel, the long product sector is penalized by this trend, because it deals with more specialty products ordered on a case by case basis for specific needs from the customers. They need good service, short deliveries and of course competitive pricing.

To solve this dilemma we decided to group a few companies, each with an expertise in its transformation sector to build up a new route to manufacture tailor-made products.

The first difficulty was to connect those companies and convince them to cooperate on an R&D program keeping their commercial freedom. This was achieved through adapted agreements.

Under the leadership of Cefival (an extruder of titanium equipped with the most recent extrusion press in the world), PFW Aerospace (a tier-one supplier to the aerospace industry with good
expertise in cold pilgering, bending and cutting as well as in machining), we put together GFE Metalle and Materialen (a master alloy supplier with an expertise in small size VAR melting) and Tifast (a newly established melter of titanium equipped with a skull melting).

The program started more than one year ago and is now showing extremely encouraging results enabling to supply already on an industrial basis the non-aerospace sector and within a short period of time some applications in the aerospace sector.

The new process which we shall describe is based on the concept that “small is beautiful”.

2. CONVENTIONAL ROUTES FOR PROCESSING TITANIUM

2.1 Heavy ingots

The most commonly used process to elaborate titanium products starts from sponge which is crushed and compacted into electrode which are subjected to a multiple melting process using a VAR. The first melting results in a relatively dirty product because of the impurities contained in the electrode. This resulted in the generalization of double (and even sometimes triple) melting.

This VAR process is slow and costly: the following curve shows the relativity of costs versus the diameter of the ingot.

Other process were developed, mostly for flat products (as for example the EB melting). But in that case also there was a big incentive to move toward heavy products because the slabs had to be processed on steel mill facilities sized for big dimensions.

2.2 Succession of converting steps in different locations

The standard of the industry is therefore to melt big ingots and big slabs and them have to forge them down through many steps to obtain the final product.

This scheme shows the complexity of the supply chain for titanium, implying several change of location (for each step of the process) therefore handling costs, heating cycles, and high inventories. A one year technical delivery time is not unusual in our industry and generates a lot of problems:

- adaptation to economical cycles
- high costs to optimize the alloy composition (because a small portion of the ingot will be used for a specific need)

3. WHY LOOK FOR A NEW ROUTE?

Aerospace industry requires relatively small series for any specific part. Even if, for some applications, it would be interesting to use new alloys, there is a resistance to change, because it would decrease lot sizes and increase inventories and costs. As an example Grade 5 is widely used when new alloys would be more adapted to reduce thicknesses and improve the weight performance of new planes.
In the same manner the development of emerging industrial application would be accelerated if new grades (cheaper or more adapted to the specific problems) could be used. But developing new grades mean more stock and this often kills the project.

Convinced that this was a major draw-back for the development of titanium, we decided to think the other-way around and to start from the customers need.

Not surprisingly the first idea of the proprietary process which has been developed came from PFW-Aerospace, eager to propose to its customers adapted solutions in small quantities with short delivery times.

Connections between PFW-Aerospace and upstream manufacturers were facilitated by the common implication of several individuals.

4.DESCRIPTION OF THE INOVATIVE NEW ROUTE

We decided to combine several processes in a manner which had never been tested before:

- the skull melting which has the flexibility to melt several ingots at extremely competitive costs: it is not the only process which allows multiple ingots (EB furnaces or plasma melting allow such a possibility but existing facilities do not make it easy).

- adapted VAR melting of small ingots if required by specifications.

- the extrusion which allows an extremely high forging ratio.

- several cold steps to finish the products.

It was deliberately decided to melt in small size in order to be able to manufacture small lots and to skip the complex initial forging steps.

Tifast, with its new extremely modern and flexible new skull melting furnaces was able to deliver very small ingots.

GFE which has a long experience in melting small master alloys ingots could provide a second melting at low cost.

Cefival with is new extrusion press could handle those ingots with minimal preparation and extrude them directly into mother tubing and/or shapes.

Those mother tubes were further cold pilgered by Specitubes (a PFW subsidiary) into finished tubing according to aerospace requirements. Those tubing were then bent by PFW Aerospace which was also able to machine the shapes.

With this process we have proved the possibility to make aerospace tubing, shapes (such as seat rails of other structure components).

The manufacturing diagram becomes extremely simple:

- Melting of small ingots (less than 300mm in diameter)

- Re-melting in a small VAR (if required by the specification): it should be noted that, on a VAR, the re-melting is 4 to 5 times cheaper than the first melting.

- Special-but simple- billet preparation

- Direct extrusion of the ingot

- Further processing as usual.

Very few industrial sites are involved. The number of heat cycles is considerably decreased. Small lots can be made at no extra cost.

The competitiveness of the process is obvious. Our estimate is that, compared to conventional processes the cost reduction is at least 30%.
5. SOME EXAMPLES OF PRODUCTION DONE WITH THIS PROCESS.

Tests have started one year ago to manufacture tubing and profiles.

Tubing were produced in Grade 9 and processed all the way down to the final bent hydraulic tubing.

Profiles were done in grade 5 in different shapes and thicknesses.
All those profiles are as-extruded, and you can observe that extremely thin wall could be achieved.

6.PROPERTIES

Mechanical properties and structures were checked at different steps of the process.

Macrostructure: grains were a little more elongated than usual.

Microstructure: even if the first tests were unexpectedly good, we are working on improving thickness of alpha and beta phases through adjustments of the extrusion temperature. Usual structures will be achieved on final products.
Tensile tests were performed with good results on elongation and still improvements to be achieved on yield strength. There also we are very confident on the final outcome.

Bending tests were OK, flattening and flaring were satisfactory.

7. SOME METALLURGICAL ADVANTAGES OF THE PROCESS.

The key advantage of working on small sizes is to work with very good temperature control: during melting the process creates basically no basaltic structure, needing to be broken by later forging.

During forging the transus temperature is crossed extremely quickly allowing a good control of the balance alpha beta.

In addition the extrusion process involves more energy in the transformation than conventional forging and allows a re-crystallization of the structure.

Macrostructure of the ingot shows a very good equi-axial structure.

No significant alpha case was observed on the surface.

Some properties are different from conventionally processed material. But we are in the process of showing that the final properties for the customers are equal or better: very often redundant forging is just made to overcome non-perfect structure linked to slow cooling of pre-forging. Very often redundant forming is also linked to redundant defects!!!
8. CONCLUSION

All the companies involved in this research program are in the process of optimizing the manufacturing steps: changing temperature, forging ratios, etc...

Some products are practically ready to be put on the market with total compliance with existing specifications. Some products still require additional tests and customers approval.

But we are confident in having developed an innovative process which will significantly reduce costs and lead time for the aerospace industry but also for industrial application. Cost saving could be enough to allow titanium to replace some other material such as stainless steel.

The ability to deliver small batches should enhance the creativity of our customers and allow in the future further progress.

ACKNOWLEDGEMENTS

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-Rudiger FOX Managing Director of PFW Aerospace, who as a customer, brought the initial idea and pushed constantly the actors for progressing in the test program.

-Volker GUTHER Manager Advanced Materials of GFE Metal and Masteralloys who contributed with his knowledge in melting of titanium alloys.

-Christophe DELAUNAY Technical Director of CEFIVAL who coordinated the whole program and continues to steer it with daily improvements.

I want also to thank the first customers who have shown interest in our development and will help to transform this innovation into a breakthrough for the titanium industry.

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An innovative research cooperation

• Due to connections between individuals it has been possible to develop in a simple manner a **multi-company research cooperation** implying the whole supply chain from raw material down to the final product ready to be assembled.

• Companies involved in this development are
  
  – **CEFIVAL**: a French specialist of hot extrusion equipped with the most modern press in the world, CEFIVAL belongs to the Italian CALVI Group.
  
  – **PFW Aerospace**: a Germany based international company belonging to SAFEGUARD International and specialized in tubing systems, cargo-loading systems and some structural parts for the aerospace industry.
  
  – **SPECITUBES**: a PFW subsidiary based in France
  
  – **GFE Metal & Materials**: a German specialist of titanium master-alloys with a strong expertise in VAR melting due to its connection to ALD Vacuum Technologies (a AMG group subsidiary)
  
  – **TIFAST**: an Italian Company equipped with the most modern skull melting facilities operating in the western world.
SMALL IS BEAUTIFUL!

— Present manufacturing processes are based on the idea that « big is beautiful »:
  • Reasons are both economical and technical:
    – Large ingots reduce the melting cost
    – Continuous processes imply large quantities
    – For flat products titanium has to be processed on equipment designed for steel
  — This trend penalizes long products were demands is often for smaller lots and where optimization of properties require tailor-made alloys.
  — For long products and new development « small is beautiful ».
Traditional COST Curve for VAR melting
Traditional manufacturing routes
Traditional manufacturing routes
Why look for a new route?

- Small series
- New alloys adapted to specific needs
- Shorter supply chain
- Less inventory
- Reduced costs
• Skull melting:
  – Flexible raw material sources:
    • Sponge or low cost scrap without preparation
  – Low cost production
  – Flexibility in ingot shape and size and possibility of multiple ingot casting
• VAR remelting
  – Adapted VAR to small size second melting
• Special ingot preparation
• Extrusion of tubing or shapes
• Normal final processing
CEFIVAL NEW EXTRUSION PRESS
SOME EXAMPLES
SOME EXAMPLES
SOME EXAMPLES
SOME EXAMPLES
SOME EXAMPLES
SOME EXAMPLES
SOME EXAMPLES
**PROPERTIES**

**FICHE D'ESSAI**

**EXAMEN MACROGRAPHIQUE**

**RÉACTIF** : 30% acide liquide + 10% HNO₃ + 60% H₂O

Référence : T7265 sans base.

Mise en évidence de la macrostructure au microscope : présence de grains allongés.

X 1.5

Référence : T7265 avec base.

Mise en évidence de la macrostructure sur coupe transversale.

X 6.1

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**EXAMEN MICROGRAPHIQUE**

**RÉSULTAT** : Solution aqueuse à 0.5% HF

Référence : T7635 (sens Travers)

Échantillon

**Échantillon**

Détail de l'image précédente.

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**CEFIVAL**
Some metallurgical advantages

- Homogeneity of chemical composition, equiaxial structure of starting ingot.
- Good temperature control
- Good control of alpha-beta balance
- Full advantage of extrusion properties (high energy transformation)
Conclusion

- We have proved the feasibility of the new production route
- Some parameters still need to be optimized
- Cost reduction is proved
- Short lead times and small lots are easy to do
- Customer certification has started
- Some products can already be delivered.