VII INTERNATIONAL MEETING ON TITANIUM

TITANIUM-STEEL EXPLOSION BONDED CLAD PLATES

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INTRODUCTION

A clad plate is a composite of 2 or more plates joined together in a continuous manner by a true metallurgical bond.

However, due to metallurgical limitations between materials or to the dimensions of the final product, some plates cannot be bonded by conventional techniques.

In these cases, explosion cladding is the only commercial technique available since it has theoretically no limitations at all. Said technique has been used for more than 25 years to produce large Titanium steel clad plates, for example.

Usually, for fabrication purposes, the base metal offers the strength and low cost of one metal. It can be either rolled or forged and is more often normalized low carbon steel. But it may also be high strength steel or stainless steel (Fig. I).

The cladding metal, the more expensive one and therefore the thinner one, is selected for its corrosion resistance properties. It may be stainless steel, copper, nickel and alloys there of, aluminium or even more noble metals such as Titanium, Zirconium or Tantalum (Fig. II).

Altrough explosion cladding process is now 30 years old, it is not yet widely known by the public. Our purpose today is to give you a general idea of how the process works and show you typical properties of explosion bonded clad plates. We will end with a few words on cost effectiveness. To do so, we will consider Titanium-Steel clad plates only.

Cladding technology

In explosive cladding technique, true metallurgical bond is achieved between the 2 plates by detonating an even layer of explosive placed on top of the assembly.

As shown on figure III, the cladding metal is originally positioned parallel but at a slight distance above the backing metal. The assembly is then covered by a layer of explosive which is detonated from one point located usually on one edge of the assembly.

Figure IV illustrates what is happening during the process: the cladding metal is propelled across the standoff space by the detonation and a jet emanates from the collision point which results from a plastic flow of the metal surfaces slightly ahead of this point. The jet carries with it impurities and surface films that normally prevent bonding.

When all of the parameters - standoff-velocity and quantity of explosive - are properly controlled a weld interface of the type shown in figure V is obtained.

General characteristics of explosion bonding

Explosion bonding main characteristics are:

- a wavy interface which increases several times the surface of contact between the 2 metals.

- the fact that the bond is obtained at room temperature without any heat effect

- hence, almost any metal can be made into clad plates.

- bonding is achieved under very high pressure and high deformation velocity. Therefore, the 2 metals do not flow and there is no noticeable change of their dimensions.

Mechanical characteristics

After bonding, NOBELCLAD Titanium clad plates are heat treated to stress relieve the materials (Holding temperature: 540 °C far 2 hours per inch of thickness with a maximum of 6 hours), then flattened if necessary and controlled.

More common control consists of an ultrasonic inspection according to international standards (ASTM - SEL or AFNOR) to check the integrity of the bond. Shear tests and if required tensile tests or bend tests, are also performed.

Typical values are given in figure VI. These tests quantify the bond strength of the plate well above ASTM recommendation of 140 MPa.

Dimensions of clad piates

Theoretically, explosion cladding has no size limits. In practice, there are some restrictions such as weight of plates or quantity of explosive. However, the main one is the dimensions of Titanium sheets available. To overcome this, NOBELCLAD has developed the explosive cladding of prewelded sheets and does produce plates up to 20 m^2 as daily routine.

Typical Titanium thicknesses range from 2 to 12 mm.

Heat effect

Fabrication often calls for processes - forming, deep drawing, welding - where plates are to be heated.

Since explosion bond is a direct metal to metal one, heat may generate a diffusion at the interface which in turn may cause the formation of intermetallic compounds, brittle and fragile.

In order to show the quality of NOBELCLAD Titanium clad plates, we have taken out a sample on a plate from commercial production (Fig. VII). Mechanical characteristics of both components are given in Fig. VIII.

Fig. IX, X and XI state the various heat treatment we have performed and, for each one, results of bend tests and shear tests.

There results show clearly that the diffusion phenomenon does exist for Titanium clad plates but starts at temperatures high enough to enable the usual fabrication processes, provided temperature is carefully controlled.

Based on above study, we have had 2 heads - one hemispherical and one elliptical - made with success (Fig. XII). Fig XIII shows a micrograph after forming.

By optimizing the hot rolling conditions, it has been possible to obtain explosion + hot rolled Titanium clad plates. After treatment, these "bang and rolled" plates present shear strength values slightly below the direct bond values but still over 140 MPa.

Applications

Titanium clad plates are used in industrial applications like marine heat exchangers, nuclear condensors, chemical reactors, strippers, etc... (Fig XIV-XV). A less conventional application is found in electrical transition joint where Titanium is used as a barrier between aluminium

and steel to prevent diffusion.

The explosion cladding technique is of course rather expensive but can also cut the price down. The thicker the material is, the more effective the clad plate is.

For thinner gage, the "bang and roll" technique can also be an alternative.

CONCLUSIONS

Explosion Titanium clad plates bave been used all over the world for more than 25 years with excellent results.

Today, mastering the prewelded sheets cladding or the "bang and roll" technique allow you to get larger plates.

This makes Titanium clad plates even more attractive, by reducing the cost of forming and welding procedures.

Research programs are still going on and tomorrow we should offer wider range of thicknesses larger plates, new materials as well as new shapes.

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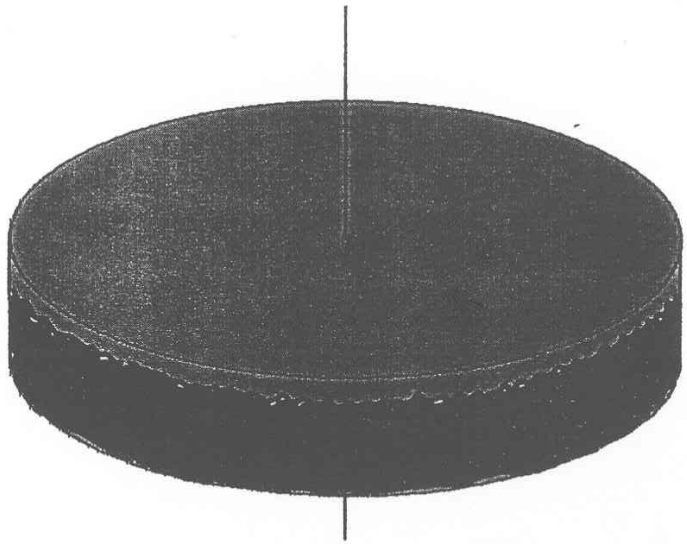

Hemispherical head : dia. 380 mm
Elliptical head : dia. 300 mm

Ti/Fe EXPLOSIVE METALCLADDING

Blank for deep-drawing test

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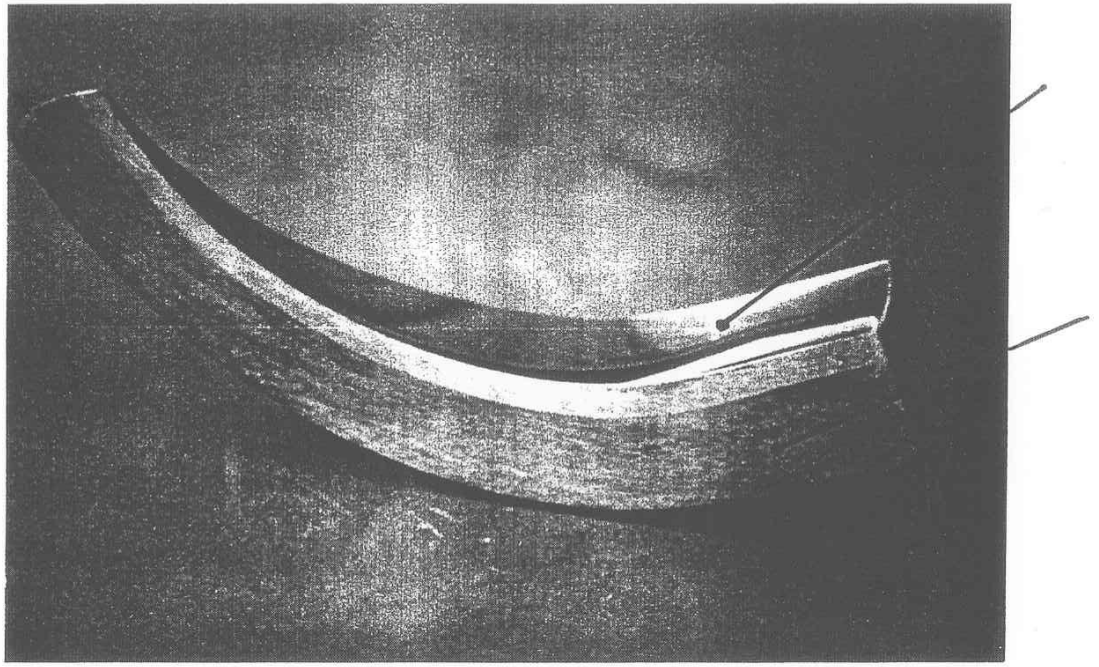

Ti/Fe EXPLOSIVE METALCLADDING

Hemispherical head part

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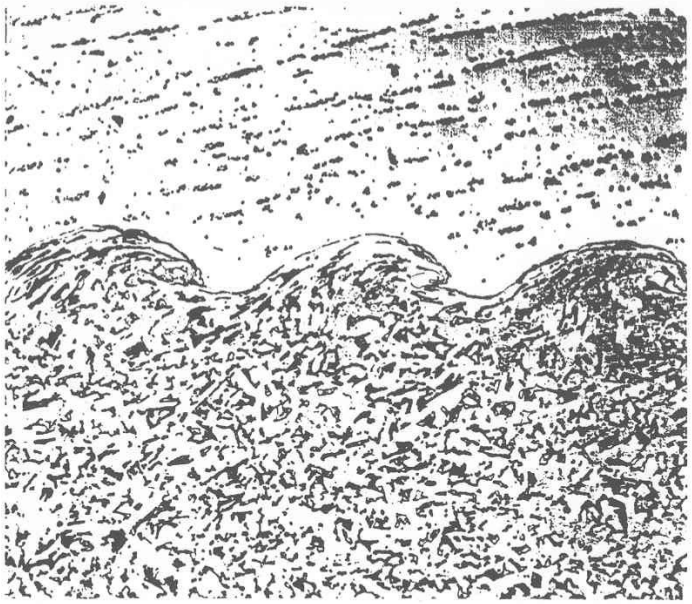

TITANIUM

STEEL

Ti/Fe EXPLOSIVE METALCLADDING

Explosive welding area from hemispherical deep-drawing

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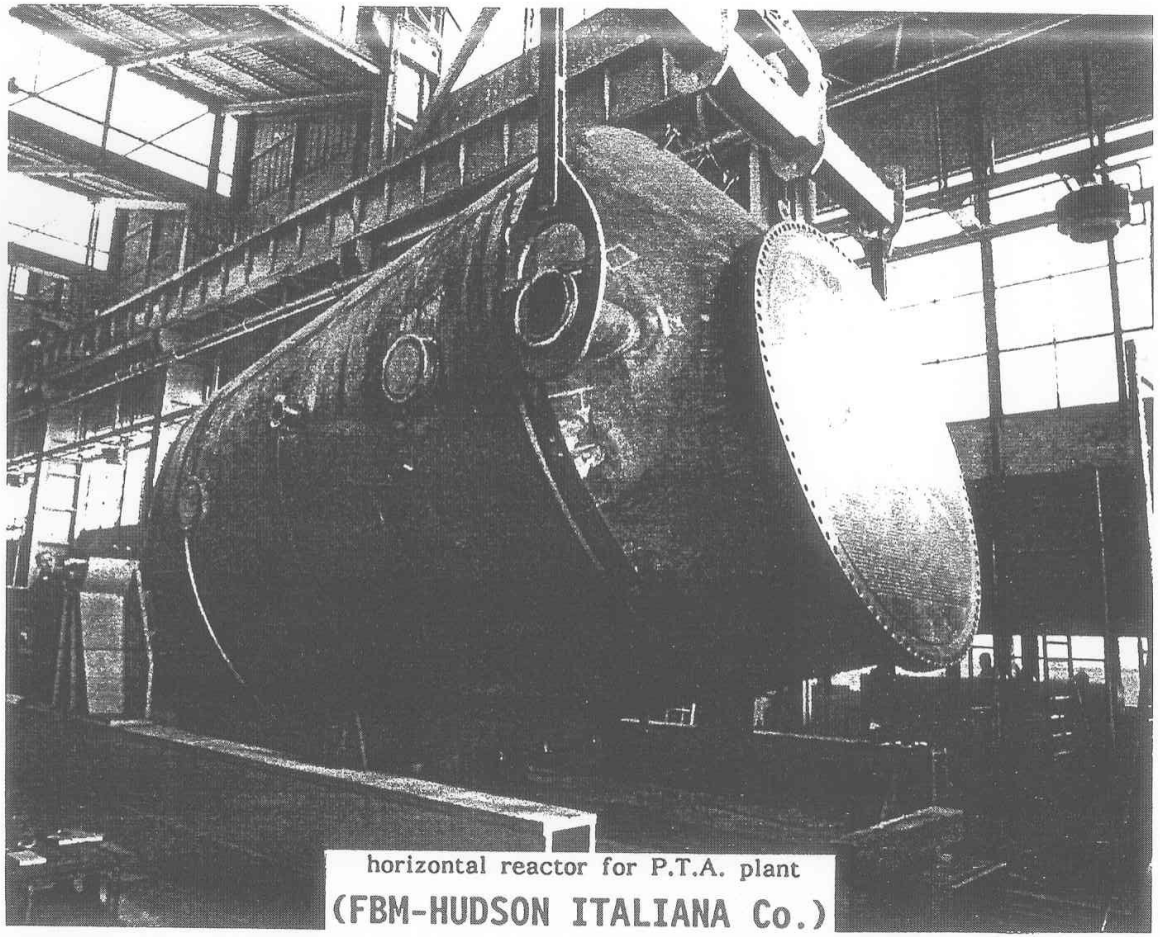

horizontal reactor for P.T.A. plant
(FBM-HUDSON ITALIANA Co.)

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Ref.	temp. (° C)	time (min)	Shear strenght (MPa)
A	540	120	27/30
B	A + 650	15	25/27
C	B + 700	15	22
D	C + 750	15	20
E	D + 800	15	19/20
F	A + 800	30	18
G	F + 850	30	16
H	G + 875	30	15
I	H + 900	30	12/13

Ti/Fe EXPLOSIVE METALCLADDING

Shear test results

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- Titanium (gr. 1, 2, 7, 11)
- Stainless steel (austenitic, ferritic, duplex)
- Copper and alloys (Cu-Ni, Cu-Al, Naval Brass, Muntz Metal)
- Nickel and alloys (Inconel®, Monel®, Incoloy®, Hastelloy®)
- Aluminium and alloys (1000, 5000, 6000 std)
- Zirconium
- Tantalum
- Silver

EXPLOSIVE METALCLADDING

Cladding metals in today mass production

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- Carbon manganese steel
- Cr Mo alloyed steel
- Mo and Mn Mo alloyed steel
- Ni alloyed steel
- High yield steel
- Quenched and tempered steel
- Stainless steel
- Armour steel
- Aluminium and alloys

EXPLOSIVE METALCLADDING

Base metals in today mass production

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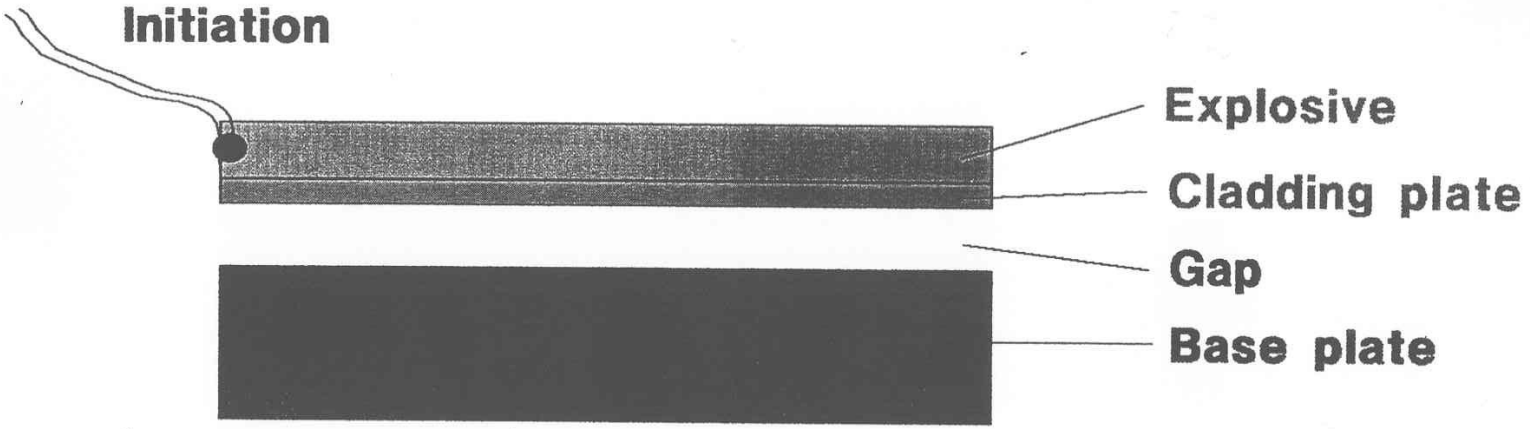

EXPLOSIVE METALCLADDING

Arrangement

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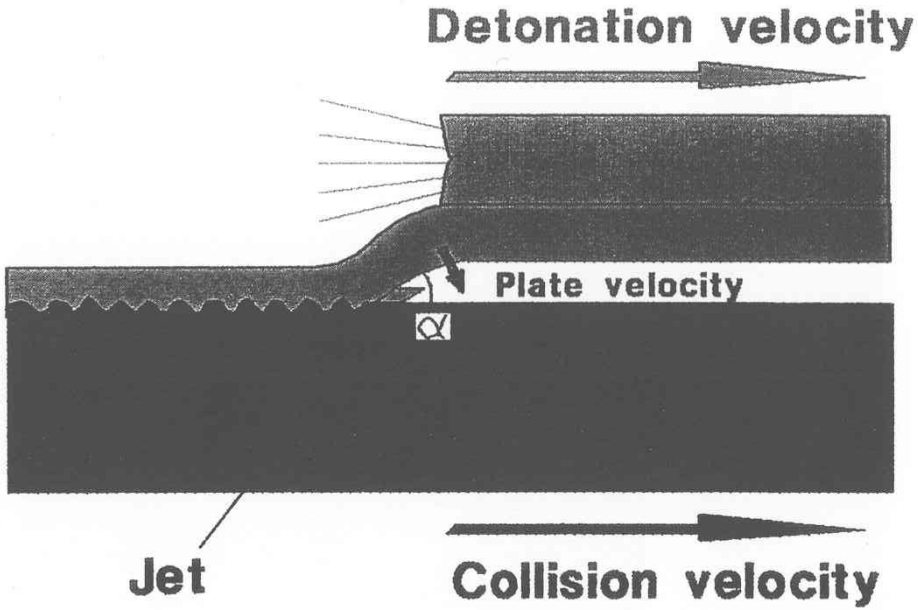

EXPLOSIVE METALCLADDING

Cladding phenomenon

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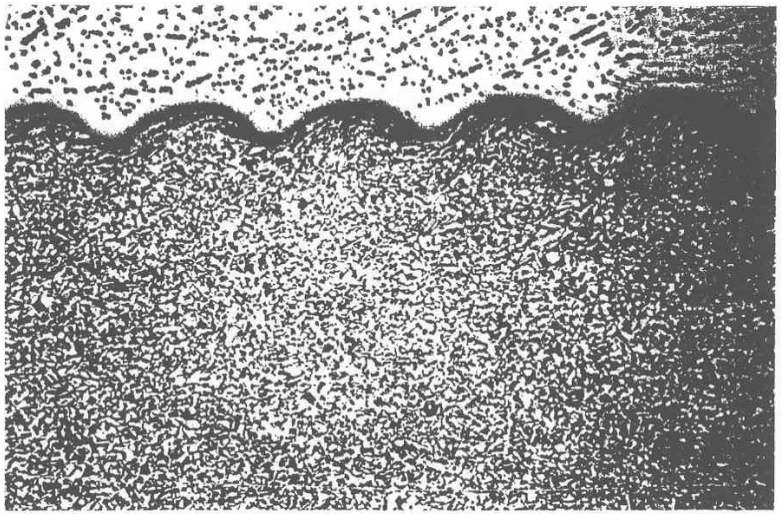

TITANIUM

STEEL

Ti/Fe EXPLOSIVE METALCLADDING

Explosive welding area

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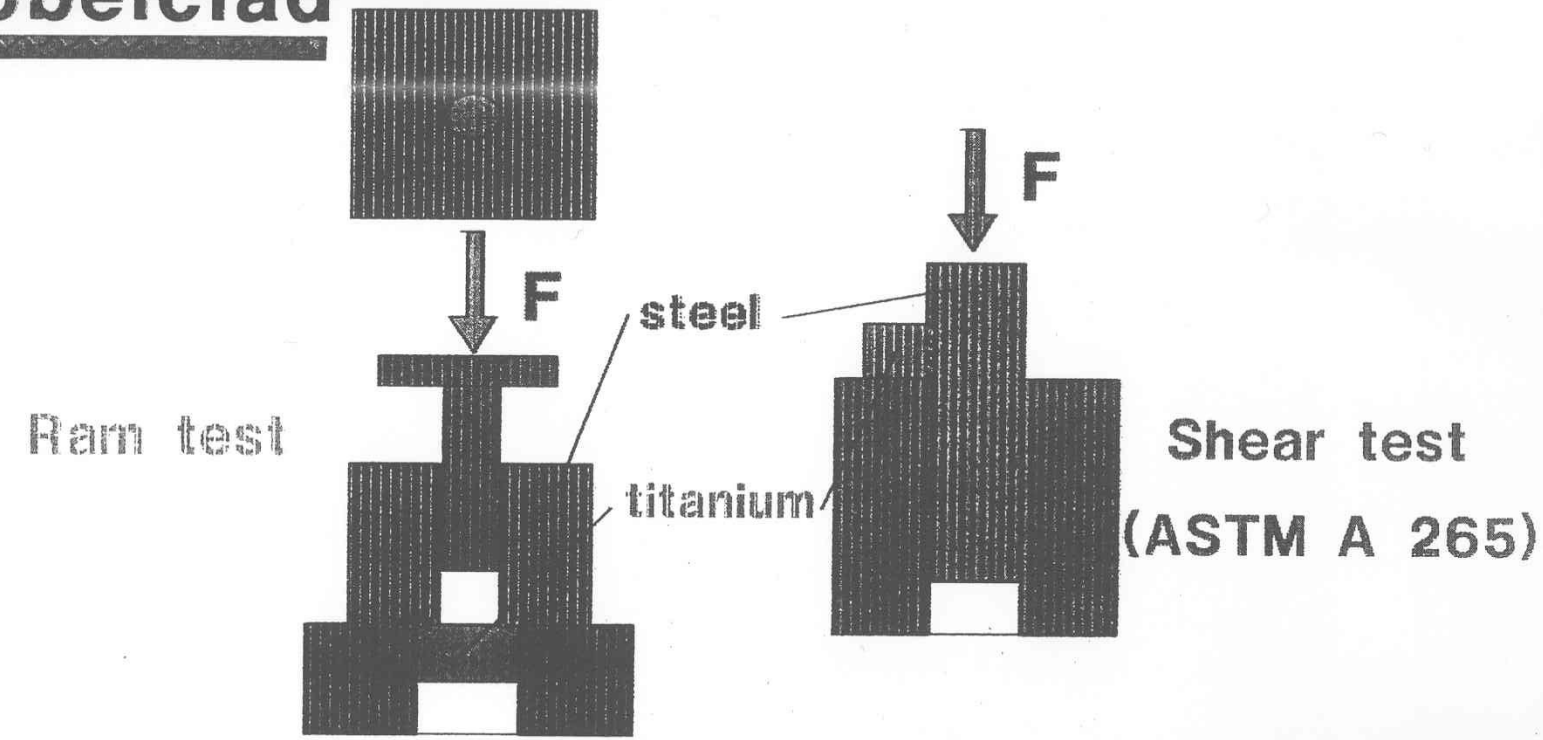

180/250 ⟵ tensile strength (MPa) ⟶ 200/300

Typical values for Ti/Fe clad plate

EXPLOSIVE METALCLADDING

Mechanical tests

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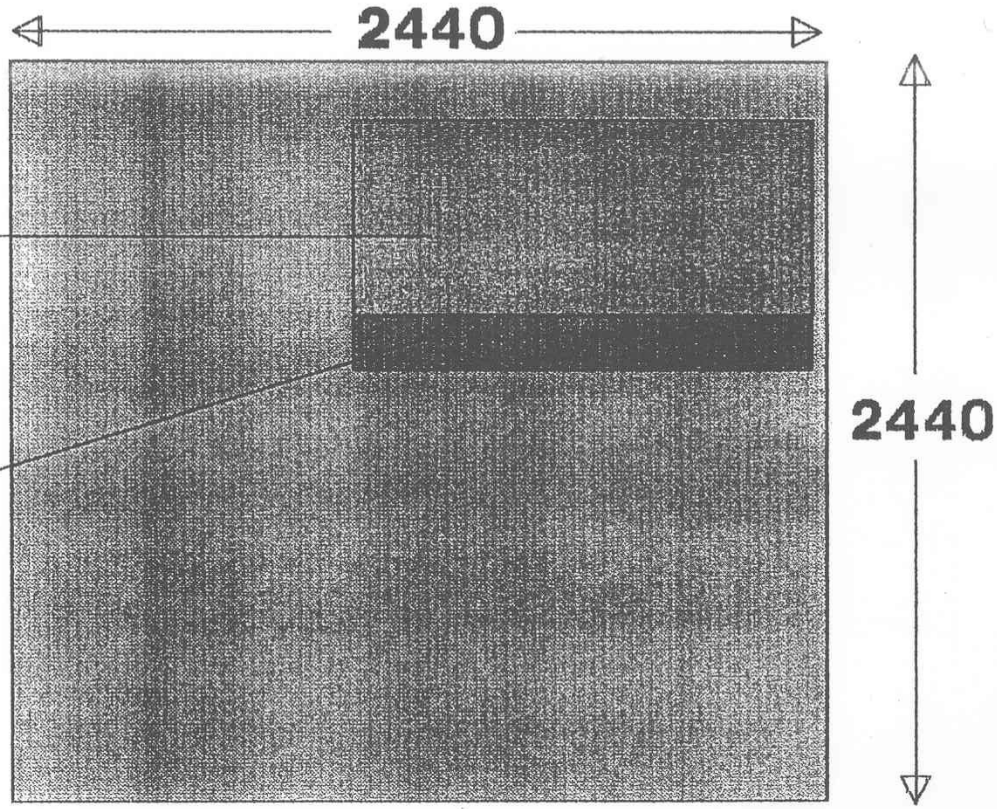

Sampling area
for bend tests

Sampling area
for shear tests

Ti/Fe EXPLOSIVE METALCLADDING

Sampling areas

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	Metal (ASTM Std)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
Cladding plate	Titanium B265 gr. 1	253	324	30
Base plate	Steel A515 gr. 60	313	473	29

Ti/Fe EXPLOSIVE METALCLADDING
Plates mechanical characteristics

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Ref	temp. (°C)	time (min)
A	540	120
B	A + 350	15
C	B + 700	15
D	C + 750	15
E	D + 800	15
F	A + 800	30
G	F + 850	30
H	G + 875	30
I	H + 900	30

Ti/Fe EXPLOSIVE METALCLADDING

Thermal conditioning

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Ref	temp. (°C)	time (min)	Results dia. 50	dia. 100
A	540	120	GOOD	GOOD
B	A + 650	15	GOOD	GOOD
C	B + 700	15	GOOD	GOOD
D	C + 750	15	GOOD	GOOD
E	D + 800	15	GOOD	GOOD
F	A + 800	30	GOOD	GOOD
G	F + 850	30	GOOD	GOOD
H	G + 875	30	GOOD	GOOD
I	H + 900	30	FAILED	GOOD

Ti/Fe EXPLOSIVE METALCLADDING

Bend test results

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