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"METALLURGIA, TECNOLOGIE AVANZATE E APPLICAZIONI INNOVATIVE DEL TITANIO"

La relazione seguente è suddivisa in quattro paragrafi ben distinti.
Sarà esaminata la grande disponibilità del titanio sulla crosta terrestre; le eccezionali caratteristiche del titanio, con particolare attenzione a quelle che sono definite le proprietà "chiave" del metallo: basso peso specifico ed elevatissima resistenza alla corrosione.
Inoltre saranno discusse le molteplici applicazioni del titanio, non solo in riferimento al settore aerospaziale, ma a tutte quelle applicazioni che vengono genericamente dette industriali.
Infine si farà accenno alla buona lavorabilità del titanio con esempi di pezzi ottenuti per stampaggio a caldo e a freddo, per fusione e per forgiatura.

"Metallurgy, advanced technologies and innovative applications of titanium"

I will discuss four areas this morning. First I will cover titanium availability; second, I will review properties of titanium, and I will review some of the unique properties of titanium (fig. 1); and third, I will discuss applications of titanium. The main emphasis in applications will be on non-aerospace, or what we call industrial applications. And then, finally, I will show a few examples of titanium products to illustrate to you how easy it is to make titanium components.

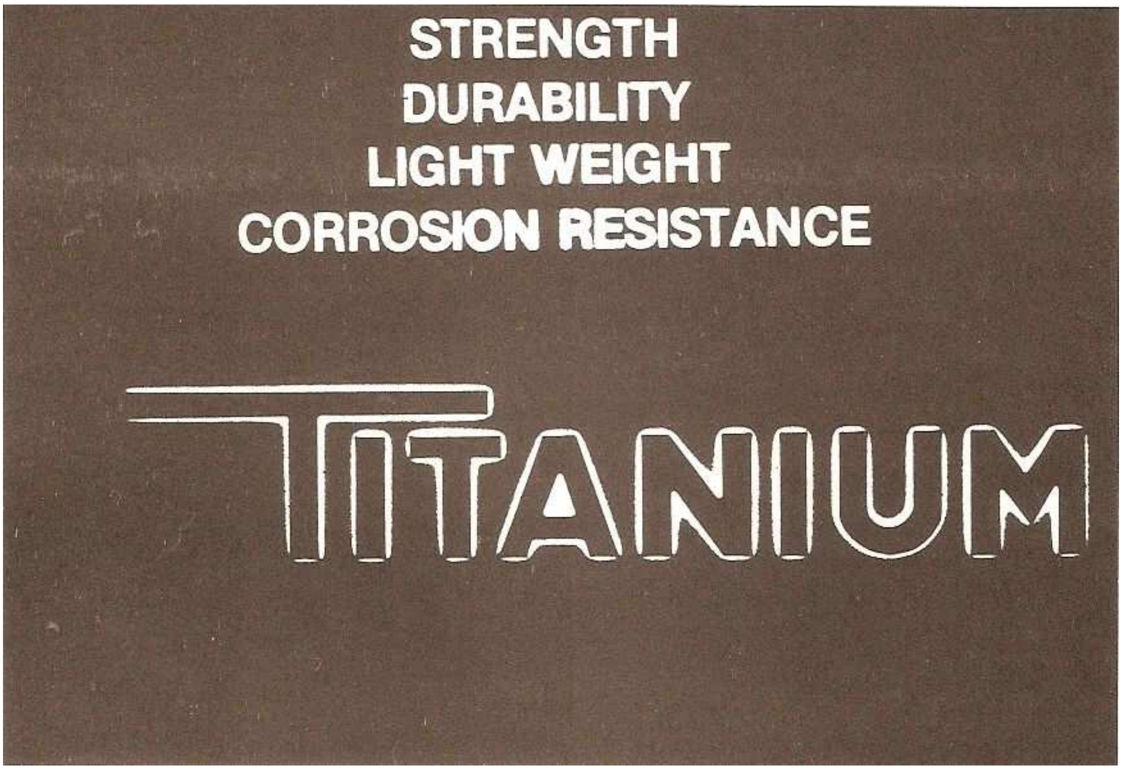

Fig. 1: Unique properties of titanium
(Proprietà fondamentali del titanio)

Availability

Titanium is not a rare element. In fact, you can see in fig. 2, that titanium is the fourth most abundant metal in the earth's crust, following after aluminum, iron, and magnesium.

Titanium is well dispersed throughout the earth, and as you can see in fig. 3 there are workable deposits of titanium ore throughout the globe. Thus, it is not sensitive to political issues or political problems that may exist in the world. So we might ask, if titanium is so abundant, if it is so well dispersed, why is it not used more?

The growth of titanium has been restricted to a certain extent, by the cost of the metal--the cost of winning it from the ore. It is fairly expensive in terms of energy. However, there has been a gradual decrease in the amount of energy. There has also been a rather large increase in the usage of titanium.

Fig. 4, shows the growth of the titanium industry in the United States from about 1950, the very beginning of the industry, to 1984.

The free world consumption of titanium would be about twice the numbers you see here. As you see in the early days in 1950 through 1965, titanium usage was limited to aerospace; in about 1965, significant new applications in the non-aerospace began to occur, and we have been experiencing growth in this non-aerospace area. Much of the remainder of this presentation will be on the growth in this area, plus what the future holds.

Interestingly, if we are to look at titanium on this graph, we can compare it to aluminum.

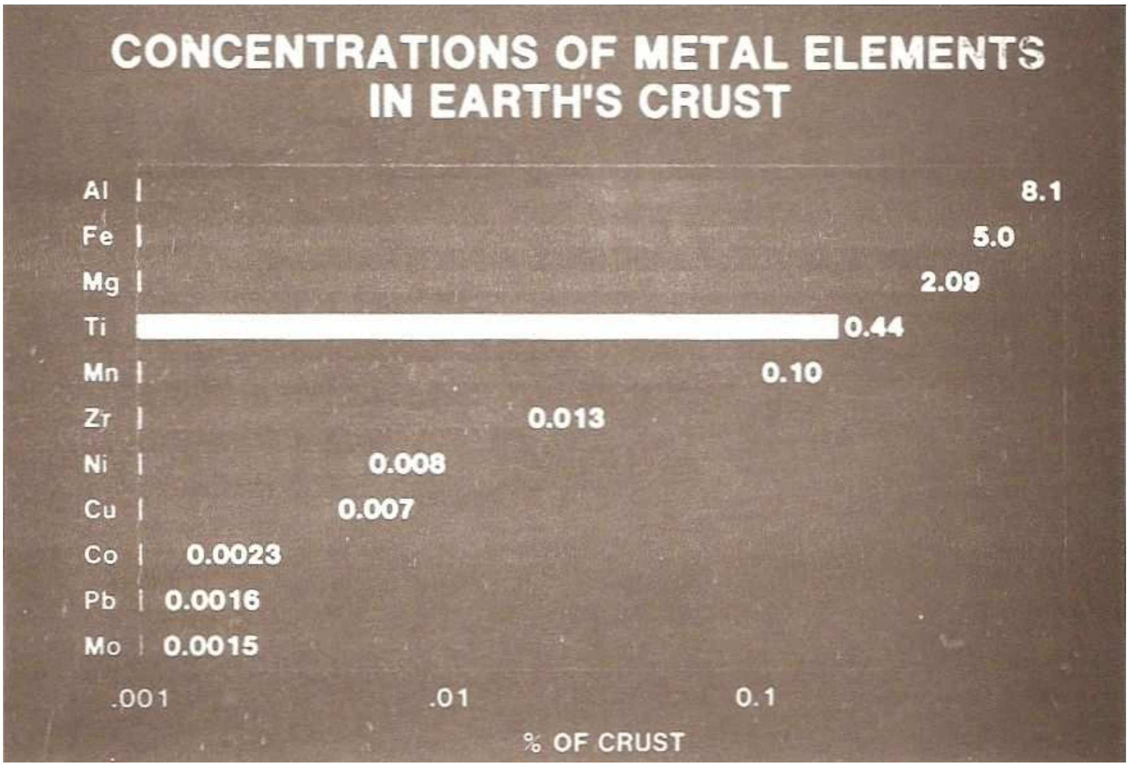

Fig 2: (Concentrazione dei metalli sulla crosta terrestre)

Fig. 3: Titanium – ore deposits
(Giacimenti di titanio)

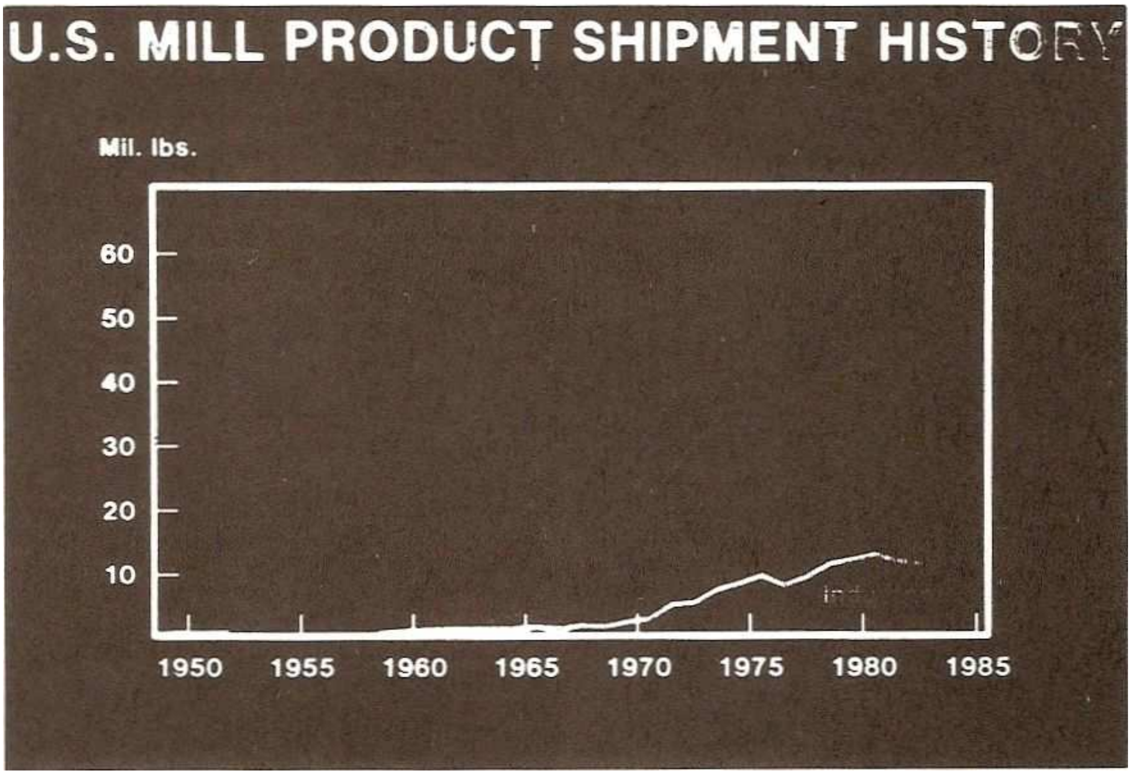

Fig. 4: (Crescita dell'utilizzo del titanio nel settore industriale e aerospaziale in U.S.A.)

We find that today we are at about the same level that aluminum was in 1940. But definitely we feel that it is on a growth curve.

Titanium properties

Now I would like to move to the key important properties of titanium (fig. 5). They center around two characteristics: first of all, corrosion resistance. Titanium has excellent corrosion resistance in all natural media, including chlorides and organics, very resistant to salt water and chloride solutions.
The second main characteristic of titanium is that it has a low density, about one-half that of iron and slightly higher than aluminum.
However, the metal, as you can see, has high strength capabilities, so when you combine the low density with high strength, you have a very efficient engineering material.
Another favorable characteristic of titanium includes its high temperature strength. The gentleman from FIAT Aviazione showed that titanium can be utilized up to 300 or 500 degrees centigrade because of its high temperature strength and its low density.
Other interesting properties that on occasion are very useful in design application include: it has very good ballistic resistance; it has low thermal expansion which is very similar to that of glass and composites, so it is very compatible with those materials; it has a low elastic modulus, which makes it an unique spring material, a very efficient spring material; it has on the corrosion side, good heat transfer; it is very effective in heat exchangers.

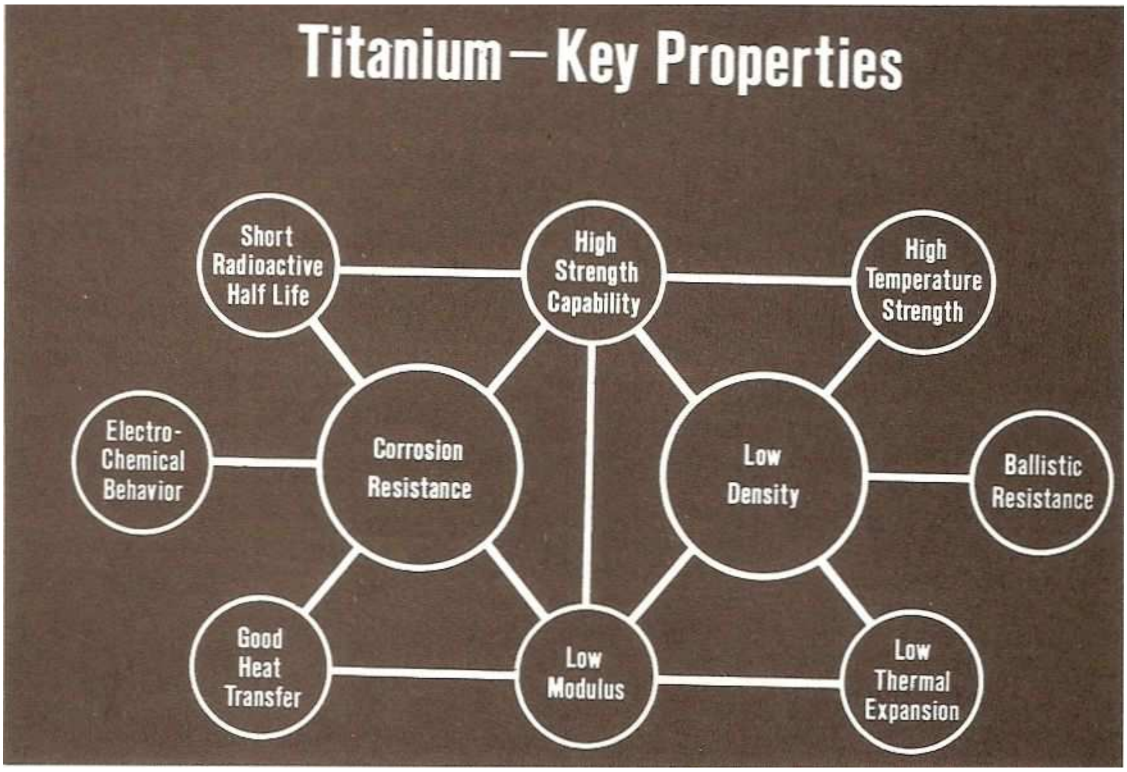

Fig. 5: (Proprietà “peculiari” del titanio)

Titanium also has some very unique electrochemical characteristic, and I will show you some examples later; it also has a very short radioactive half-life, which can be useful in processing uranium and spent uranium.

The fig. 6 was merely to show you an example of the strength ranges that are capable in titanium. The strength ranges from about 350 megapascals in the low strength alloys up to nearly 3500 megapascals. So Titanium is much like steel. It has very wide strength ranges. Very high strength levels are possible with certain alloys of titanium.

Titanium is used in chloride-type environments that are oxidizing and, more recently, we have developed new alloys that are sui table for reducing, environments, on the left-hand side of the graph (fig. 7). We have developed new alloys for corrosion resistant applications. They have very high strength levels, and now will result in the use of titanium in oil and geothermal uses.

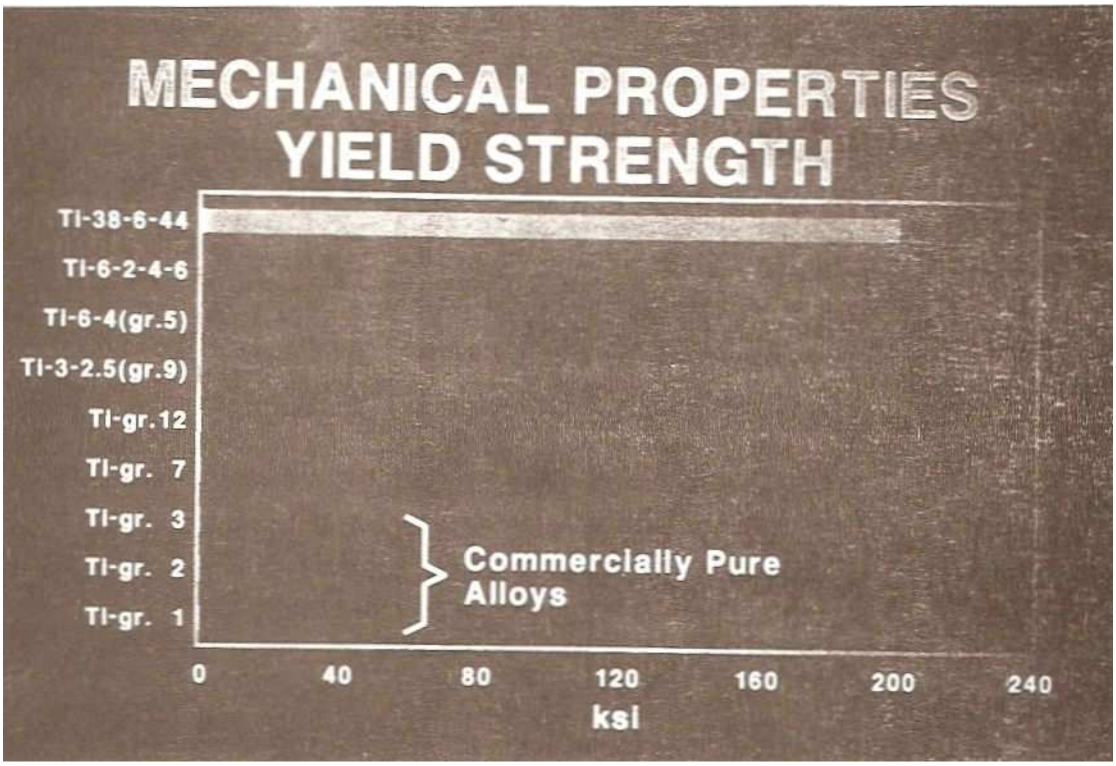

Fig. 6: (Proprietà meccaniche: resistenza allo snervamento)

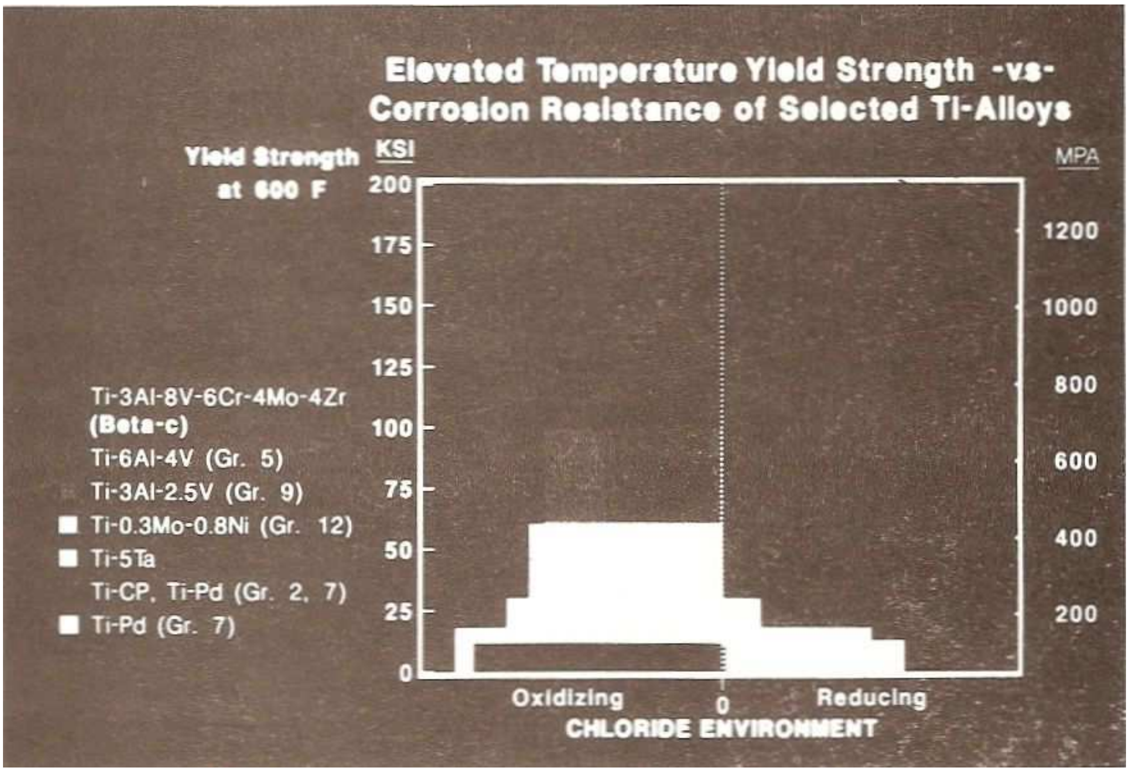

Fig. 7: (Resistenza allo snervamento ad elevate temperature e resistenza alla corrosion di alcune leghe di titanio

We are making progress in the development of better corrosion resistance and we are also making progress in the development of higher strength alloys.

Application of titanium

I am limiting my remarks on aerospace, but I cannot ignore the subject, because it is one of the largest consumers of titanium.

The jet turbine engine is about one-third by weight in titanium (fig. 8). Titanium is utilized in the construction of the compressor section or the front end of the engine, including compressor blades and compressor discs and various ducting (fig. 9).

Another aerospace application is in airframes. In fig. 10 you see the Airbus: this indicates a typical application in airframes. Very often titanium is used in the section of the airframe where it tends to be hot, and this can be in and around the engine area. It is also sometimes used for structural members, including landing gears, hydraulic tubing, fasteners, and springs (fig. 11).

This is the military side. This happens to be the wing carry-through structure for the Tornado (fig. 12). And this is made out of a titanium alloy, very critical to the performance of military aircraft.

Now I want to change from aerospace engines and airframes, and discuss industrial applications; but first, let me present a historical view of the Titanium industrial market.

The first usage of titanium in the industrial world was around 1965. And we have shown in (fig. 13) the various markets that utilize titanium, by percentage.

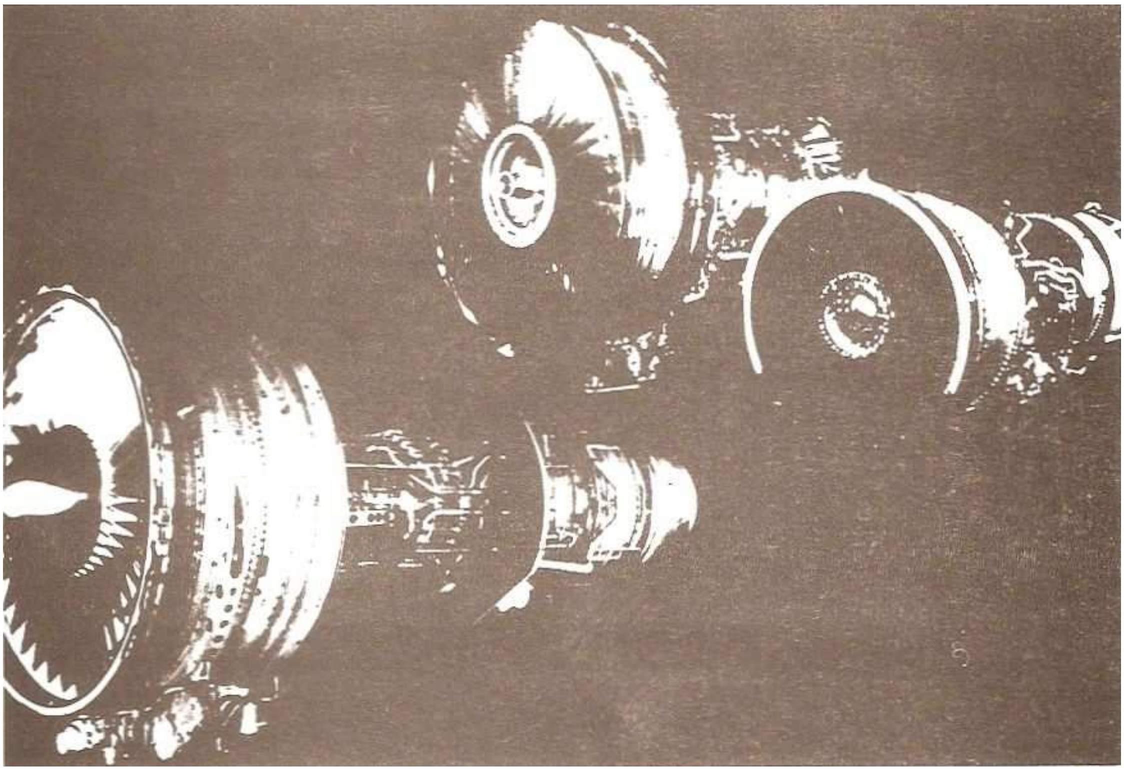

Fig. 8: Titanium application in aerospace
(Applicazioni del titanio nei motori aeronautici)

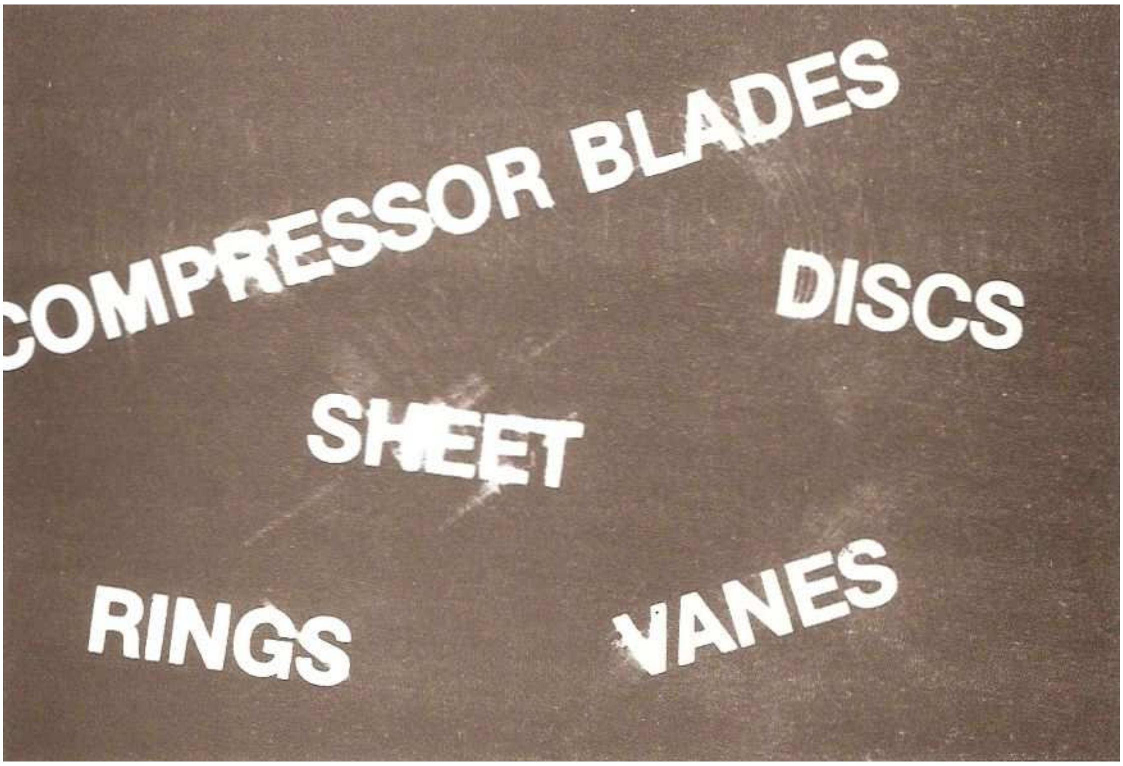

Fig. 9: Some aerospace engine components made out of titanium
(Vari componenti i motori aeronautici costruiti in titanio)

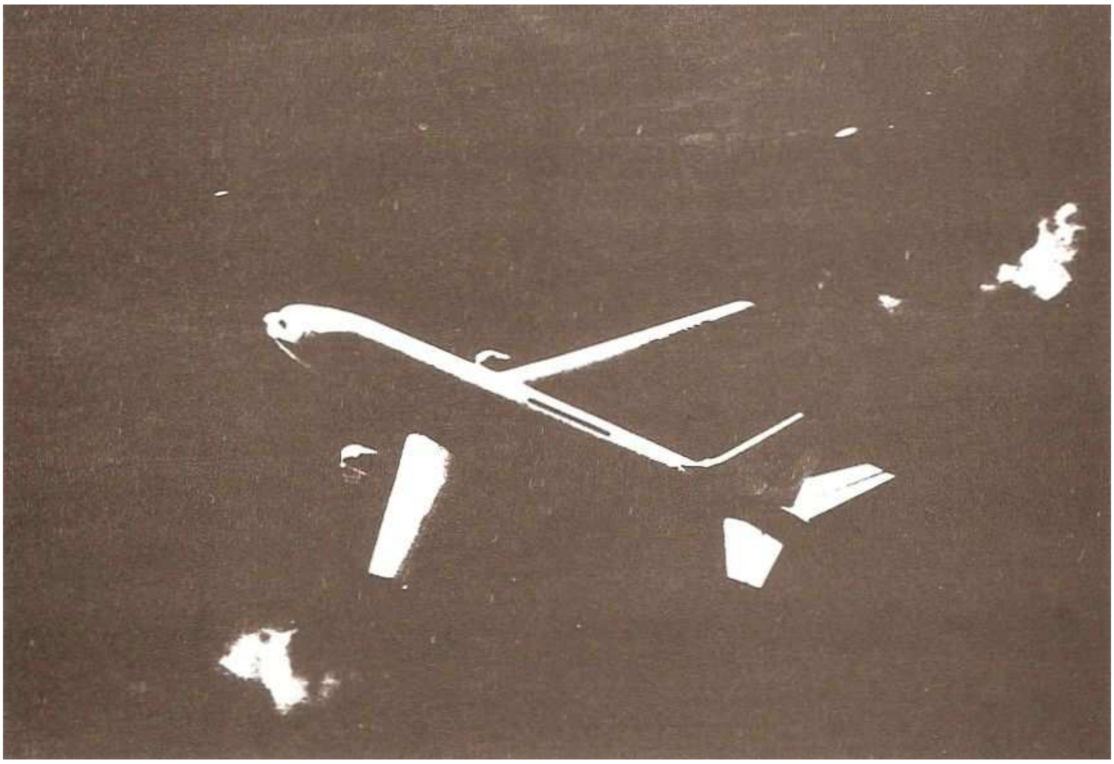

Fig. 10: Titanium application in aerospace airframes (Applicazione del titanio nelle strutture aeronautiche)

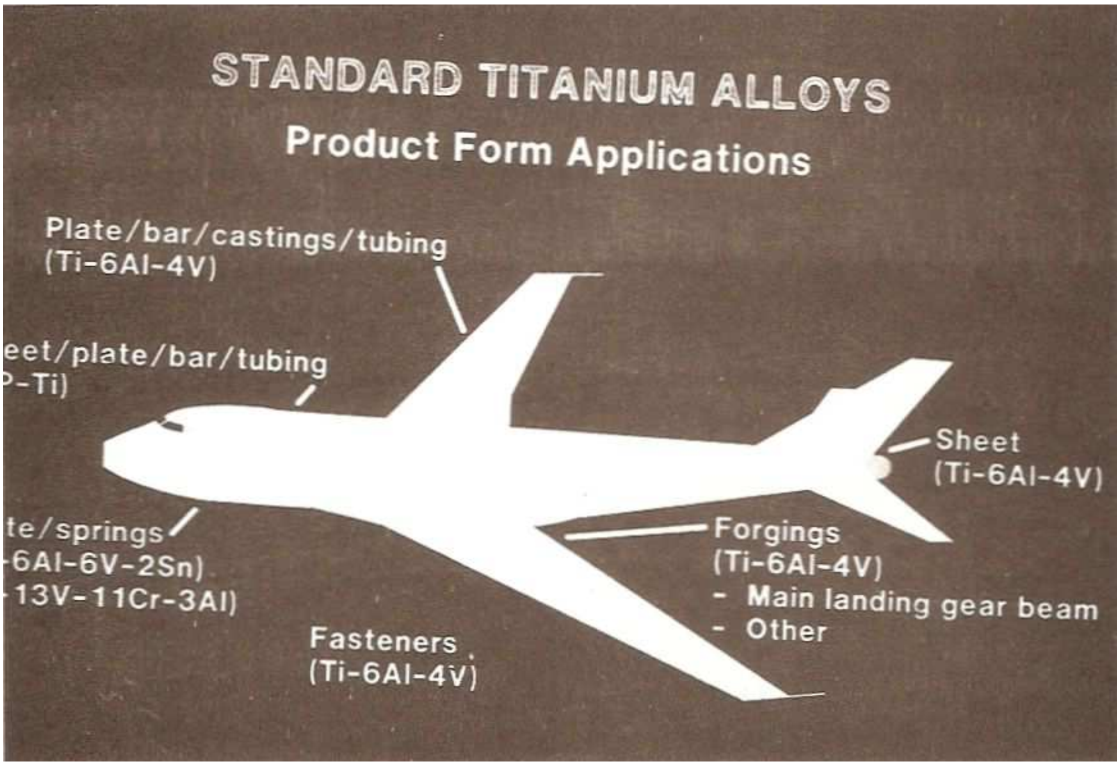

Fig. 11: (Altre applicazioni aeronautiche delle leghe di titanio)

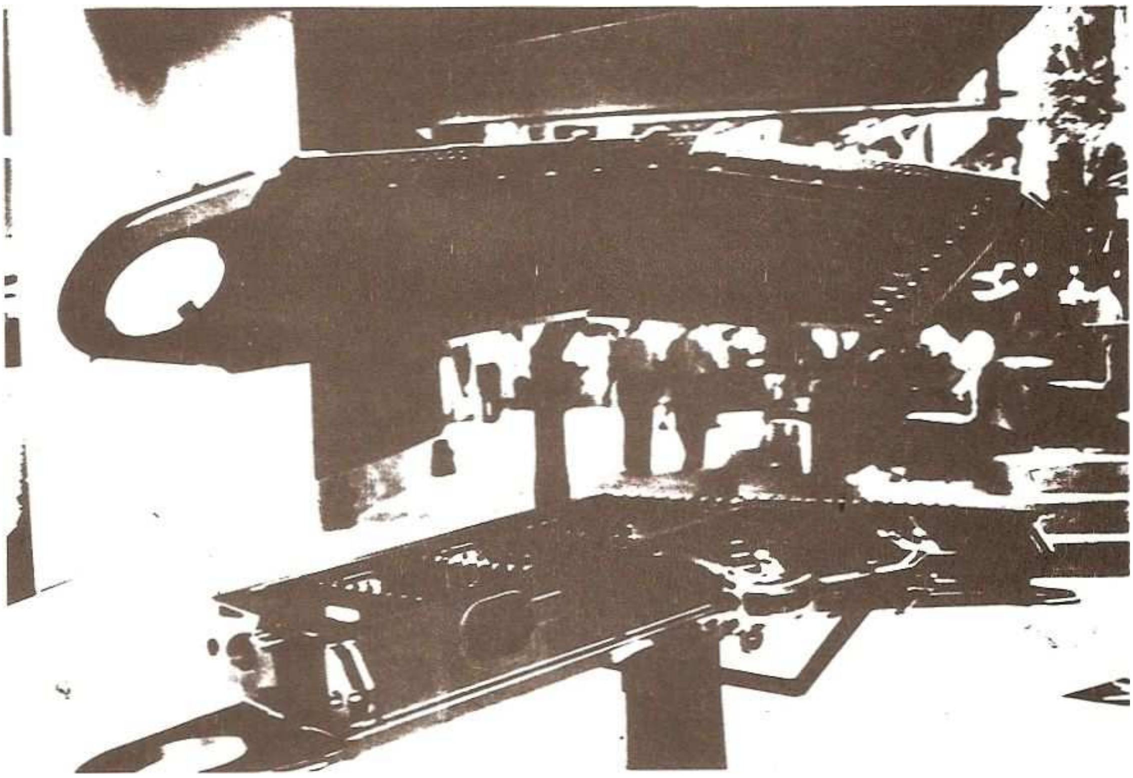

Fig. 12: Wing carry – through structure for the Tornado (Struttura portante di un'ala del Tornado)

INDUSTRIAL MARKET DISTRIBUTION

MARKET:	% DISTRIBUTION 1965	1973	1977	1985
General Chemical	50	30	32	21
Electrodes	50	32	13	19
Power	0	16	35	25
Hydrocarbon	0	8	8	4
Pulp/Paper	0	4	5	7
Geothermal	0	0	0	3
Miscellaneous	0	10	7	21
Total pounds (1,000,000):	1.5	4.5	9.0	12.0

Fig. 13: (Distribuzione percentuale dei settori industriali in cui è applicato il titanio)

For example, in 1965, 50% of the titanium used in non-aerospace or industrial markets, was used in chemical plants, where its corrosion resistance was important. Another 50% was used as electrodes in the generation of chlorine.

Now as we move to 1973, we see that we have new applications, in the power industry. The power industry now utilizes large quantities of Titanium in heat exchangers. One power plant can utilize as much as 500,000 pounds of titanium.

Also in 1973 we find that titanium is being used in the pulp and paper industry.

Now as we move on out into 1985, we see some changes in the numbers. But we see that there has been growth in the pulp and paper; we see now some utilization in geothermal. And finally, what is very interesting, 20% of the usage is miscellaneous applications. Now let's review some of these applications.

Let's first cover chemical plants (fig. 14). Fig. 15 is an example of a titanium tank for storage of the chemical sodium chlorate. I would like for you to note the large size of this vessel. This very large vessel is typical of the types of fabrications that are now being made out of titanium. Another example is a chemical vessel for use with calcium chloride (fig. 16). Again, note the size of the vessel. Another interesting example: this truck has a titanium shell and carries nitric acid (fig. 17). Here we have the advantage of corrosion resistance and light weight. There is a limit in the United States as to the total weight that can be on the road. By utilizing titanium, more nitric acid, could be carried because of the light weight.

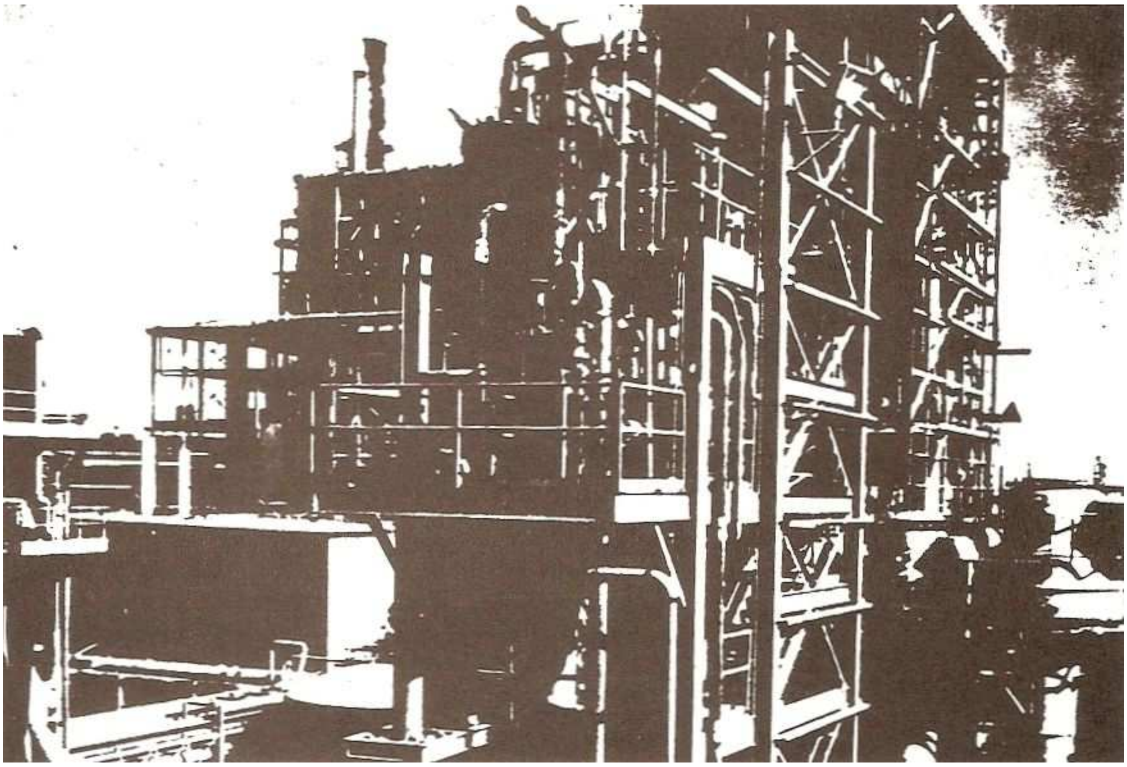

Fig. 14: Titanium application in chemical plants
(Applicazione del titanio negli impianti chimici)

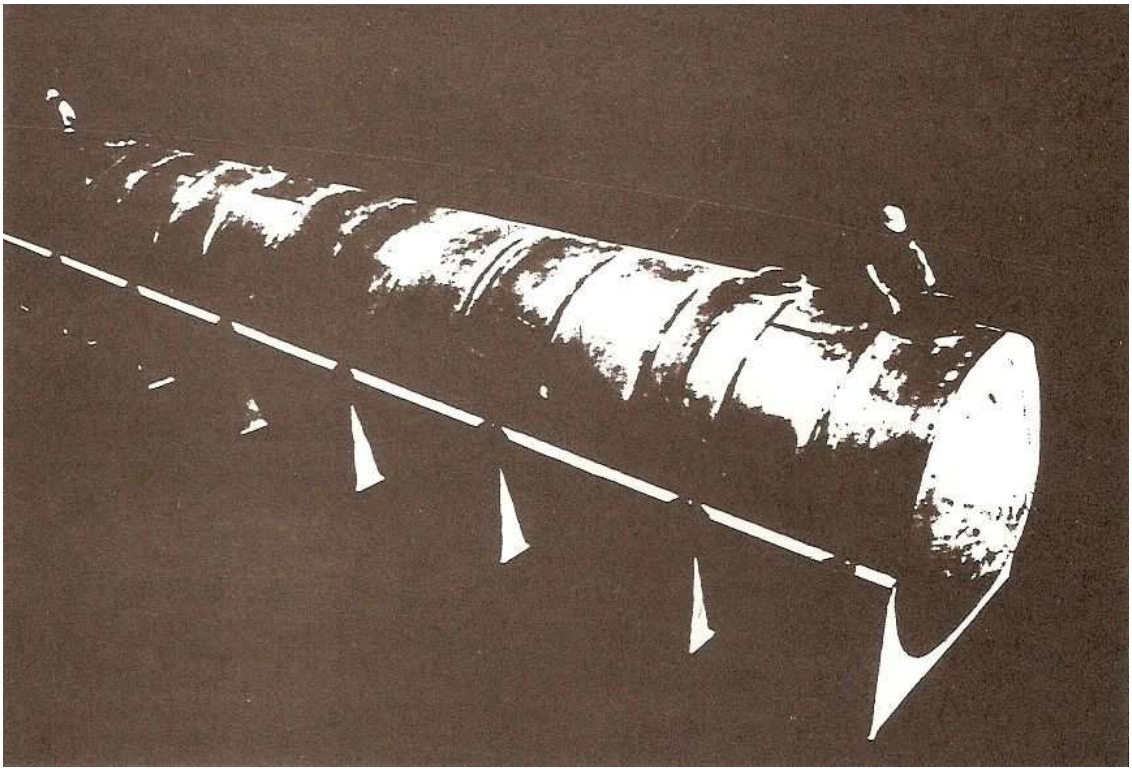

Fig. 15: Titanium tank for storage of sodium chlorate
(Serbatoio per lo stoccaggio di sodio clorato)

Fig. 16: Chemical vessel for calcium chloride
(Serbatoio per cloruro di calcio)

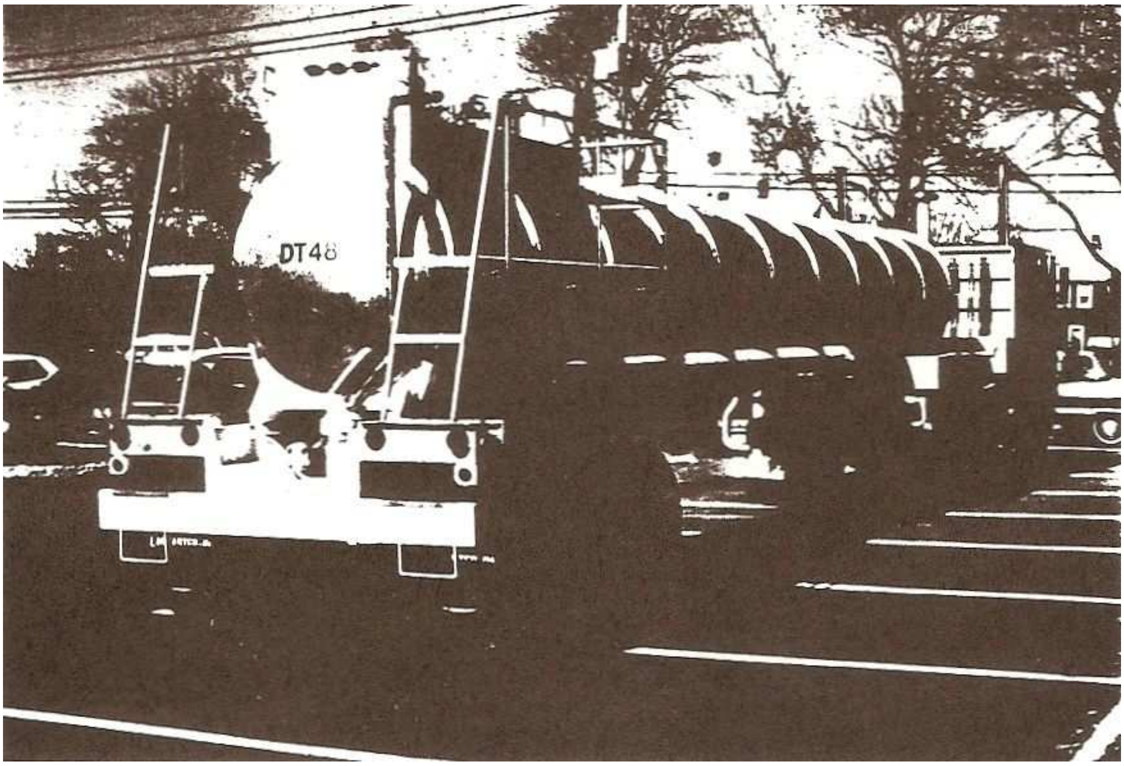

Fig. 17: Truck with a titanium shell for nitric acid
(Autocarro con serbatoio per acido nitrico)

Another example of where weight is very important is a very high speed Beckman centrifuge (fig. 18). Titanium is chosen for two reasons: its very high strength and its low weight makes its low weight makes it possible to go at very high speeds.

Another example of unique technology in the use of titanium is electrochemical. This technology was developed in Italy and is for the generation of chlorine on precious metal-titanium anodes (fig. 19).

Titanium is used extensively in heat exchangers. Titanium has a low thermal conductivity, and it was unexpected, in the very early days, to find that titanium was very good in heat transfer. The basic reason is that the heat transfer is dependent on the film on the surface.

Titanium in most environments does not corrode, and there is very, very good heat transfer.

Many competing metals (copper, nickel, some of the stainless steels) corrode, and as a result, the heat transfer decreases with time (fig. 20). But titanium has excellent heat transfer because of its surface film and lack of corrosion.

A good example of a heat exchanger is this plate-type heat exchanger (fig. 21); it is put together with many cold formed sheets of titanium. These are used very often in sea water cooling. One typical application is on oil rigs off-shore. This is the primary cooling heat exchanger.

Another example of a heat exchanger, is a tube inside of a tube (fig. 22). This was developed for a municiple sewage treatment plant utilizing wet oxidation process. In this application the corrosion resistance, a high temperature and good heat transfer are required.

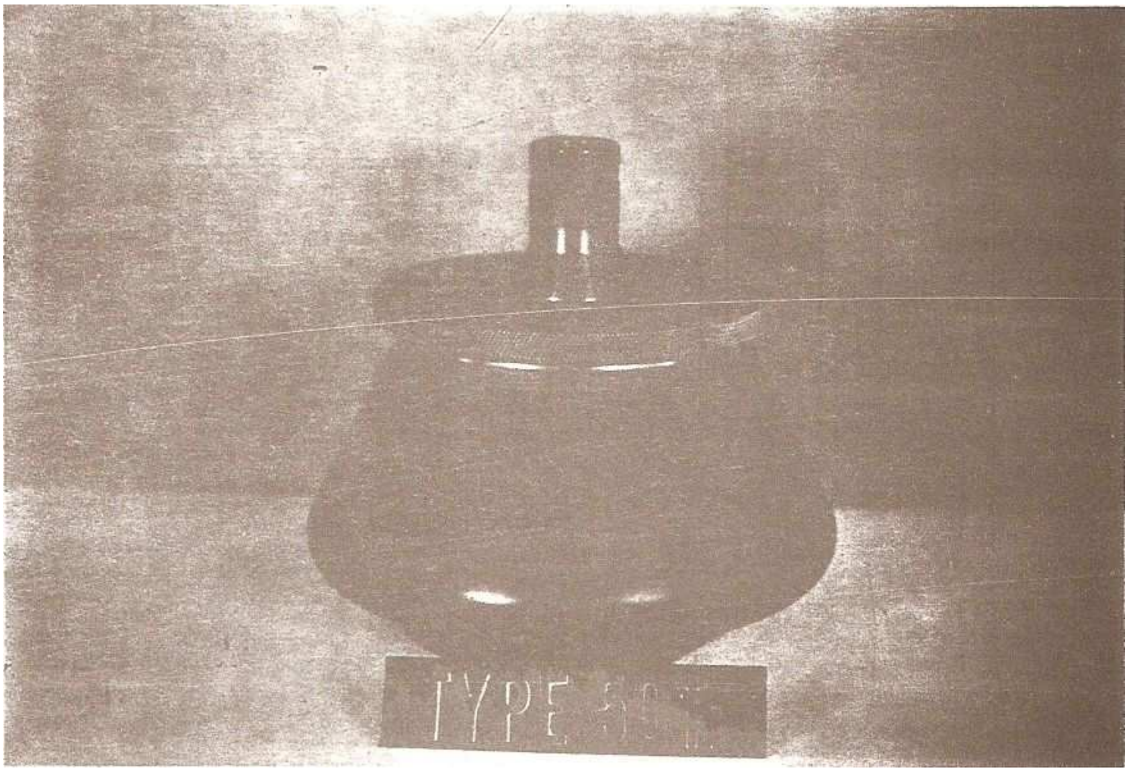

Fig. 18: Beckman centrifuge
(Centrifuga Beckman)

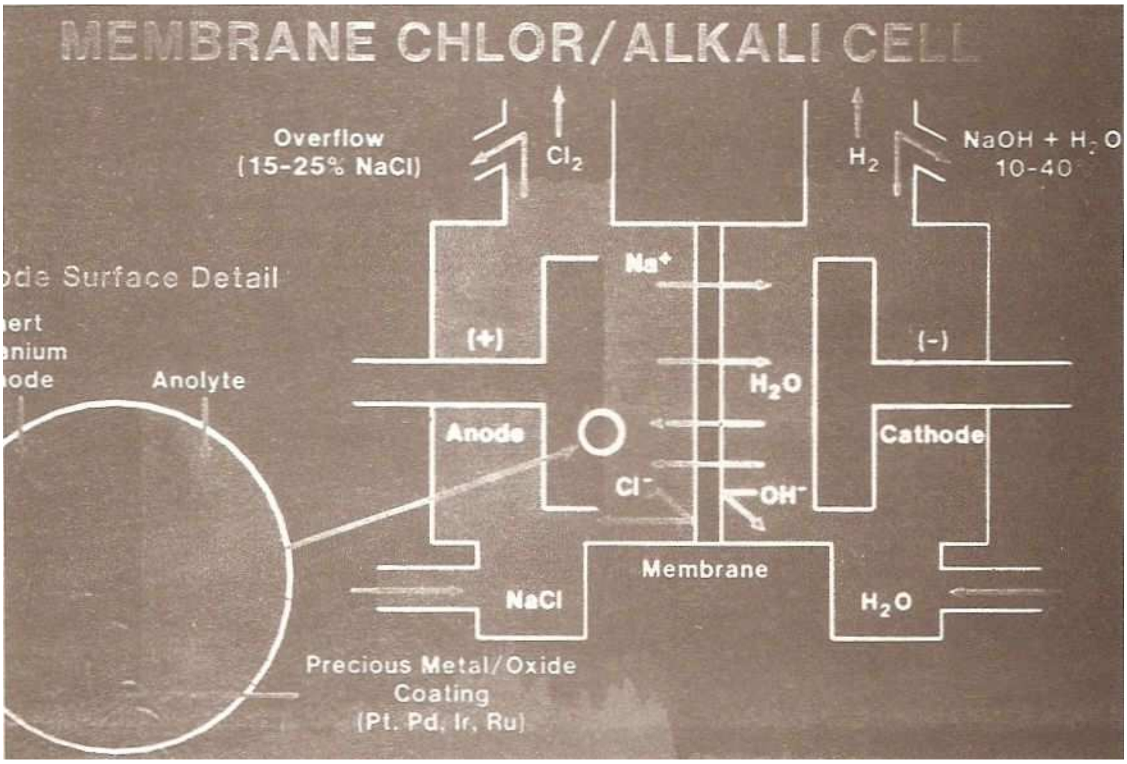

Fig. 19: Titanium anodes
(Anodi in titanio)

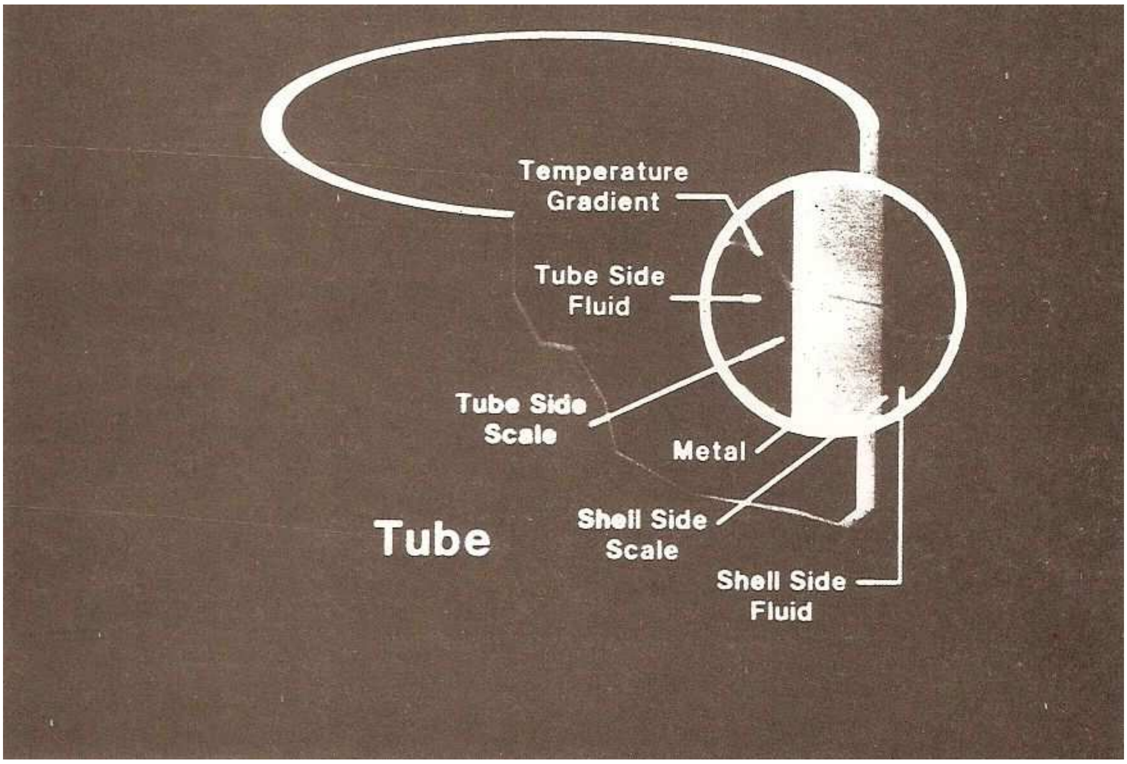

Fig. 20: Temperature gradient in a titanium tube
(Gradiente di temperatura all’interno di un tubo in titanio)

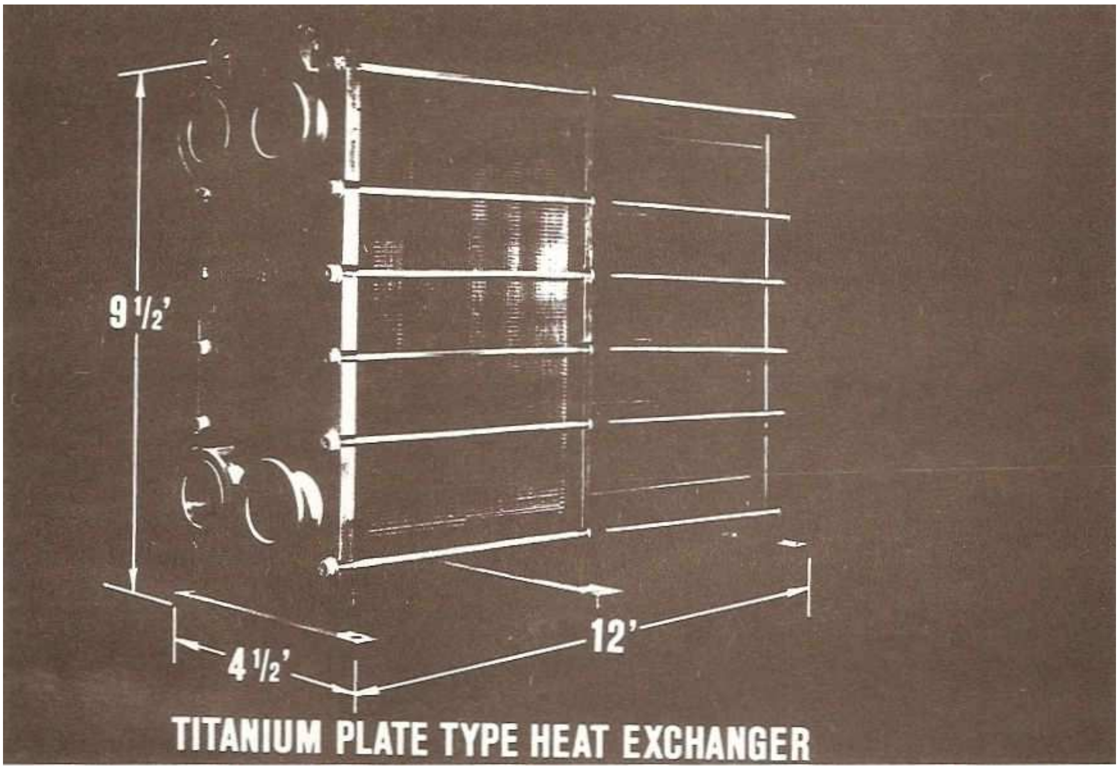

Fig. 21: (Scambiatore di calore a piastre)

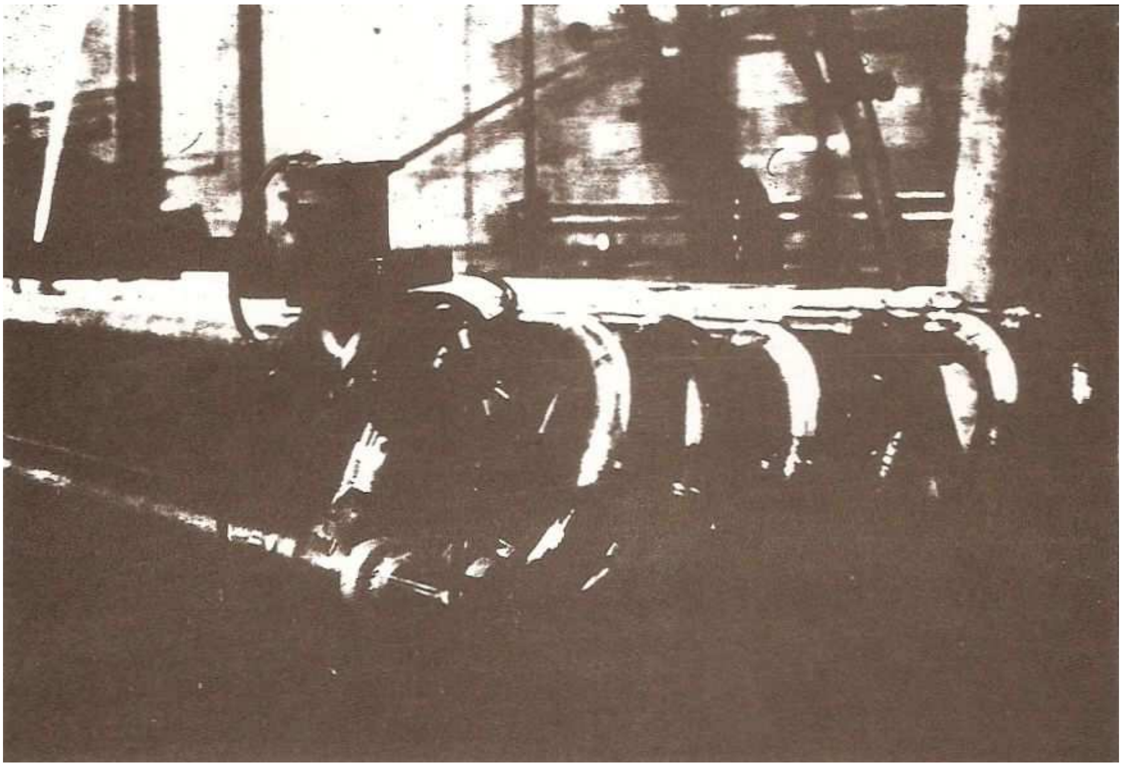

Fig. 22: Titanium tube inside of a tube type heat exchanger
(Scambiatore di calore a tubi coassiali)

Another example of the characteristics of titanium is its good ballistic resistance. This is the protection around a pilot in an A-10 fighter (fig. 23), titanium is there because of light weight and excellent ballistic characteristics.

Another interesting area is the use of titanium in automobiles. Titanium has been used for some time in racing and high performance automobiles (fig. 24).

In the last four or five years, in the attempt for the auto industry to become more efficient with their vehicles, to improve gas mileage or to improve performance, they began to look at titanium as a possibility. From this early development two companies have very active programs in titanium, one being Ford Motor Company, and the other being Mitsubishi in Japan.

Mitsubishi has announced that they will be utilizing titanium intake valves in a 1986 production high performance automobile. There is a possibility that Ford will have some engine components in about 1989. But why titanium? It is offering, not just total weight savings, but improved performance in engines.

I would like discuss about springs: these are suspension springs from a titanium alloy (fig. 25). The spring on your left is made out of steel the spring on your right is made out of titanium. They both will do the same performance in an automobile. The weight of the steel spring is 14 pounds; the weight of the titanium spring, 5 pounds. The other advantage of titanium is that the spring on the right can be made more compact, can be made shorter; the steel spring cannot. This is why titanium springs are used in aerospace, because they can be put into smaller compartments.

Also valve springs are now being made, and are showing very good performance.

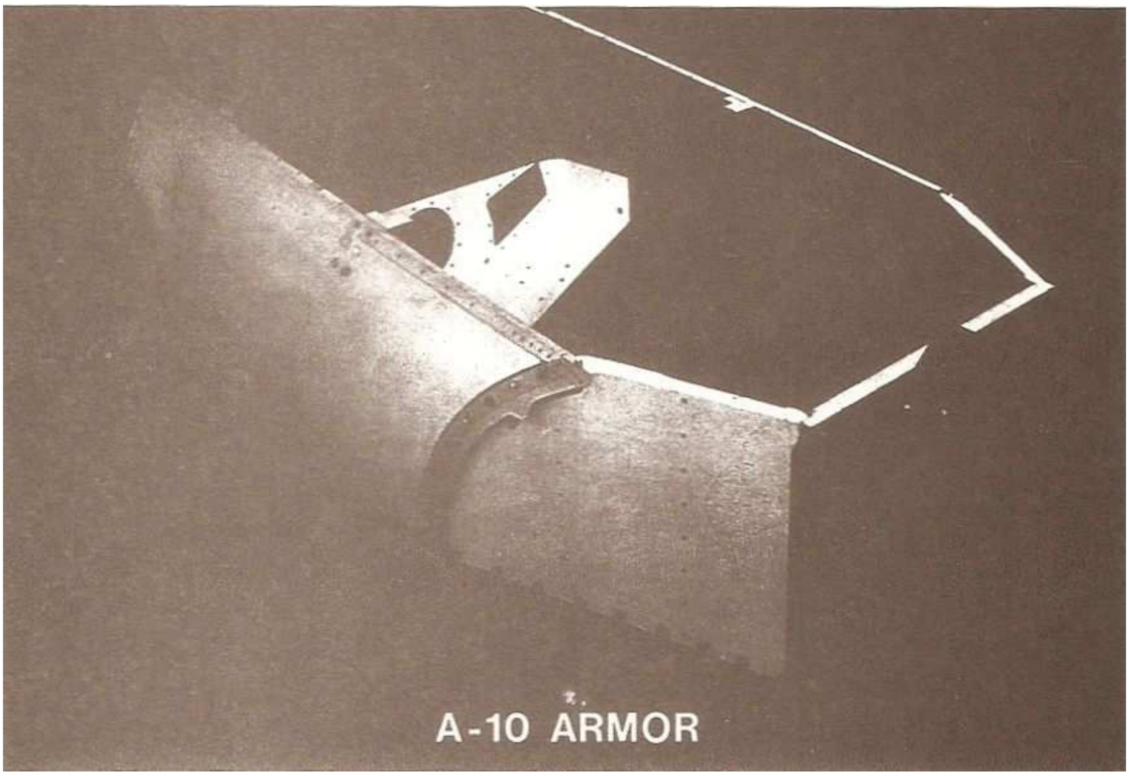

Fig. 23: Titanium application in ballistic area: protection around a pilot in an A-10 fighter (Applicazione del titanio nel settore balistico: protezione del pilota in un areo da combattimento)

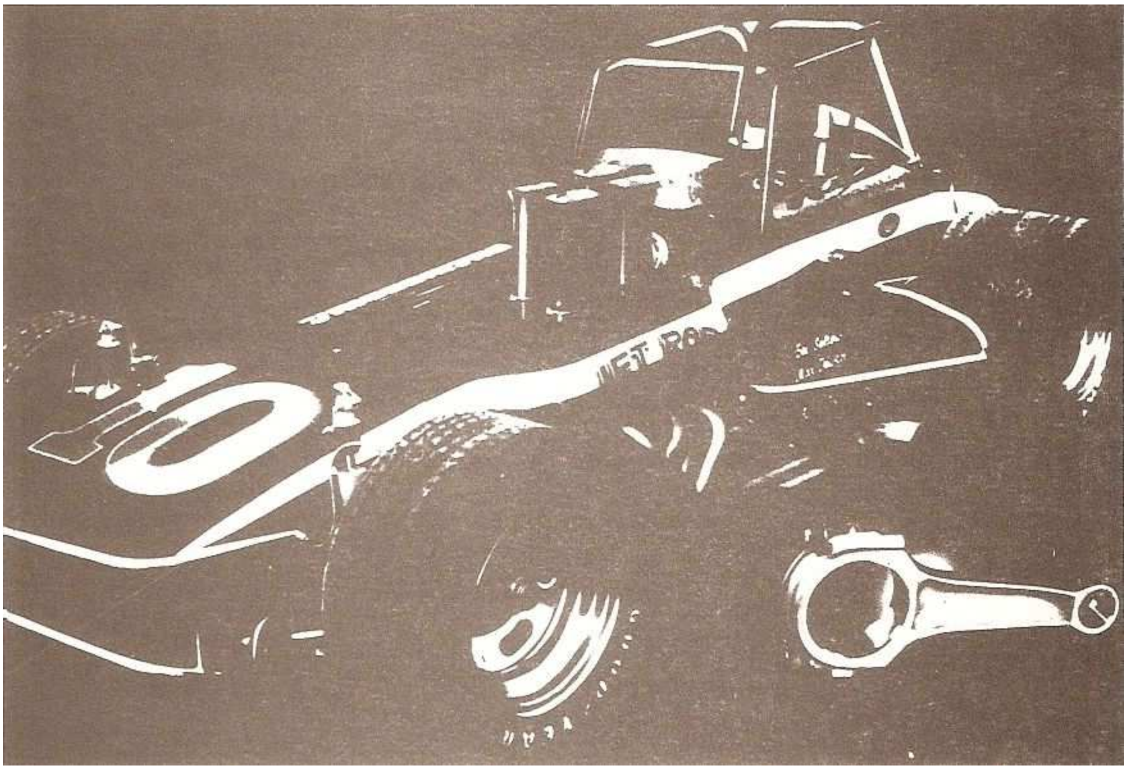

Fig. 24: Titanium application in sutomotive area (Applicazione del titanio nel settore automobilistico)

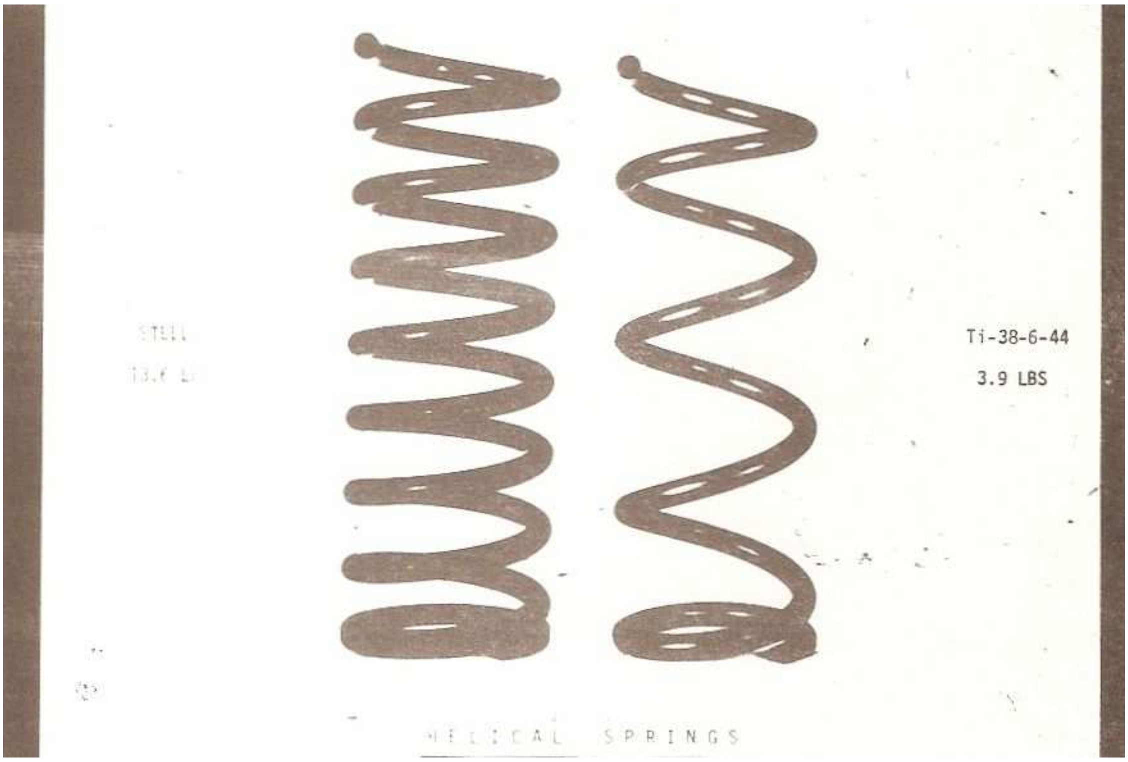

Fig. 25: Titanium-alloy spring – VS – steel spring (Molla in lega di titanio confrontata con molla in acciaio)

Here is an example of a forged valve (fig. 26). Titanium makes very good intake and exhaust valves. Combined with springs, the fuel consumption of an engine can be decreased, approximately, l to 2 miles per gallon.

Another interesting example of titanium is the use in the body. In fig. 27 you may recognize some of those parts: a femur, a hip joint. The very rough looking area is titanium powder that is used in the healing process to make a stronger joint with the bone.

Titanium is a very good implant material for three reasons. One, you recall, it is very good in chloride environment and because the body is sodium chloride, there is no corrosion. Number two, titanium is very strong, and three it is light.

In Fig. 28 you can see a cardiac valve.

A problem in our country, as well as around the world, is how to store nuclear wastes. The solution that we appear to be utilizing, is to store the wastes in salt mines. And the concept that is being evaluated in a prototype is to store in titanium cans because of the excellent corrosion resistance of titanium in a salt environment (fig. 29).

Another area of concern is air quality. And in this respect, we are very concerned with the emissions of sulphur compounds from power plants. There will be restrictions on the emissions. We expect titanium will be a part of the solution to some of the problems (fig. 30).

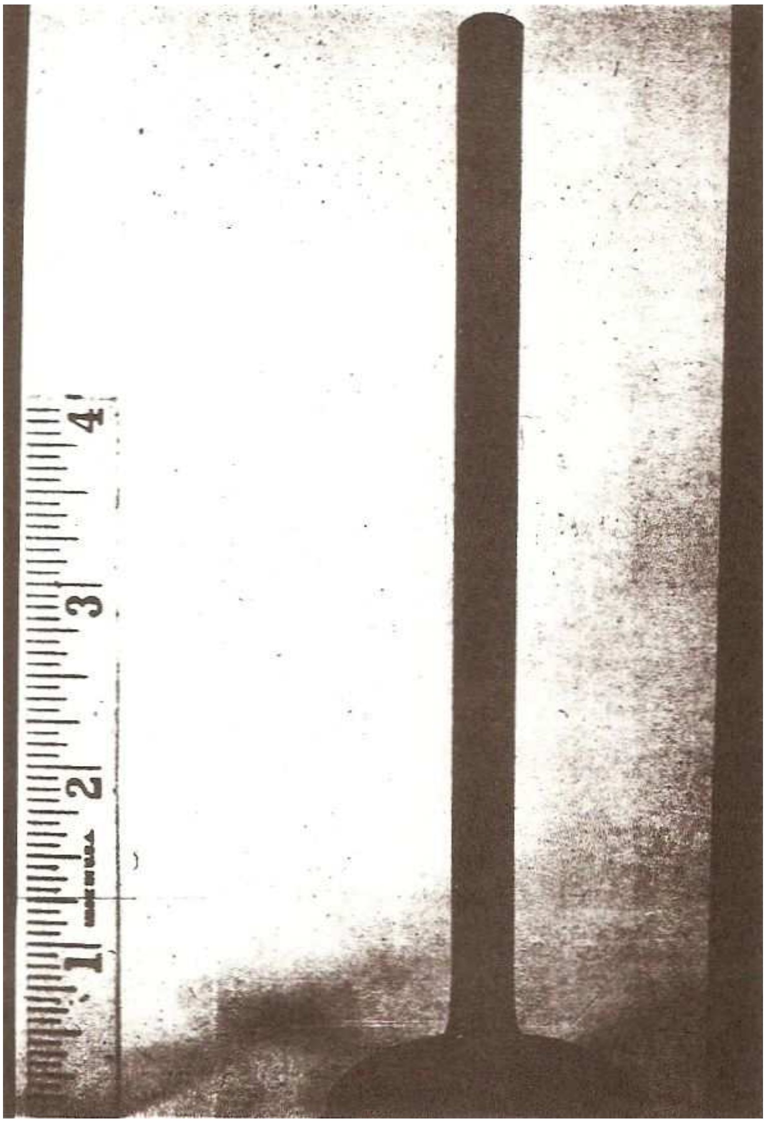

Fig. 26: Forged valve
(Valvola ottenuta per forgiatura)

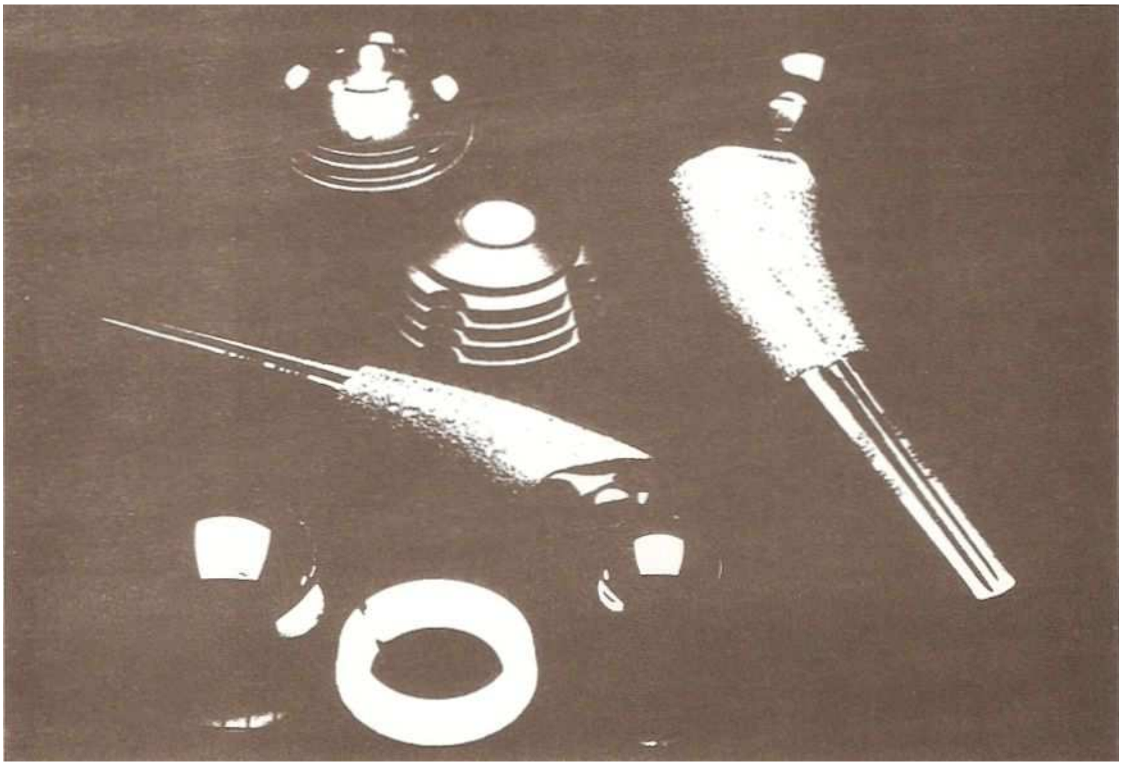

Fig. 27: Titanium application in medical area
(Applicazione del titanio nel settore medicale)

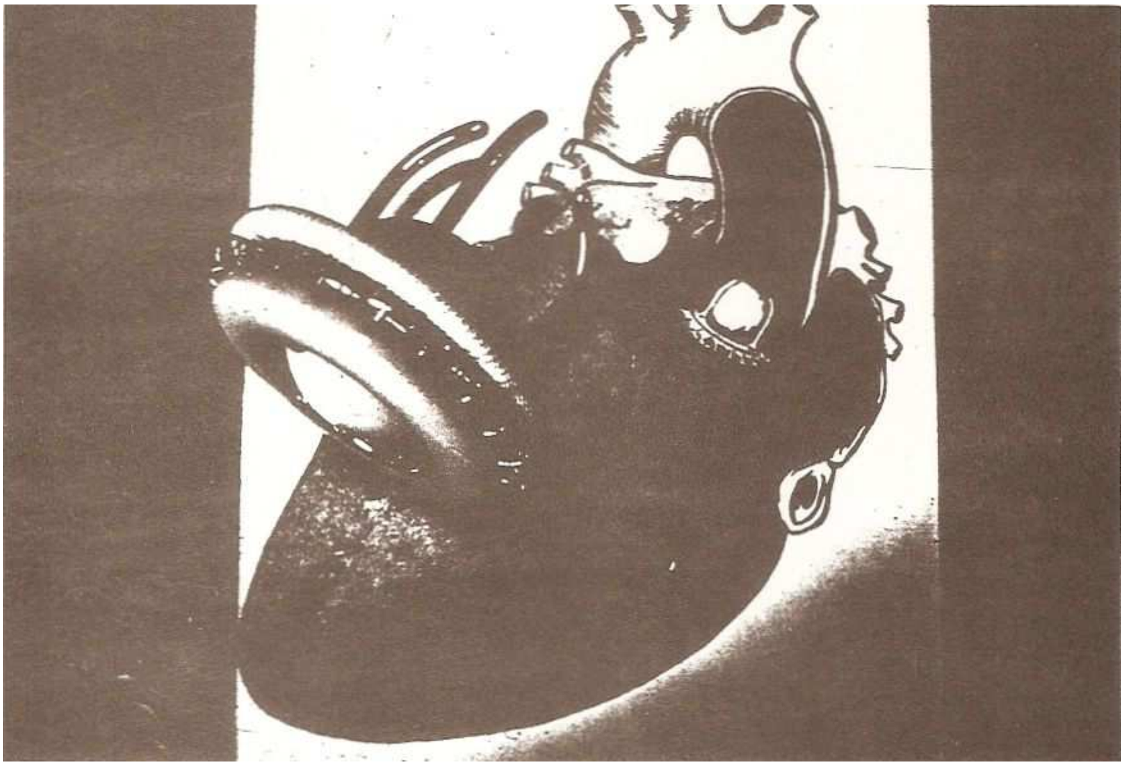

Fig. 28: Cardiac valve
(Valvola cardiaca)

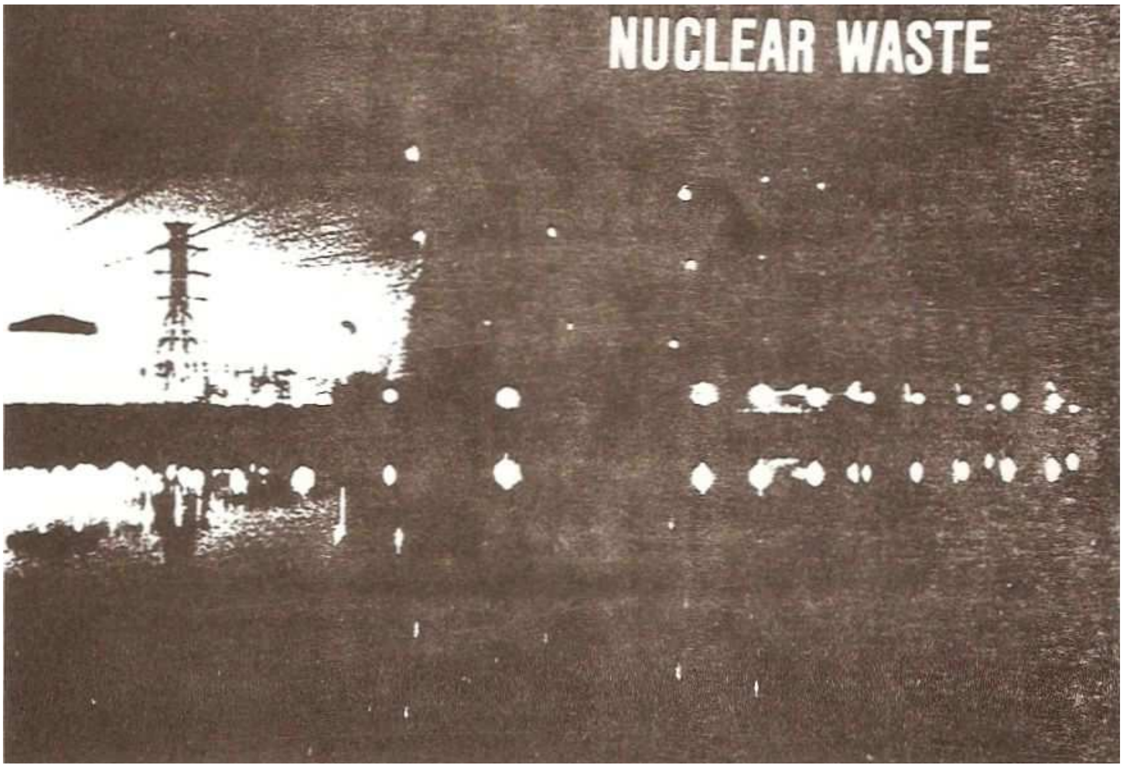

Fig. 29: Titanium application in nuclear area
(Applicazione del titanio nel settore nucleare)

Fig. 30: Titanium application in antipollution area
(Applicazione del titanio nel settore antinquinamento)

Fig. 31 shows a scrubber unit for a typical power plant, and there are two very corrosive areas: the quench and also the mixing zone as the gas goes out the stack. Titanium alloys perform better than any other material in this application. Here is an example of a small scrubber for a chemical plant.

A new area that the titanium industry is now exploring for new uses is the exploration for energy at very deep depths. As we go deeper and deeper for these reserves of energy, the environment is much more corrosive. Common materials like steel and some of the stainless steel will not work. As of this year we have now had titanium alloys approved for use in very sour gas or hydrogen sulphides environments (fig. 32). As a result, we believe that this is going to open up some new significant markets. We have a piece of large pipe that we have produced for this market in the last year as an example of the types of pipes that will be produced for this market. An example of oil field use includes Schlumberger equipment for measuring various oil well characteristics. This is all titanium components, because of the corrosion resistance and light weight.

Another application for titanium is off-shore structures (fig. 33): there already are titanium heat exchangers on this particular rig but we expect more the structure itself being made out of titanium, because of corrosion resistance and light weight.

A large portion of rig cost is spent in ballast and with lighter weight materials, there is actually an economical use af titanium in some of these applications.

We are involved with several companies exploring these particular areas.

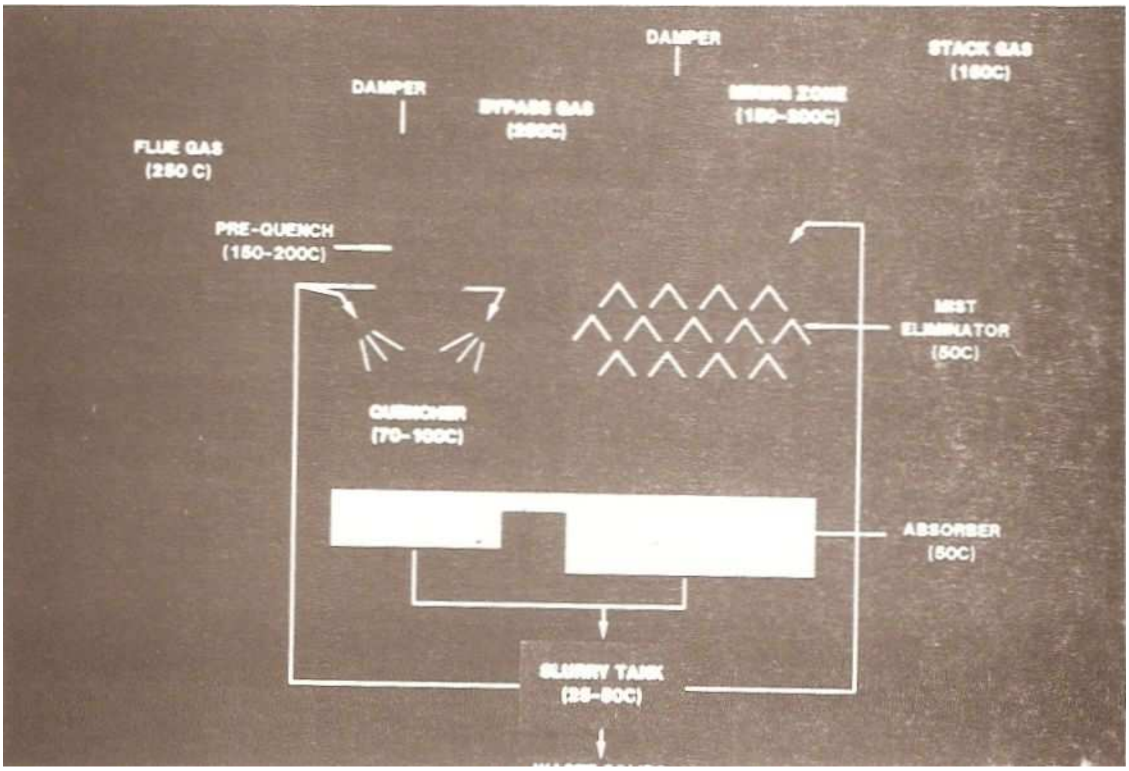

Fig. 31: Scrubber unit
(Scrubber)

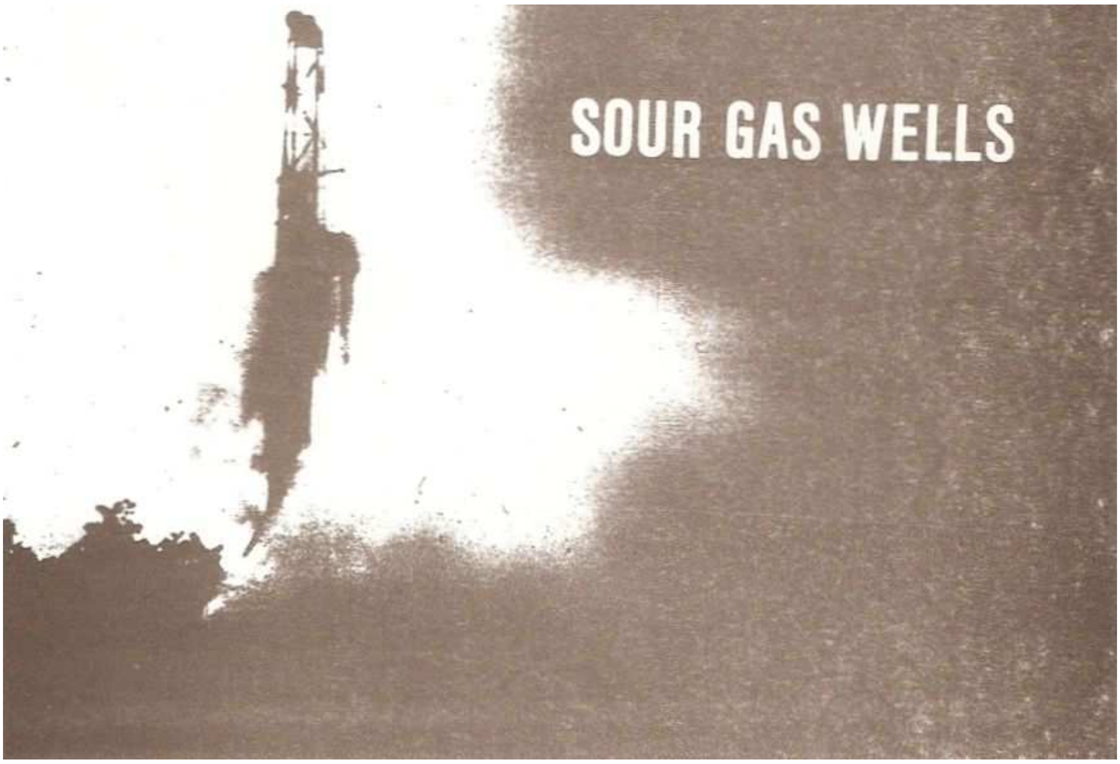

Fig. 32: Titanium application in corrosive environments
(Applicazione del titanio negli ambient particolarmente corrosive)

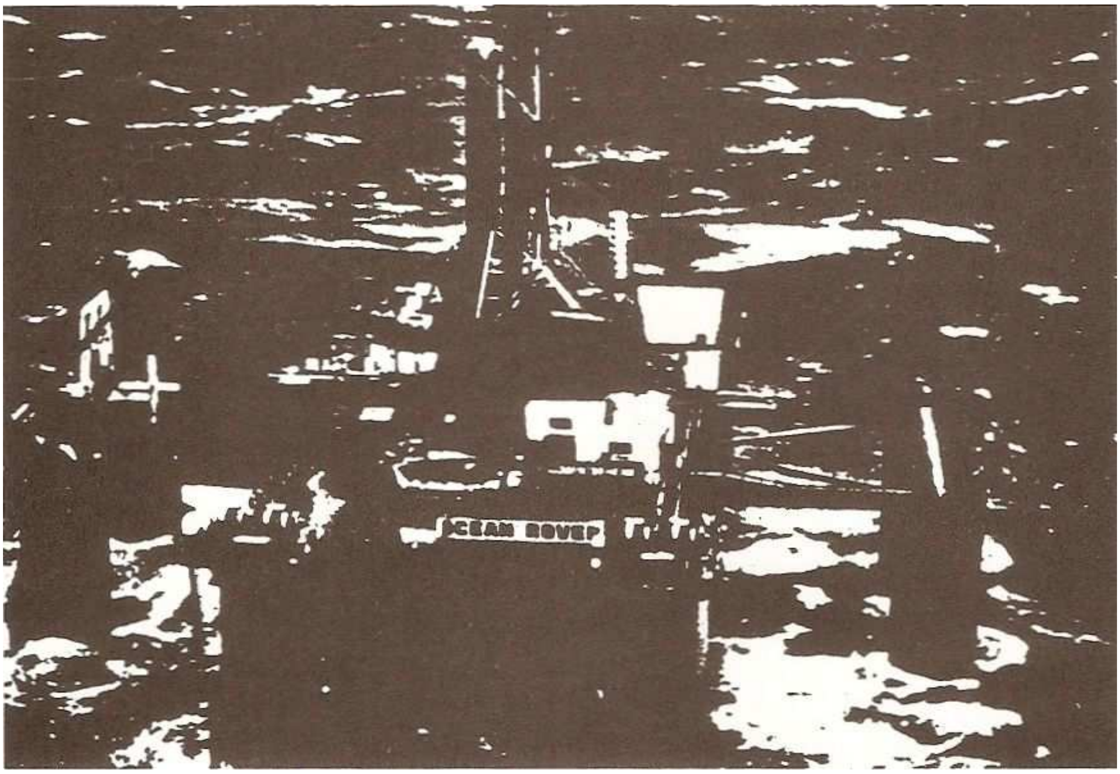

Fig. 33: Titanium application in off-shore structures
(Applicazione del titanio in parte delle
strutture degli impianti off-shore)

Another example is the use of titanium at the bottom of the sea floor as a stess-joint. The spring characteristics are important and the pipe can flex or bend (fig. 34). The first of these will go in within the next year.
Everybody is fascinated with the use of titanium under water, because of its excellent corrosion resistance. This is an example of the first all-titanium vehicle, and it was called the Alvin (fig. 35a e fig. 35b), and had a capability depth of 3500 meters. Since this time, another vehicle has been made, Seacliff, and it has a capability depth of 6500 meters.
These are made of titanium alloys.
Another example of an application in the water: this is a hydrofoil built by Boeing (fig. 36). There are many components of titanium. The main power plant that moves the water, the jet pump, is made of titanium.
And finally we are all fascinated by the concept of building submarines out of titanium (fig. 37). The fact is well known that the USSR has a titanium fleet of Alpha Submarines, the total hull made of titanium. It would appear that in the western world that this will not occur in the near future; however, there will be, larger amounts of titanium used an military vehicles, submarines. They will be used in a variety of applications. Already, all the ball valves on USA submarines are made from titanium.
The last application area is geothermal (fig. 38). Titanium is very attractive for geothermal wells that are at very high temperatures, where there is a large quantity of energy available.
There are three areas in the world where these kind of wells exist. One, in the Pacific Basin, the second one in California, and the third area here in Italy.

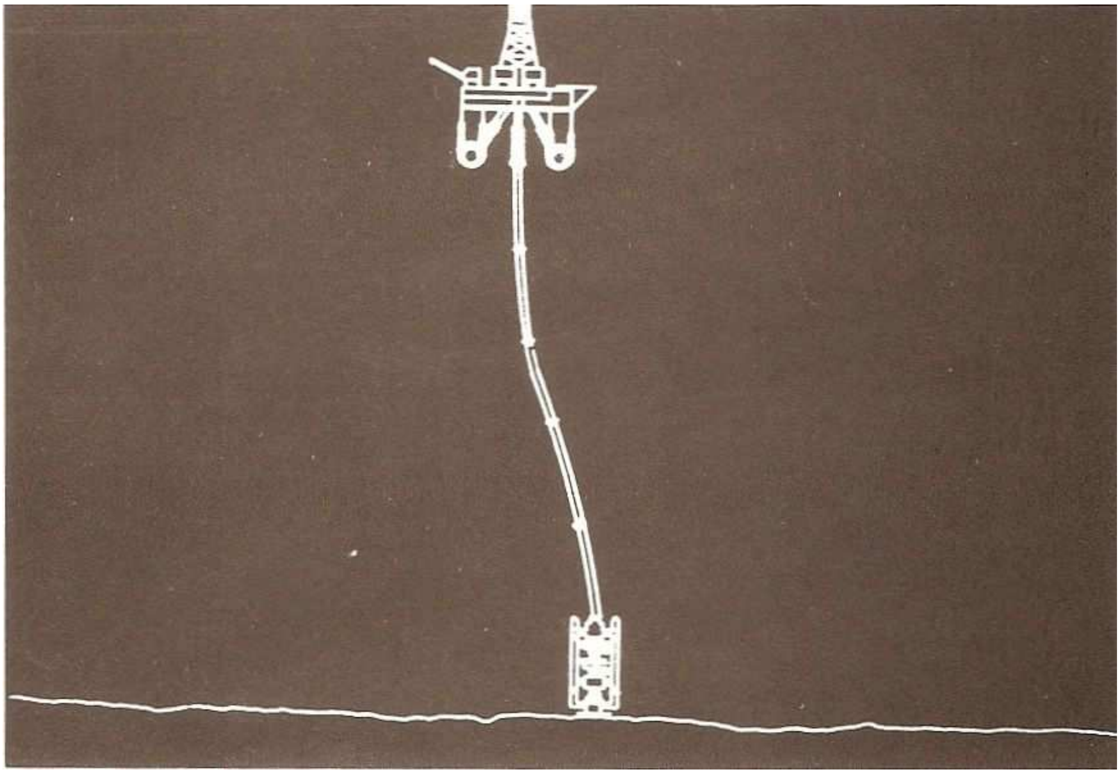

Fig. 34: Piping for off-shore drilling
(Tubazioni per perforazioni petrolifere sottomarine)

Fig. 35a: Titanium application in naval area
(Applicazione del titanio nel settore navale)

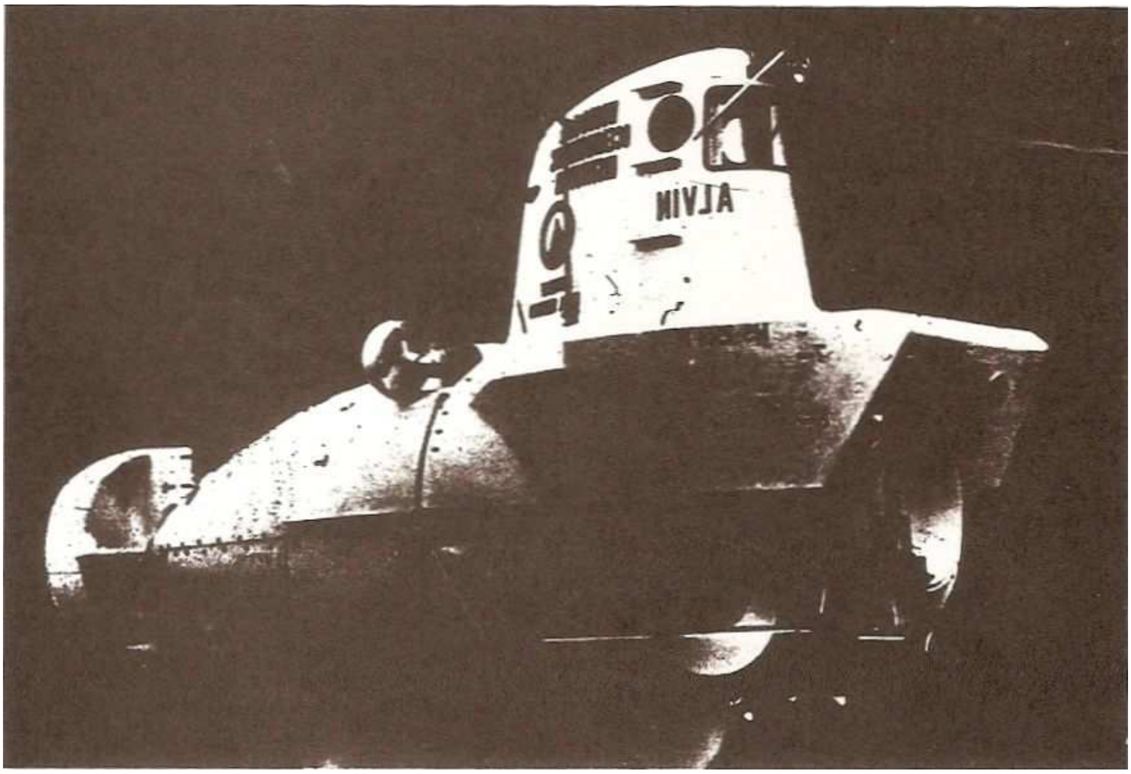

Fig. 35b: Submarine Alvin
(Sottomarino Alvin)

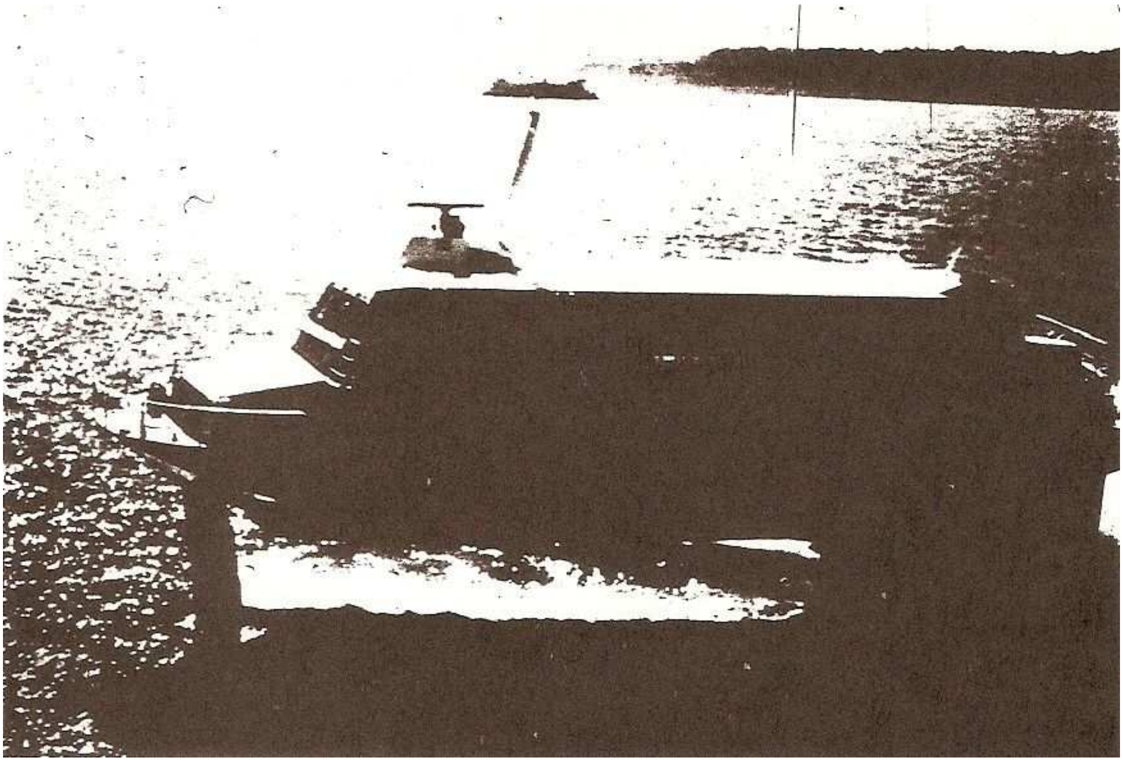

Fig. 36: Boeing’s hydrofoil
(Aliscafo della Boeing)

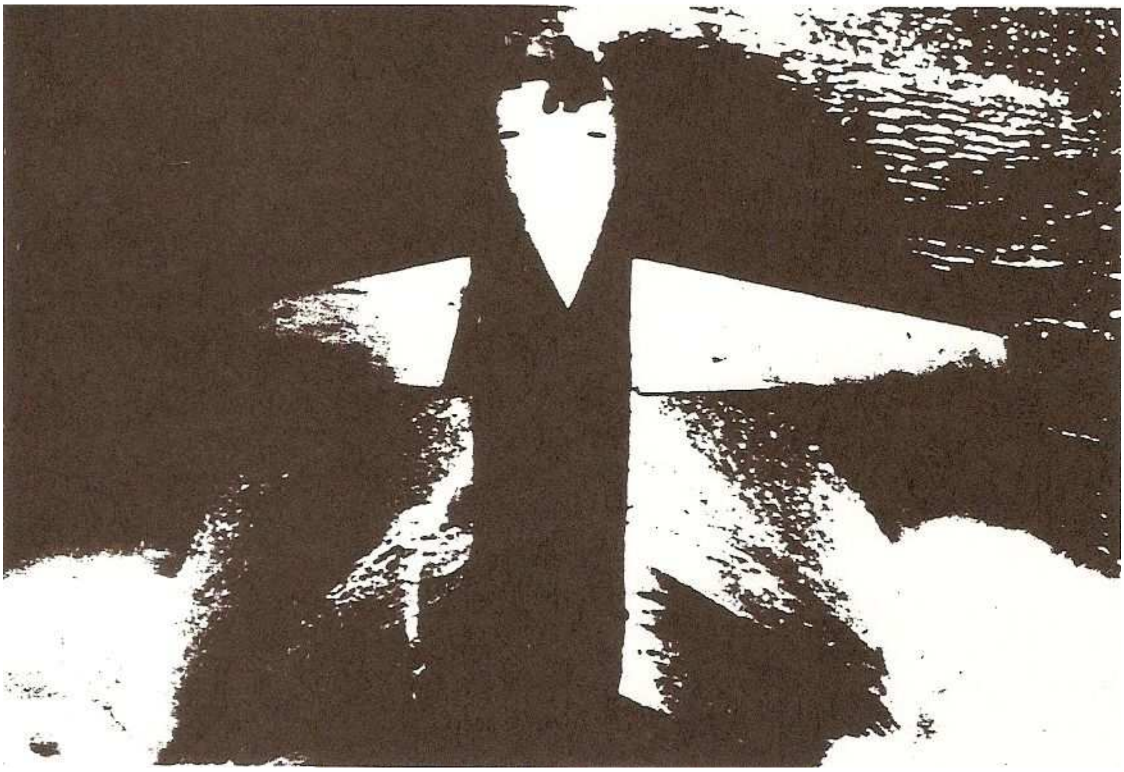

Fig. 37: Submarine Alpha
(Sottomarino Alpha – USSR)

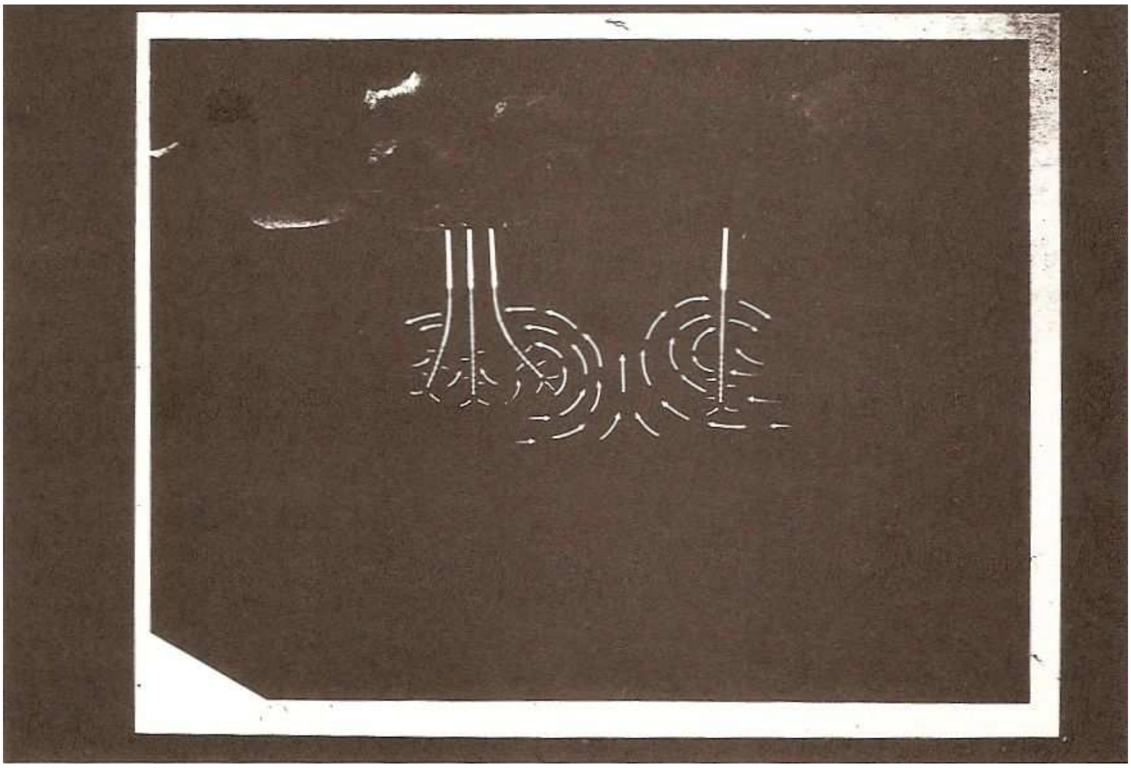

Fig. 38: Titanium application in geothermal area
(Applicazione del titanio nel settore geotermico)

We are developing the area in California utilizing titanium piping. And I would challenge you to look at this possibility here in Italy.

Titanium products

Titanium can be fabricated into all common shapes. Typical products that can be made out of titanium are illustrated. All of these products are made from of titanium powder. These are a variety of products that have been hot-formed from titanium or cold-formed (fig. 39). New technology is being developed to make it easier to form titanium. Here is an example of a forging (fig. 40). This is a helicopter rotor forging (fig. 41).

Titanium can be easily fabricated like most other common metals.

Finally, we have examples of castings of titanium (fig. 42). As you can see these are very intricate castings, and these can now be done in titanium. Five to ten years ago this was not possible, so there has been technology growth in fabricating of this metal.

In summary, the key properties to titanium are: it has high strength, it has very good durability, it's lightweight, and it has excellent corrosion resistance (fig. 43).

Grazie!

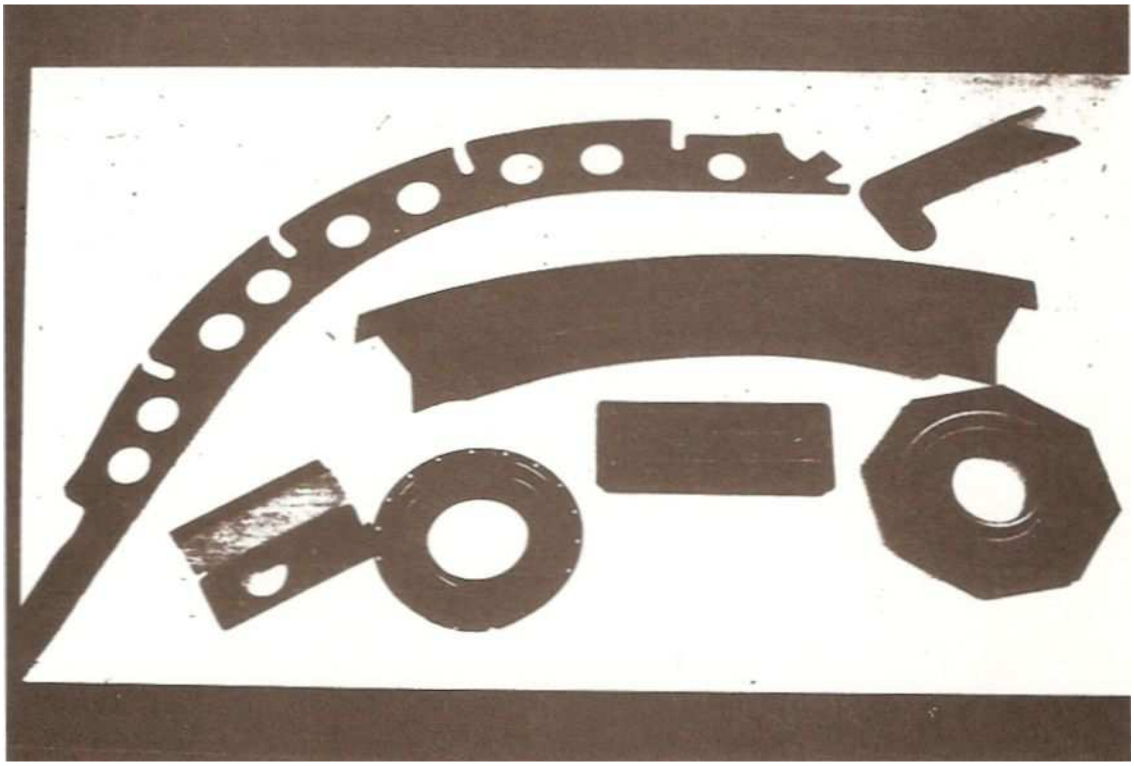

Fig. 39: Titanium hot-formed and cold-formed products
(Stampati a caldo e a freddo in titanio)

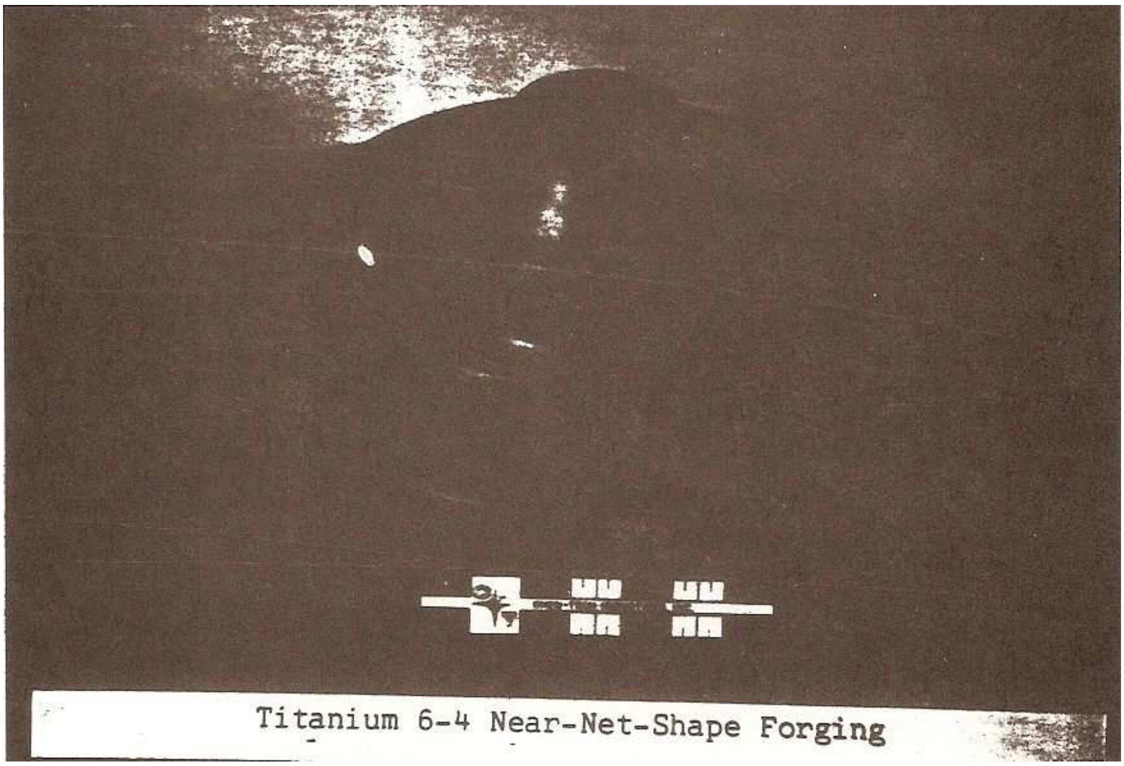

Fig. 40: (Forgiato in lega Ti6Al4V)

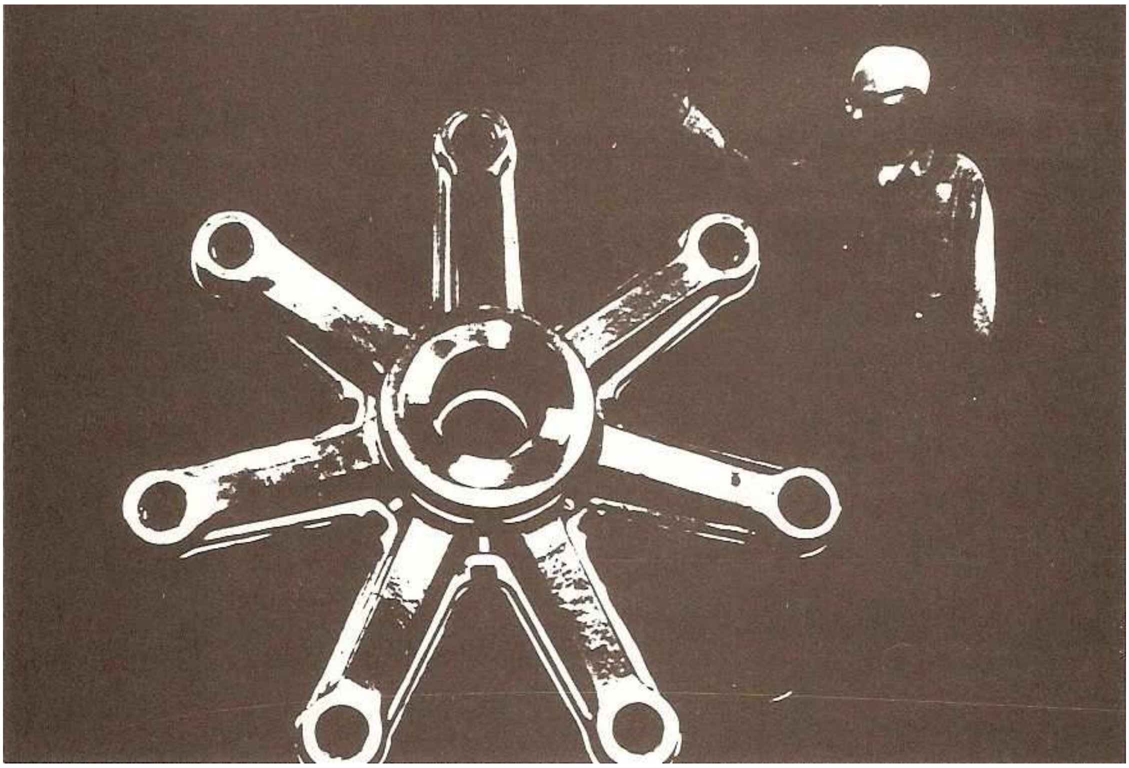

Fig. 41: Helicopter rotor forging
(Rotore di un elicottero –forgiato-)

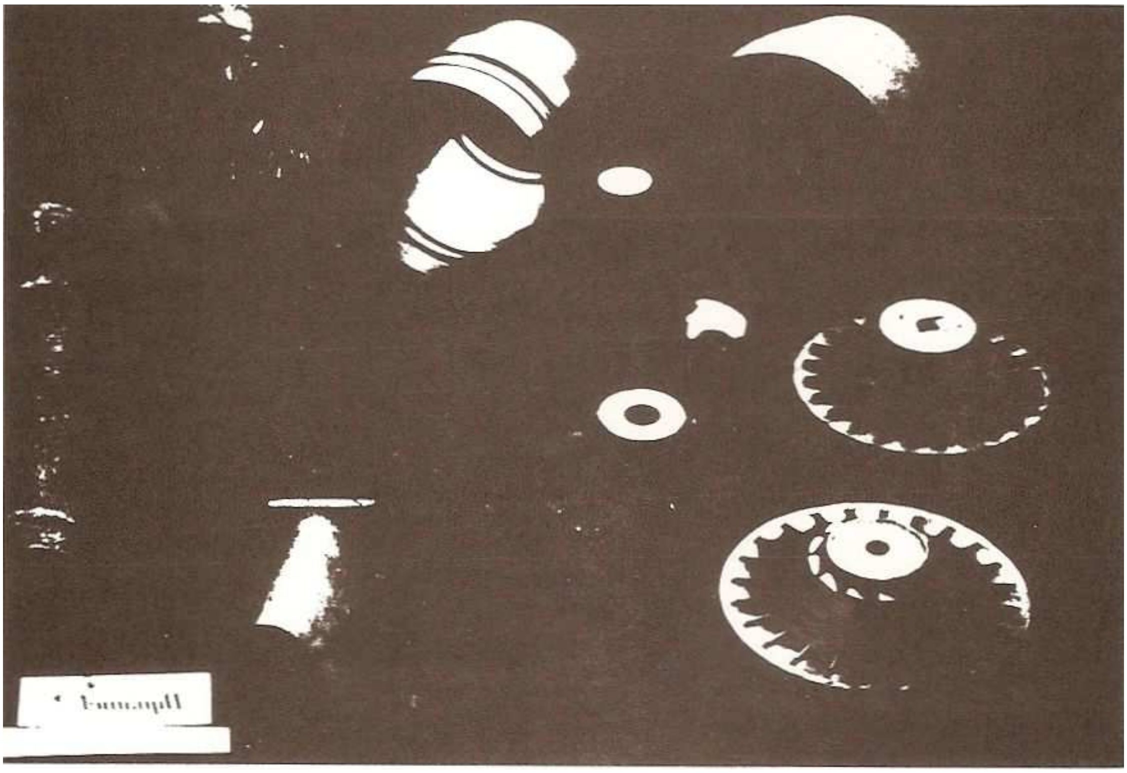

Fig. 42: Titanium castings
(Fusioni in titanio)

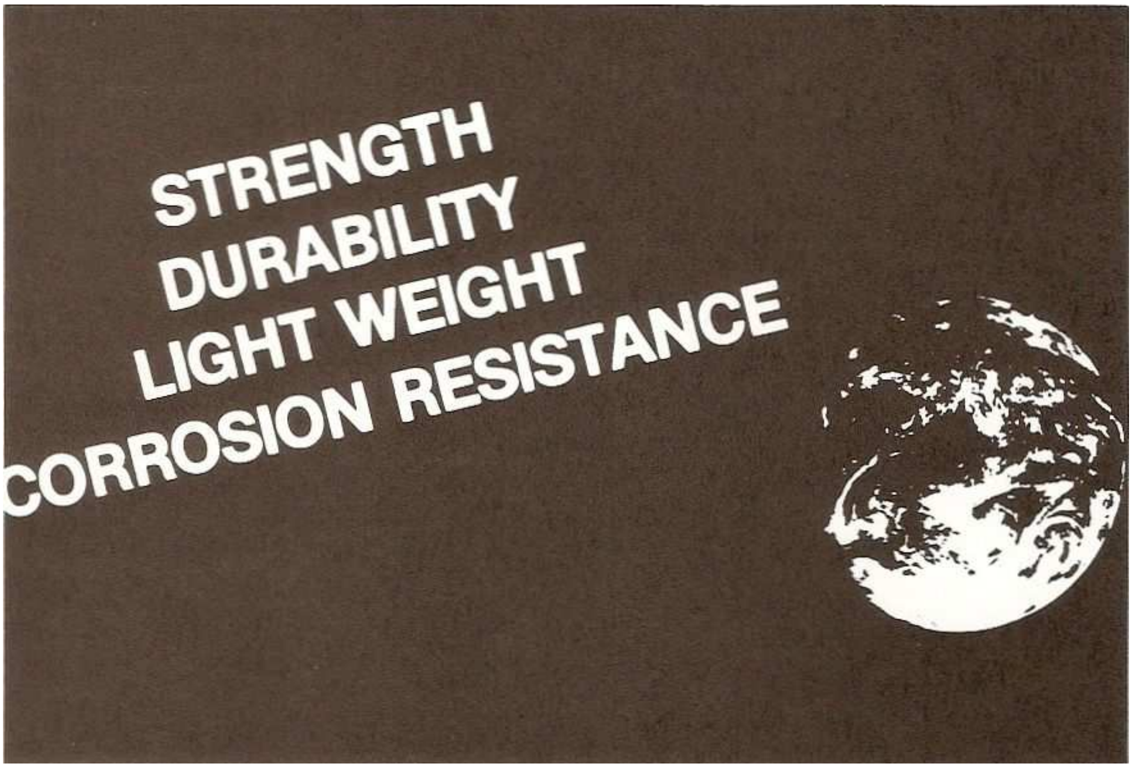

Fig. 43: Fundamental properties of titanium
(Proprietà fondamentali del titanio)