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CASTING TITANIUM SLABS IN AN ELECTRON BEAM FURNACE

Good afternoon. There is a coauthor of this paper, Charles Entrekin, who couldn't come with me and he told me he will answer any questions by mail. Five years ago we presented a paper at the "Vacuum Metallurgical Conference" at Pittsburgh to describe direct casting of titanium slabs that we pioneered in the early 80's.

Today, more than 3,000 metric tons of titanium slabs have been cast and made into milled products and the objective of this presentation is to give an update on the status of titanium cast slabs, to make a comparison between the cast slabs and the conventionally made slabs, either by rolling or by forging and then to provide some guidelines for product optimization.

Axel Johnson (Fig. 1) started a scrap process for titanium in the early 70's and in 1983 we decided to expand our operation into an electron beam furnace and this technology was a logical extension for us because really the electron beam was a very efficient way to recycle titanium scrap. In only one melting step titanium scrap is transformed into semi-finished form and in that way we maximise the added value.

Our electron beam operation is located in Morgantown. It has a 2 MW cold hearth EB furnace so we got 4 EB guns of 600 kW each. Melting rates range between 0.5 and 1.5 metric tons per hour depending on the product requirements. The process has shown significant versatility in raw material feedstock. The furnace can be fed with various types of particulate scrap blends including turning solids and titanium sponge as well as large bars or electrodes for remelting. Initially we produced small slabs of 2 metric tons but the yields and the productivity were not optimum. So in 1985 we developed a larger 5 metric ton slab that has been very, very successful. At the present time we are developing a capability for producing up to 15 metric ton slabs.

This is a schematic view of our furnace (Fig. 2). We have a melting chamber, the electron beam guns are at the top of the furnace. On the right we have the feeding chamber where particulate scrap is fed into the hearth and then we have an ingot chamber that can be removed so that we can pick up an ingot. All this is done under high vacuum.

Here we can see a remelting or casting of a slab and to us this is one of the great things of this process, the casting flexibility, we can really cast any cross-section, any geometrical shape. This is possible because we can position the energy in discrete amounts in any place of the mould and that allows us very good control on the solidification conditions.

In Fig. 3 there is a view of a 2 metric ton slab. The dimension are 6" in thickness by 28" in width and 130" long. The largest slab is 12" thick and 44" wide and about 4.5 meters long.

In Fig. 4 we see 2 slabs that have been conditioned, machined on the surface.

In Fig. 5 we are trying to make a comparison between the normal conventional processing of a slab and an electron beam slab, the cast slab. This is similar, like in steel where you have the old way to make a slab and then you have continuous casting. In the conventional case we can use scrap or sponge, then we have to recompact it, an electrode has to be assembled, then there are two VAR steps and then we have a chamber step with an overall yield, metallic yield of about 96%. In an electron beam we can just blend scrap and sponge and we make it in one melting step, we end up with the slab. We condition and the yield at that point is about the same. But in the first case we have a round ingot, in the second case we have a slab already.

Continuing the processing, the ingot has to be forged or rolled into a slab and then conditioned and all the way to flat rolled product, with an overall yield of about 65%. lf we do it with a slab from an EB, we get about 70% overall yield and that's about 8% better than the conventional forming.

The grain structure of the EB slabs shows a typical solidification structure. It's coarser than a forged or rolled slab. Conventional slabs have recrystallized grain, resulting from the mechanical work associated with the transformation from a round ingot into a slab form.

In the EB process, the slab are hot-topped to minimize the shrink or cavity, but on occasion some porosity is present. This characteristic does not yield harmful results because the total defects are healed during the further rolling or processing. Detecting small pipe porosity in a cast slab by ultrasonic testing is difficult because the core solidification structure interferes with the V.T. response. Only large pipe defects can be detected. We feel that this is adequate because the small porosity defects are harmless and do not affect the product yield and disappear upon further processing. Really, these small porosities are inside defects, there is no connection to the atmosphere, to the air and so when you roll they heal.

As is the case with most cast products, the cast surfaces of the slab are not adequate for rolling, so we have to condition the slabs. Machining, we have found, produces better results than grinding.

Typical chemical composition of slabs: the normal grades 1, 2, 3, 4, 7 and 12 of CP and also in Fig. 6 we have put some typical Japanese grade 1 slabs and some Soviet slabs. And if you compare those with the grade 1 that we make, the first one in that list, you will see that there is some higher residual elements, higher carbon, higher oxygen, higher iron and then aluminum and a little bit of nickel, molybdenum and vanadium. This is because we work with blends of scrap and there is always some residual elements in scrap as compared with the other two cases where people used pure sponge. The one thing that we have is lower nitrogen and hydrogen content. Hydrogen is normally below 10 ppm and nitrogens are less than 100 ppm.
These types of residual elements have not shown harmful effects from the view point of corrosion properties, however they do affect the yield strength of the material. On the other hand the elongation and ductility of the product coming from EB slabs are enhanced and we think this is because of the lower hydrogen and nitrogen content.

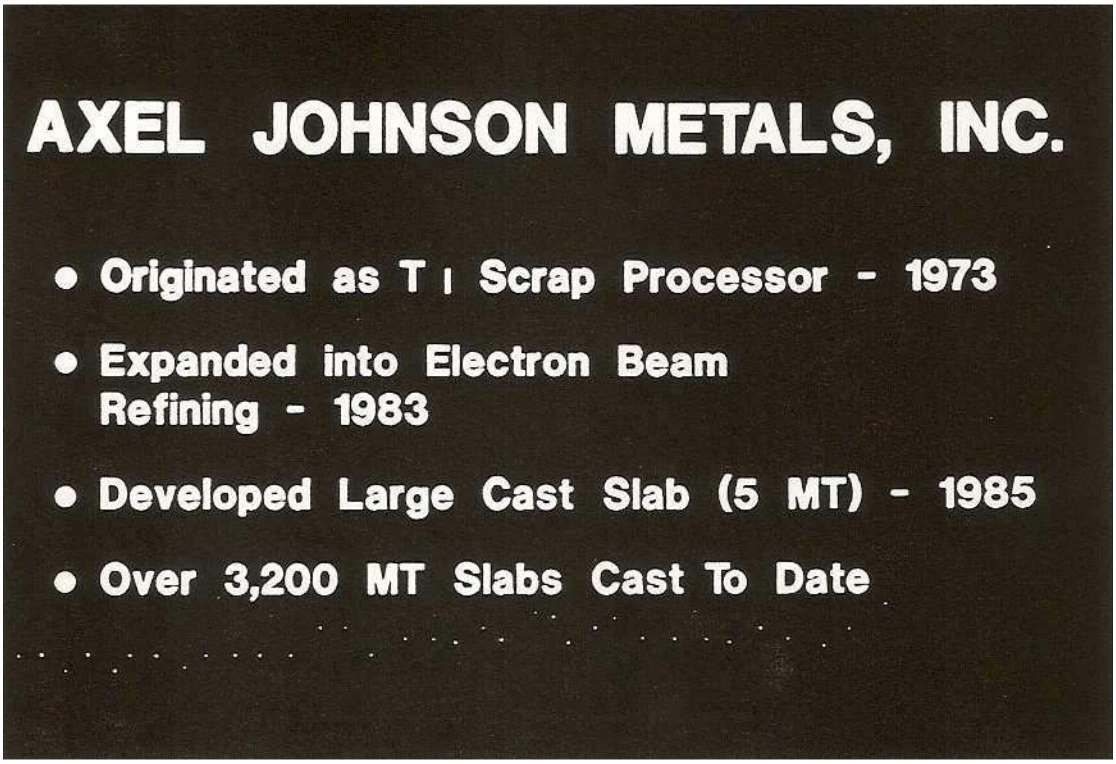
To relate the mechanical properties of commercially pure titanium, an oxygen equivalent formula is used. These formulas are empirical in nature and relate the effects of various elements to the strengthening effects of oxygen. There are several versions, the first one is attributed to Timet where they show that nitrogen has 2.5 times the effect of strengthening than oxygen and iron about half. Then there was another formula we call the Timet modified that added also the effect of carbon. On the other hand, RMI has also a formula that doesn't show the effect of iron but just considers carbon and nitrogen and that's because they work with very low iron contents. In order to understand the mechanical properties of products produced from our slabs, we had also to include another element and that is aluminum, and we call that the A. Johnson oxygen equivalent. Normally this equivalent oxygen is one or two points higher than the one predicted by the Timet or the RMI formulas. We have tried to relate the oxygen equivalent to the mechanical properties and in table 8 we show levels of oxygen equivalent we need to develop the mechanical properties for the different grades.

If products made from our slabs are heat treated the same way as conventional products, we end up with yield strengths that are the higher side of the range. If we look at the microstructure we find that the grain size of the product from our slab is about 0.5 of the size of the conventional product.
We believe that the residual elements slow down the grain growth and what we are suggesting is that higher annealing temperatures are necessary to get the yield strength a little bit on the lower side. So we recommend a rolling temperature 900-980°C, an annealing temperature around 850°C: that's about 50° higher than the conventional temperature for strip. Then, for plate we need lower temperatures: about 780°C (Fig. 9).

So, to finalize this presentation, these titanium slabs have been a great technical and commercial success over the last 5 years and they are regarded, in some cases, as the standard product for most applications. They have proved to be extremely convenient and an economic method to recycle very large proportions of titanium scrap. Their uniform rectangular shape and internal soundness have provided the users with up to 8% higher yields. The mechanical properties of these milled products are equivalent to those of conventional products and it can be tailored to most applications if the proper heat treatment is used. Many slabs are now produced in electron beam furnaces from standard raw material charge consisting of 15-25% sponge, and sponge is a problem in our furnace if the chloride content is high. At the present time we are really watching the development of the electrolytic sponge technology because we think it can be very compatible with our furnace.

Finally I want to add an announcement that the Axel Johnson method has received recently approval to proceed with the design and construction of a second EB furnace in Morgantown, Pennsylvania. This furnace will be a next generation furnace, featuring at least 3 MW in power, maybe 4, and it will have two melting chambers. This unique furnace design, we call it maximelt, because we are trying to maximize productivity, is a result of our experience with the first furnace and we are really looking forward to starting production in the first quarter of 1990.

Thank you!



AXEL JOHNSON METALS, INC.

- Originated as Ti Scrap Processor - 1973
- Expanded into Electron Beam Refining - 1983
- Developed Large Cast Slab (5 MT) - 1985
- Over 3,200 MT Slabs Cast To Date

Fig. 1 - Axel Johnson development

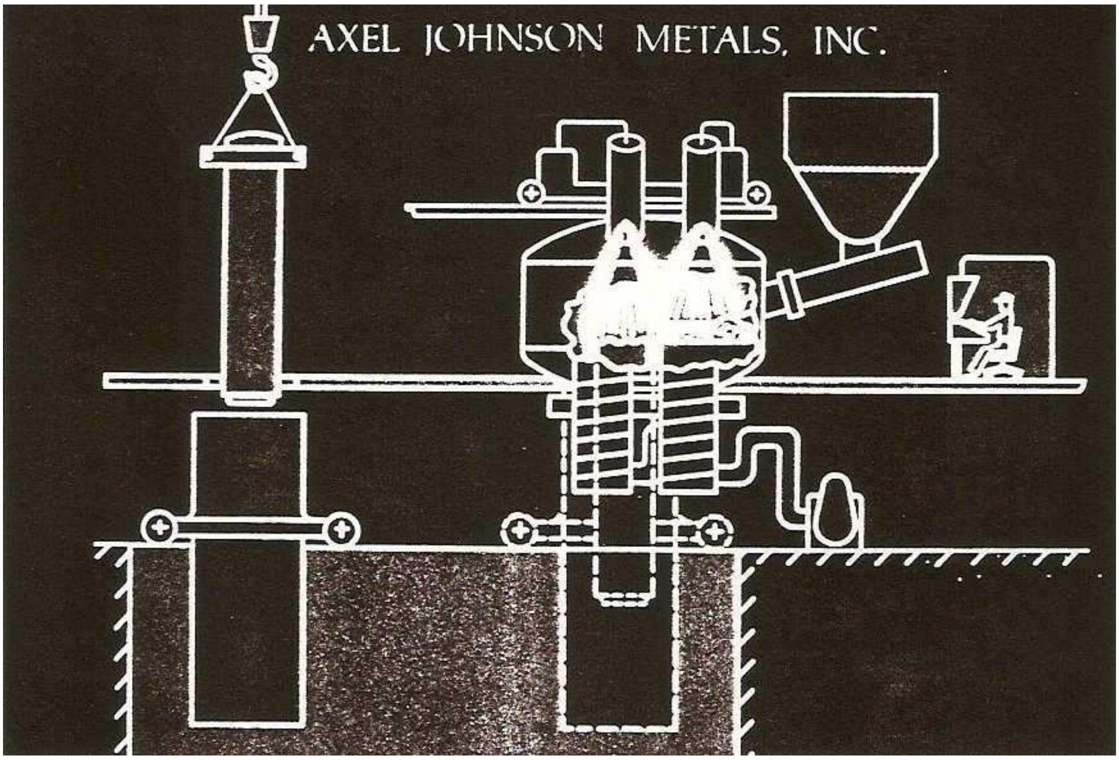
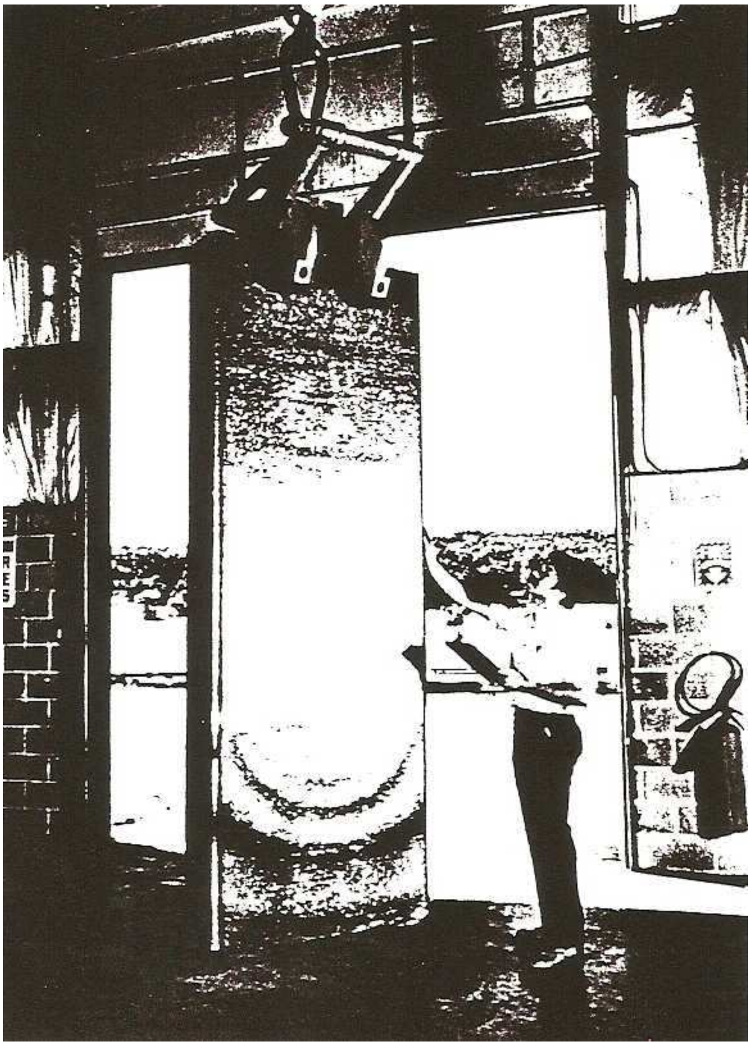


Fig. 2 - Schematic view of Axel Johnson Electron Beam Furnace

Fig. 3 –
2 metric ton slab



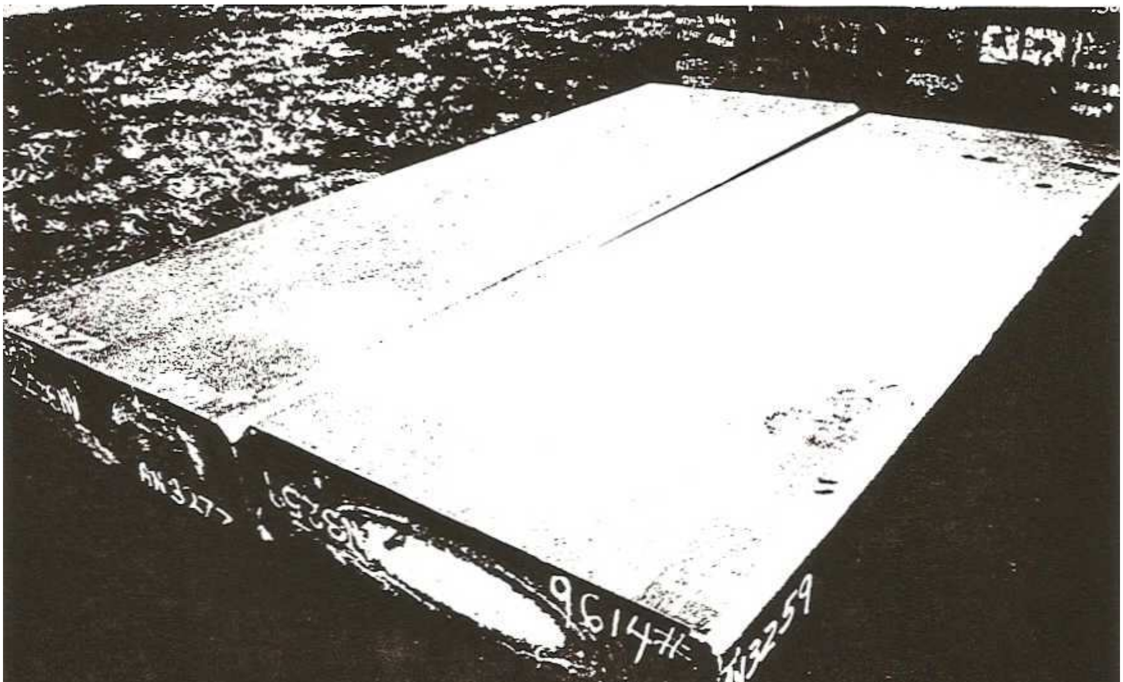
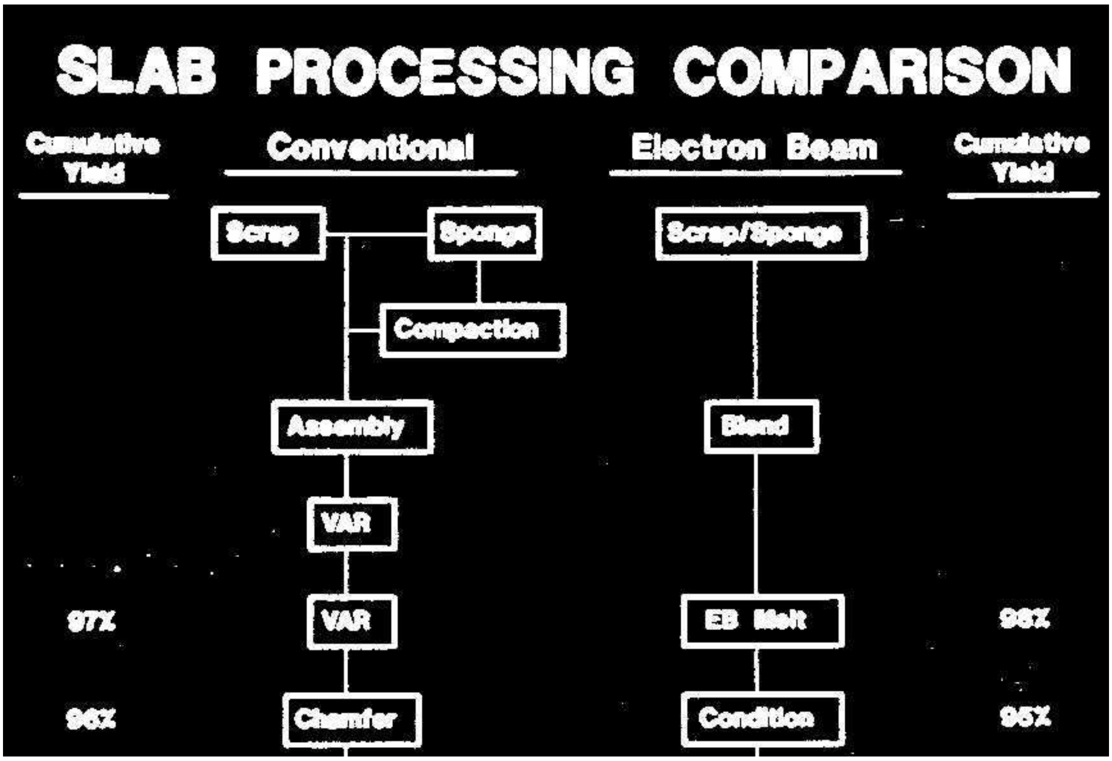


Fig. 4 - Electron Beam melted slab, machined surface



SLAB PROCESSING COMPARISON

Cumulative Yield

Conventional

Electron Beam

Cumulative Yield

Scrap

Sponge

Compaction

Assembly

VAR

97% VAR

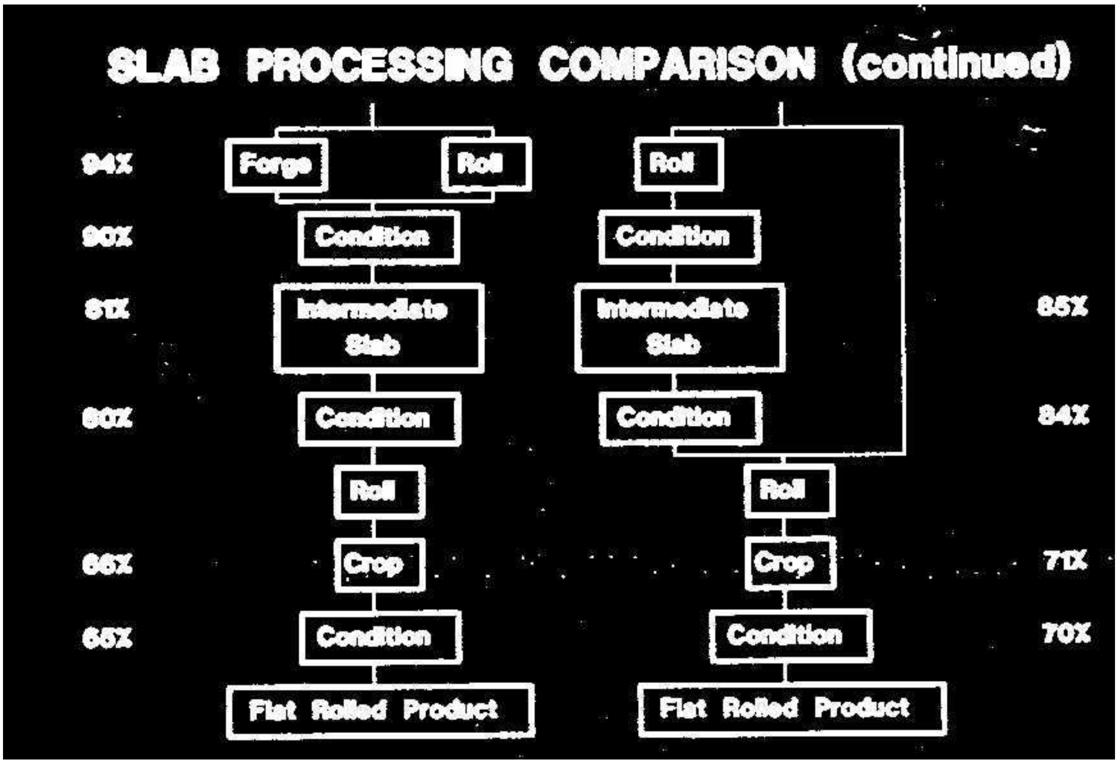
96% Chamfer

Scrap/Sponge

Blend

EB Melt 98%

Condition 95%



SLAB PROCESSING COMPARISON (continued)

94% Forge Roll

90% Condition

81% Intermediate Slab

80% Condition

Roll

66% Crop

65% Condition

Flat Rolled Product

Roll

Condition

Intermediate Slab 85%

Condition 84%

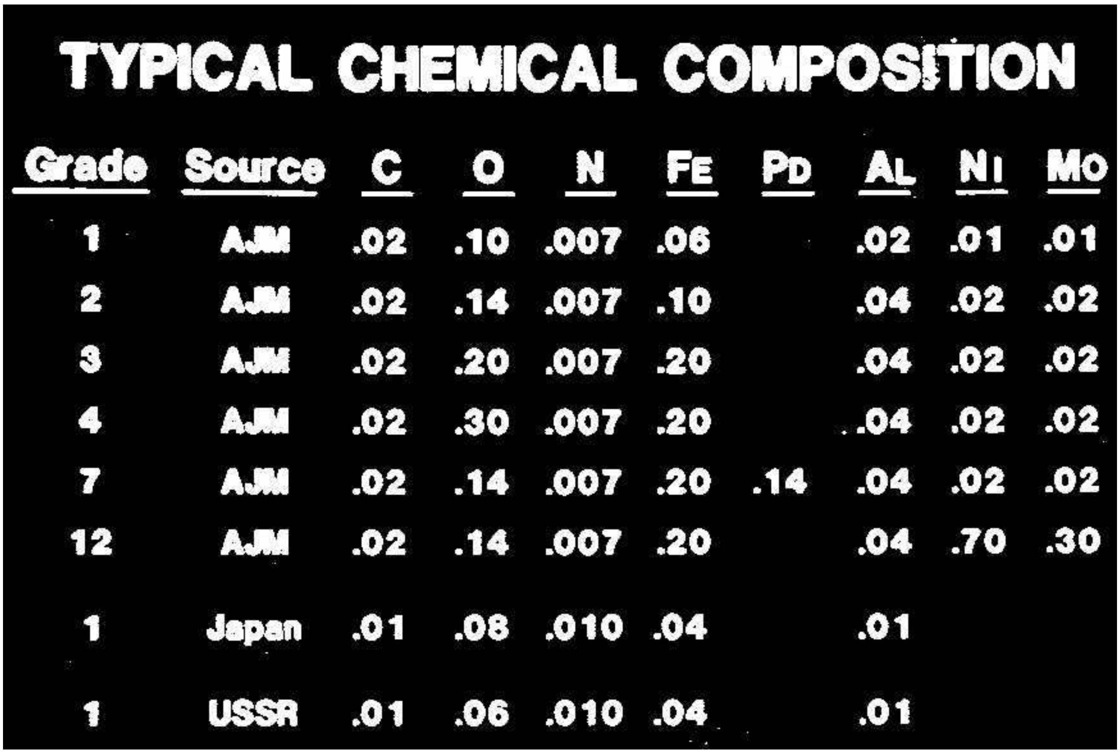
Roll

Crop 71%

Condition 70%

Flat Rolled Product

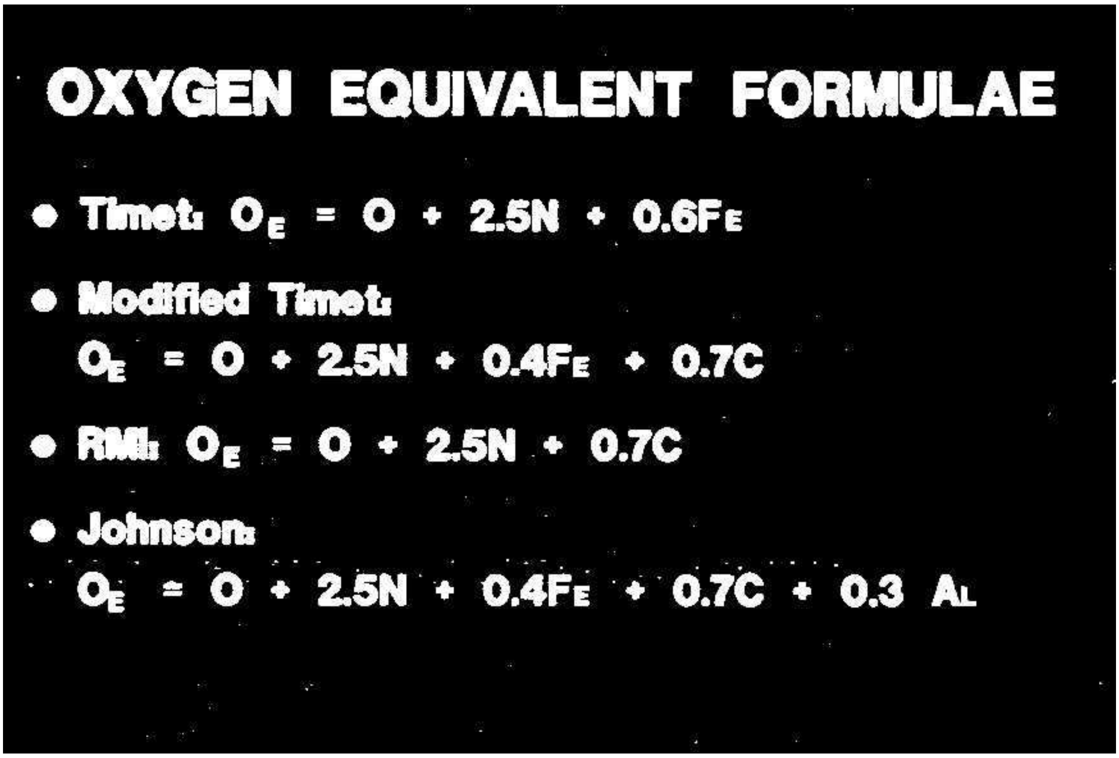
Fig. 5



TYPICAL CHEMICAL COMPOSITION

Grade	Source	C	O	N	Fe	Pd	Al	Ni	Mo
1	AJM	.02	.10	.007	.06		.02	.01	.01
2	AJM	.02	.14	.007	.10		.04	.02	.02
3	AJM	.02	.20	.007	.20		.04	.02	.02
4	AJM	.02	.30	.007	.20		.04	.02	.02
7	AJM	.02	.14	.007	.20	.14	.04	.02	.02
12	AJM	.02	.14	.007	.20		.04	.70	.30
1	Japan	.01	.08	.010	.04		.01		
1	USSR	.01	.06	.010	.04		.01		

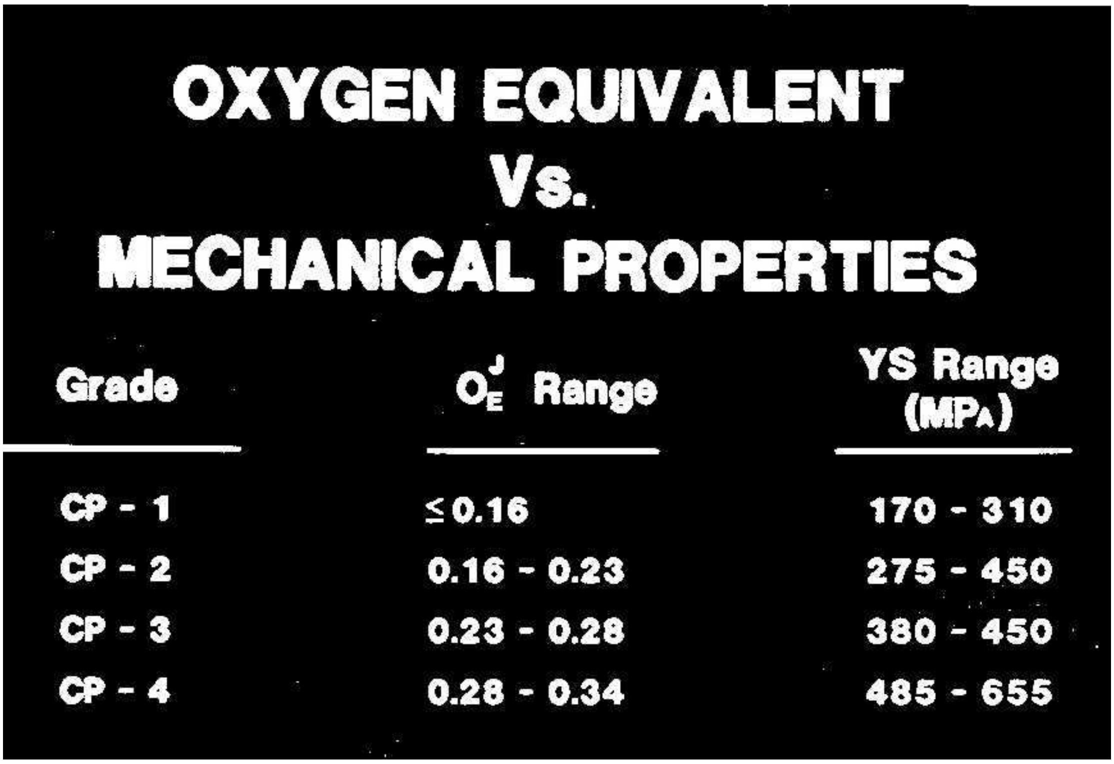
Fig. 6



OXYGEN EQUIVALENT FORMULAE

- Timet: $O_E = O + 2.5N + 0.6Fe$
- Modified Timet:
  $O_E = O + 2.5N + 0.4Fe + 0.7C$
- RMI: $O_E = O + 2.5N + 0.7C$
- Johnson:
  $O_E = O + 2.5N + 0.4Fe + 0.7C + 0.3\,Al$

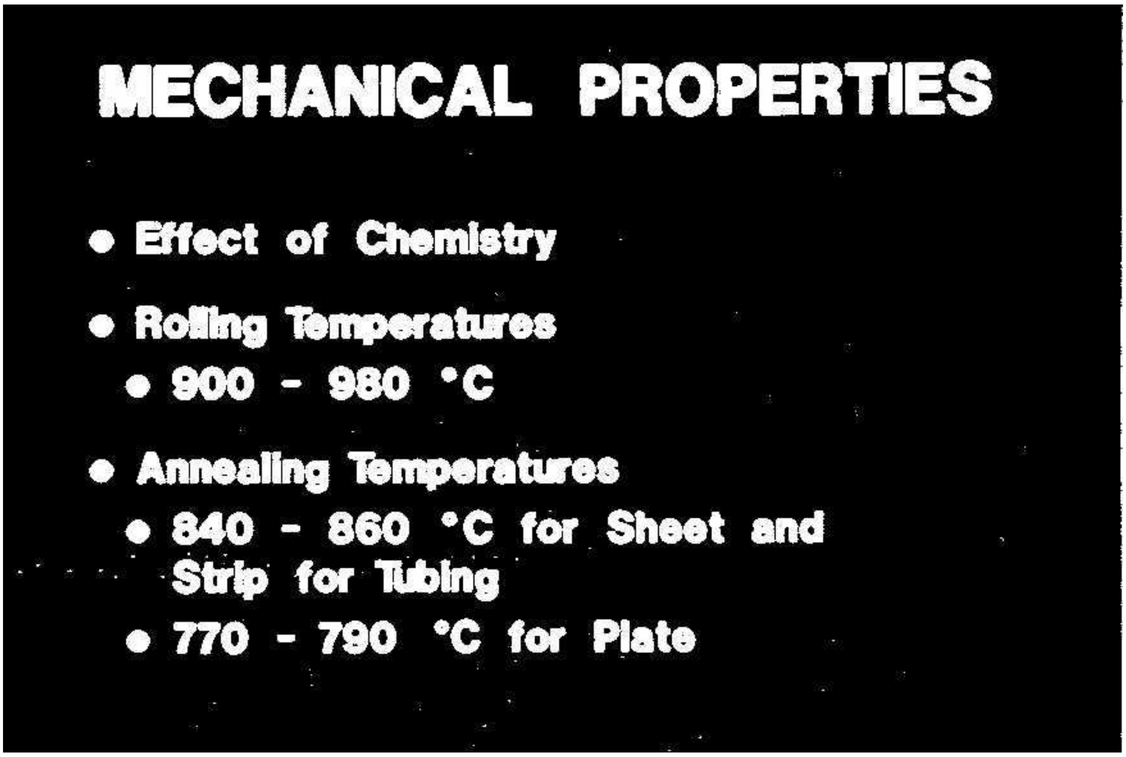
Fig. 7



OXYGEN EQUIVALENT
Vs.
MECHANICAL PROPERTIES

Grade	O_E^J Range	YS Range (MPA)
CP - 1	≤0.16	170 - 310
CP - 2	0.16 - 0.23	275 - 450
CP - 3	0.23 - 0.28	380 - 450
CP - 4	0.28 - 0.34	485 - 655

Fig. 8



MECHANICAL PROPERTIES

- Effect of Chemistry
- Rolling Temperatures
  - 900 - 980 °C
- Annealing Temperatures
  - 840 - 860 °C for Sheet and Strip for Tubing
  - 770 - 790 °C for Plate

Fig.9 - Modified heat treatment for Electron Beam melted slabs