STATE-OF-THE-ART OF THE PROPERZI TECHNOLOGY
FOR ROD AND INGOTS PRODUCTION

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Abstract

The liquid metal produced in the pot lines of any smelter is transformed into semi-finished products (rod, slabs, billets) and re-melt products (T-bars, sows, ingots). The semi-finished products, generally referred to as “semis”, and the re-melt products are identified as “commodities” and have a reference price worldwide as well as standardized shapes and characteristics. In 1949 Properzi developed the continuous casting and rolling system for the production of aluminium rod, semis, to be used mainly for the production of conductors and cables. Over the years the consumption of electrical power has increased dramatically throughout the world and the cable industry has requested rod made from a wider and wider range of more sophisticated and complex alloys. The production rate, originally limited to 1t/h or less, has currently reached 15t/h. Benefiting from the experience gathered with large sized rod production plants, Properzi extended the continuous casting method to the production of aluminium ingots. The author explores the various stages of these developments and the new application of the continuous casting method that still remains the basic technology which is the backbone of the Properzi method.
1. Preamble – A short review of the aluminium commodities

If one stands outside a modern smelter they would see a continuous coming and going of trucks that transport containers full of both semi-finished products (rod, slabs, billets) and re-melt products (T-bars, sows, ingots) from the production site to the nearest port and on to their final destinations. The semis and the re-melt products are identified as “commodities” and have a reference price worldwide as well as standardized shapes and characteristics.

Shape, weight and packaging all find a remarkable place among these so-called “characteristics” of aluminium commodities which are determined or influenced by the following requirements:

- a) easy, safe and cheap production
- b) easy, safe and cheap transportation
- c) easy, safe and cheap usage in downstream processes

There is a very tight link among the three influential factors listed above, but the final result (shape, weight and packaging) does not represent, in all cases, the optimum solution but rather the best compromise, considering all the different needs.

Perhaps the rod users would always prefer to receive loose coils but this is not compatible with long distance transportation. Therefore, the tight coils (2.0 to 3.6 tons each) are the standardized system – the best compromise – for packaging the rod when distant transportation is foreseen and/or the rod production line exceeds the capacity of 25,000 tons per year. Additionally, we could say that the freight forwarder would prefer to have sows with a more square shape (to optimize the load of trucks) but this is not possible because without a cast angle the casting process would not be possible. We could continue with this analysis and we would find several cases where what we know and what we see every day is just a compromise that has been made in order to meet the different needs.

In the next chapters we will analyze the shape and weight of two very diverse commodities: ingots and wire rod and discuss the possible improvements for some applications.

2. Why are the “light” ingots so heavy?

Ingots represent one of the most commonly used commodities produced by primary smelters. As we have seen, it is a re-melt form that finds application in several sectors of industry, the automotive sector being the most important. More than one-third of the global consumption is supplied in ingots form.

These days, when you buy primary ingots you receive ingot bundles, having a nominal weight of 1,000kg, composed of multiple rows of ingots. Typically, the ingots’ weight ranges from the nominal 22.7kg (50lb) to 23.5kg whereas the purity ranges from 99.8% down to 99.5%, depending on the smelter characteristics and other factors.

The ingot design has varied slightly throughout the years, from producer to producer, but the shape that is well-known to everyone has become the most preferred and the standard. These ingots are also known as “open top cast ingots”.

If we look deeper into the routine of those who use ingot bundles, we would see that although ingots are always meant for remelting in a dedicated furnace, the ingots might be handled bundle by bundle (by a forklift or similar lifting device) or ingot by ingot (by manual handling) depending on the size of the furnace or crucible and depending on the final application and working cycle. When the user has a small furnace typical of a die casting operation, then the ingots are definitely handled manually, one by one.

Figure 1 shows a typical bundle of open top cast ingots.

After this preamble, the question that one can ask is this. Since the ingots have been designed for remelting, either bundle by bundle or ingot by ingot, why are they so heavy? There is scientific evidence showing that moving such a heavy load all day long might, in the long run, affect the discs of the operator’s spine. The word “might” has been used because doctors believe that “our scientific books do not read our diseases”. In other words, which is scientifically true cannot be applied to all of the operators that manually handle ingots during their work-shift.
To understand the background of the present shape of ingots and the reasons why the standard weight is 22.7kg (50lb), we should go back 50 years to the pioneer systems – the ingots casting machine open top type – available at that time to transform the liquid metal into solid form. We should also consider the poor level of automation that was available at that time, when the standard weight of 50lb was introduced to the market. Just as an example, Figure 2, which was taken from the cover page of the book “Aluminium Cast House Technology 2005”, shows the pioneer ingot casting machine at Comalco Bell Bay – Tasmania in 1968. Since that time, the casting and solidification technology has improved tremendously but the basic concepts of the open top systems have not changed a great deal.

The filling process is not continuous and must be interrupted between two subsequent moulds. Several studies have been done on the filling star wheels, but still a difficulty remains to pour, in steady regime, a precise quantity of metal in each mould, again because the process is not a continuous one and it is affected by the start and stop sequence. Therefore the pouring flow in each mould goes from zero flow to maximum flow and back to zero flow again.

The de-moulding operation is carried out mechanically with the help of automatic hammers but it still remains a critical phase of the process.

Today, as it did 50 years ago, the hourly output of a mould chain depends on the weight of the ingots and the length of the mould chain according to the equation:

\[
P = \frac{W \times L}{I_s \times t_s} \times K
\]

Where:
- \( P \) is the hourly output of the line
- \( W \) is the ingot mass
- \( L \) is the line length
- \( I_s \) is the spacing between moulds
- \( t_s \) is the solidification time
- \( K \) is a corrective coefficient

The above equation is the background of the compromise regarding the weight of each ingot to reach an acceptable production output. If we increase the length of the conveyor (\( L \)), the capital expenditure (CapEx) increases due to an increased space requirement and a higher number of moulds. The space between two consecutive moulds (\( I_s \)) can be reduced but only up to a certain extent; the solidification time is more or less a fixed number unless the CapEx is further increased. In conclusion, the designer of the open top mould conveyors had to play with the weight; 50 lb is a round number and it was tolerable by the human body and was within the workplace regulations at that time.

The 22.7 kg (50 lb) open top aluminium ingots are used worldwide and the technique to produce such commodities is well-proven and well-established but does not represent the latest state-of-the-art, although it has become a consolidated tradition. However, even the most well-established traditions must be replaced when new process techniques are developed which offer an increase in quality with lower or equal CapEx and OpEx.

3. Lighter ingots for a better life

Now, if we consider that worldwide, the ingots are delivered packaged in bundles of approximately 1 ton with dimensions meant to maximize the loading of containers and trucks, is it really necessary that the weight of each ingot be 22.7kg (50lb)? Or, is it also possible that the 1 ton bundle be composed of lighter ingots? Also, considering that the ingot users load their furnaces with one complete bundle after the other, is it really necessary that the weight of each ingot be 22.7kg (50lb)? Or, is it possible that the same 1 ton bundle be composed of lighter ingots, for instance 13.6kg (30lb)?
Figure 3 shows ingot bundles produced with the patented Properzi Track & Belt ingot casting machine. These compact, stable and repeatable bundles have a weight in the range of 1,000 kg and are composed, in this application, of subsequent layers of 10 kg (+/-0.1kg) ingots. Similar bundles are produced at Alba (Bahrain) and Dubal (UAE) using Properzi equipment. The machine produces 2,000 (plus) ingots per operating hour. The dimensions of each ingot shown in Figure 3 are:

- Cross sectional area: 5,400 mm²
- Nominal length: 720 mm ±0.5%
- Average width: 114 mm (approx.)
- Nominal height: 47 mm (approx.)

The proposed new ingots for the primary producers will have the following weight and dimensions:

- Nominal Weight: 30 lb / 13.6 kg ±0.1 kg
- Length: 720 mm ±0.5%
- Average width: 114 mm (approx.)
- Height: 62 mm (approx.)
- Cross sectional area: 7,000 mm²

At the rate of 2,000 ingots per hour the expected yearly output, based on existing similar plants, is:

2,000 ingots/h X 13.6 kg/ingot X 24 h/d X 330 d/y X 0.85 ≈ 183,000 tons/year

The weight of 50lb (22.7kg) is quite dangerous for the integrity of the spine of the operators, therefore we are proposing lighter ingots – 30lb (13.6kg) which are much easier to handle and less harmful to the operator’s backbone.

Innovation is an effort that is meant to give industry not only higher profits and lower transformation costs, not only better and repeatable quality, but, above all, better working conditions for the human being.

4. Wire rod for welding alloys application: always necessary to produce 9.53mm?

Recent analysis has shown that approximately 10% of the global aluminium consumption is in the form of wire rod with the following main applications:

a) **Electrical applications.** It can be the basic commodity, in the commercially pure form of EC1370 or EC1350 (ASTM B233) or in the form of aluminium alloys, such as 6101 and 6201 (ASTM B398), for the production of bare and insulated conductors. These electrical applications cover more than 90% of the total consumption of aluminium wire rod.

b) **Mechanical applications.** It can be used as basic raw material for the production of complex alloys used in different sectors of industry such as rivets, welding alloys, insect screens, etc. This application covers approximately 10% of the global consumption of aluminium wire rod.

Rod for electrical applications is particularly required in countries where there is a great development of infrastructures. Just as an example, in India, out of 1.6 million tons of aluminium produced during 2011, more than 30% was dedicated to rod form and almost 100% of it was used for electrical applications. As a general trend, we are observing that more and more new projects for wire rod mills (linked to projects for new smelters) are located in countries where one or both of the following circumstances occur: i) low man power cost and ii) low cost of energy.
This rule of thumb is well substantiated by the evidence. In fact, Continuus- Properzi has supplied seven wire rod mills to aluminium producers in India during the period from 2006 to 2011. When they are all operational, they will have a total output of 640,000tpy of rod destined for electrical applications. In no other country in the world has such a huge rod production potential been installed in such a short period of time; not even in China! This favorable circumstance is due to the implementation of the so called ELECTRICITY ACT where the objective is to distribute power (electricity) to every single house in every village in the vast territory of India. The massive production of rod demanded by countries such as India, China and Russia requires that each single wire rod mill be sized for an annual production of 50,000tpy, as a minimum, up to 100,000tpy.

In general, worldwide, aluminium rod has a nominal diameter of 9.53mm (3/8”), 12mm and 15mm with lesser applications for 19mm and 25mm. The coils can be standard coils with a weight of 2.5 tons or jumbo coils weighing 3.7 tons or 3.0 tons.

Figure 4 shows typical rod coils and the tables I and II below show the typical dimensions of standard coils and jumbo coils.

<p>| Table I - Approximate Dimensions and Weights – JUMBO COILS |</p>
<table>
<thead>
<tr>
<th>Internal Ø [mm]</th>
<th>Outside Ø max [mm]</th>
<th>Width [mm]</th>
<th>Weight max [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>570</td>
<td>1,700</td>
<td>850</td>
<td>3,000</td>
</tr>
<tr>
<td>570</td>
<td>1,570</td>
<td>850</td>
<td>2,500</td>
</tr>
</tbody>
</table>

<p>| Table II - Approximate Dimensions and Weights – STANDARD COILS |</p>
<table>
<thead>
<tr>
<th>Internal Ø [mm]</th>
<th>Outside Ø max [mm]</th>
<th>Width [mm]</th>
<th>Weight max [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Standard</td>
<td>570</td>
<td>1,600</td>
<td>850</td>
</tr>
<tr>
<td>American Standard</td>
<td>760</td>
<td>1,650</td>
<td>850</td>
</tr>
</tbody>
</table>

In general terms, we can say that the production of aluminium rod for electrical applications follows the “global concept” that sees medium and large size plants located in the East and the Far East, whereas the rod produced is either consumed locally or exported to the western part of the world, namely Europe and North America.

The downstream industry is familiar with the rod diameter of 9.53mm and the drawing machines throughout the world are well equipped to process this rod diameter for the further production of electrical conductors. These conductors can be of many types, from the classic ACSR (Aluminium Conductor Steel Reinforced) to the AAAC (All Aluminium Alloy Conductor) and from the XTAI and ZTAI (Sag Resistant Conductors) to the most modern ACCC (Aluminium Conductor Composite Core).
We do believe that for such applications (medium and large size rod production plants) the diameter of the rod and the size of the coil do not represent the best compromise but rather the best technical solution that completely satisfies all involved Parties, i.e. Rod Producers, Rod Users and Freight Forwarder Agencies.

Now let’s consider the rod for mechanical applications and let’s try to analyze whether the diameter of 9.53mm represents the best compromise or the optimum solution.

First of all, we have to recall that rod is a semi-finished product that is almost always subjected to a drawing operation. In the conductors industry the rod diameter must be reduced from 9.53mm down to 2.7mm or 3.2mm. In the welding industry the commercial diameter of welding wire is 1.4mm or 1.6mm or other smaller diameters.

Since we have seen that diameter reduction is always necessary (except for TiBAI rod and master alloys), then why does the rod have a diameter of 9.53mm? Is it possible to dream that we could go directly from molten metal to a smaller diameter wire (ready for the final application)?

To reply to the first question, it is necessary to go back in time when the rod was produced starting from wire bars and using the dangerous technology of Belgian Loop rolling mills. This technology required the wirebars to be heated and then rolled by the Belgian Looping trains (see Figure 5) which yielded only 100/150 kg coils that had to be welded together to be drawn. The “star” of this manual operation was the worker called the “looper” (looping rolling mill operator). The looper’s job was to catch the rolled bar with big pliers as it came flying from the rolls of a previous roll stand and to insert it into the subsequent roll stands. The rod needed to be turned 180 degrees which required great personal skill, particularly in the case of the smaller and subsequently higher speed rod. It was obvious that every day the loopers were at risk of sustaining major injuries.

At that time the rod diameter of 9.53mm (3/8”) was the right compromise between obtainable output and the skill of the “looper”. Since 3/8” was also a round number, 9.53mm has remained a standard worldwide.

At the present time, worldwide, aluminium rod is supplied from the rod producers to downstream industry with a standard diameter of 9.53mm. On the lower side, there are very few exceptions where the rod is produced with a diameter of 7.6mm. Larger diameters of 12mm, 15mm and up to 30mm are produced but these diameters are not covered in the present discussion.

During the past ten years the Industry has favored the installation of medium large (6t/h up to 8t/h) and large (12t/h up to 15t/h) scale plants. As an exercise, we can calculate the speed of the rod (9.53mm) at the coiler using the following equation.

\[ V = k \times \frac{M}{\rho \times S} \]

Where:
- \( V \) is the speed of the rod [m/s]
- \( M \) is the production output [t/h]
- \( \rho \) is the specific weight of the metal [t/m^3]
- \( S \) is the cross sectional area of the cast bar [mm^2]
- \( k \) is a corrective coefficient to homogenize the various units
Table III below shows the speed of the rod calculated for production outputs of 8t/h and 15t/h and for diameters of 9.53mm, 7.60mm and 4.3mm considering that, presently, the maximum allowable process speed for the coiler is approximately 25 m/s.

<table>
<thead>
<tr>
<th>Rod diameter</th>
<th>Production rate</th>
<th>Speed of the Rod</th>
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<tbody>
<tr>
<td>9.53 mm</td>
<td>8 t/h</td>
<td>11.5 m/s</td>
</tr>
<tr>
<td></td>
<td>15 t/h</td>
<td>21.6 m/s</td>
</tr>
<tr>
<td>7.60 mm</td>
<td></td>
<td>18.5 m/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34.0 m/s</td>
</tr>
<tr>
<td>4.30 mm</td>
<td></td>
<td>56.7 m/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>106.3 m/s</td>
</tr>
</tbody>
</table>

We have indicated in red, on the above table, the speed of the rod exceeding the present limit of 22 m/s and therefore not achievable by modern coilers. The same results are shown in the graph (Figure 7) below.

Considering the above calculations, we can assume that the diameter of 9.53mm is a standard that will remain for many years to come when we talk about rod lines designed for large output, namely for electrical applications; larger diameters such as 12mm, 15mm are also available. For downstream processing with Conform machinery, existing Properzi rod lines produce rod up to 30 mm in diameter.

The rod for mechanical applications, especially the welding wire alloys (AA4043-AA4047-AA5356 and similar), has a completely different background. The users of this rod are namely automotive manufacturers and, in consideration of the lower consumption (if compared with rod for electrical applications), this rod can be conveniently produced by smaller plants having an output ranging from 1.5 t/h up to 2.5 t/h. Regardless of the diameter of the welding wire (from 0.8mm up to 2.4mm), several drawing and annealing cycles are required to go from 9.53mm down to the diameter of the application. Typically, the first drawing cycle reduces the diameter of the rod from 9.53mm to around 4.7mm and then there is the first annealing.

Based on this consideration, Continuus-Properzi decided to explore the possibility of going directly from molten metal to 3.2mm wire. A complete prototype line, from furnace to coiler, was manufactured and installed in Properzi’s factory. The line was sized for a nominal output of 1.5t/h yielding approximately 30 tons per day which is equal to approximately 10,000 tons per year.

This line was called CCW (Continuous Cast Wire) to emphasize the capability of going from molten metal to wire.
During three years of internal testing several alloys were produced and distributed as trial material. The AA4043 was certified by the Italian Welding Institute – Istituto Italiano della Saldutura.

The wire was collected in baskets having the following typical weight and dimensions:
- Weight: 500 kg
- Outside Diameter: 1,300mm
- Height: 1,500mm

The advantage of this technology is that it allows the elimination of:
- The drawing operation to go from 9.53mm to 3.2mm
- Any annealing operation(s) that would otherwise be required to get to this point.

Keeping the speed of the wire at 20 m/s, it is possible to increase the hourly output from 1.5t/h to 2.5t/h. In this case the final diameter of wire must be limited to 4.3mm. Also in this case the advantage remains the ability to skip one drawing process and the relevant annealing cycle.

When we talk about welding alloys, a small but growing niche of rod utilization, the traditional diameter of 9.53mm can be reduced to 3.2mm or 4.3mm with remarkable cost savings.

Conclusions
- Responsible research and development must be undertaken not only to improve existing systems and their design details but also to critique existing methods and technology by exploring the possibility of their replacement with new more effective solutions for both the producers and users of the commodities.
- This attitude, potentially risky and costly, will completely change the habits and traditions of the industry, but requires much effort to alter the consolidated practices and experiences that currently exist.
- The ingots of 13.6kg will contribute to improve the life of the ingot users while providing ingot producers better or equal OpEx and CaPex.
- The wire rod of 3.2mm or 4.3mm for welding wire applications allows elimination of one drawing cycle and the relevant annealing process.

References