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FROM MOLTEN METAL TO 3.2 mm WIRE FOR MECHANICAL APPLICATIONS

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Abstract

Aluminum utilization is growing at a steady rate reaching 40 million tons per year considering remelt and semis. Among semis, aluminum rod accounts for approximately 10% of the worldwide consumption, mainly for power transmission. Numerous aluminum alloys have been developed and utilized for various mechanical applications and welding purposes. Many rod alloys are difficult to produce and require highly experienced operators and the most advanced machinery and technical know-how. In the form of wire, from molten metal to 3.2 mm wire, the situation becomes even more critical and only the latest Properzi C.C.W (Continuous Cast Wire) technology provides new possibilities within this industrial field. The Author explores state-of-the-art aluminum rod equipment and the range of application for the C.C.W. technology which allows the production of 1xxx – 2xxx – 3xxx – 4xxx – 5xxx – 6xxx – 7xxx – 8xxx series aluminum alloys for many industrial and specialty applications.

Introduction

According to the most recent data available, the global primary aluminum demand in 2010 was in the range of 40 million metric tons. Industrialized countries of the world typically allocate approximately 10% of their aluminum consumption to the wire and cable industry. One exception to this is India which uses 35% of its aluminum for the production of electrical conductors thanks to the Electricity Act of 2003.

Aluminum rod is produced all over the world and is considered a commodity having a consistent price and standardized characteristics throughout the global market place. The most common aluminum wire rod diameter is 9.53 mm (3/8"). Wire rod is usually shipped in coil form. See Figure 1 for an example of typical aluminum wire rod coils and see Table I for the dimensions of typical aluminum wire rod coils.

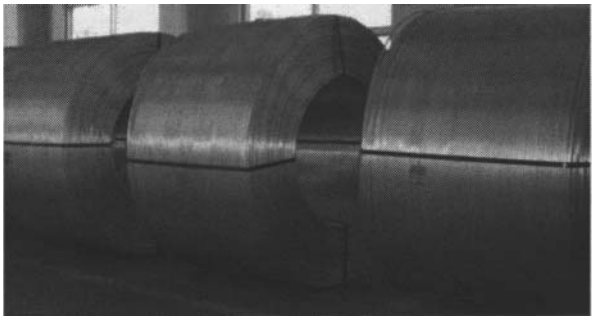


Figure 1. Typical Aluminum Rod Coils

The standard coil weight is in the range of 2,000 kg to 2,500 kg. Properzi CCR lines for production rates of 12 t/h or higher are equipped with jumbo coilers which produce coils weighing up to 3,700 kg each.

Table I. Approximate Coil Dimensions and Weights

	Internal Ø [mm]	Outside Ø max [mm]	Width [mm]	Weight max [kg]
European standard	570	1,600	850	2,500
American standard	760	1,650	850	2,500

The tolerance on the mass of each coil shall be +/- 6 %.

Aluminum Wire Rod Applications

The vast majority of the aluminum wire rod is destined for high conductivity applications and is manufactured from commercially pure aluminum, i.e. EC 1370 and/or EC1350 (according to ASTM B233) or from aluminum alloys containing added silicon and magnesium, such as 6101 and 6201 (according to ASTM B398), or from other aluminum alloys that are compatible with the rotary casting system.

Throughout the world there are a limited number of wire rod lines currently being used for the production of large quantities of aluminum alloy wire rod destined for mechanical applications such as welding wire, screws, bolts, rivets or other fasteners. In fact, aluminum wire rod production by final application can be divided as follows:

- 80% EC grade pure Al or AA1350 / AA1370 Electrical Conductors
- 15% Electrical Conductor aluminum alloys
- 5% Mechanical applications and master alloys.

Table II (below) summarizes the most common commercial applications of aluminum rod throughout the world.

Table II. Commercial Uses of Aluminum Wire Rod

Application	Aluminum Alloy
Welding Wire	4043, 4047, 5154, 5356
Zipper Wire	5056, 5086
Fasteners	5052, 5056, 5086, 6061, 6063
Insect Screen	5056, 5154
Rivets (Non-Aircraft)	1050, 5052, 5056, 5086, 5154, 5754, 6061
Electrical Conductors Alloy Wire	1200, 1350, 1370, 5005, 6101, 6201, 8175, 8176
De-ox	Pure aluminum > 98% Purity
Tie And Utility Wire	1100, 3105, 5052, 5056
Screw Machine Stock	2011, 2017, 2024
Nails	5056, 6061
Fence	3003, 3105, 6061
Antennas	5052
Impact Extrusion	1050, 3003, 6063, 6061

Therefore, the vast majority of aluminum rod production caters to the electrical market (cables and conductors), while the remaining quantity is devoted to the so-called mechanical applications which range from welding wire to de-ox and everything in between.

Aluminum Welding Wire

The aluminum welding wire market is driven in a large part by the automotive industry which produces approximately 60 to 70 million vehicles per year. In the third quarter of 2009, China alone sold an average of 1.5 million vehicles per month during this 3-month period. The usage of aluminum by U.S automakers has increased every year since federal fuel economy standards, commonly referred to as CAFE (Corporate Average Fuel Efficiency) Standards, were first enacted by the U.S. Congress in 1975; this can be seen in Figure 2 below. Currently, on average, there is approximately 120 – 160 kg (265 – 350 pounds) of aluminum utilized in each car thereby requiring a discrete amount of aluminum welding wire made from alloys such as 5356, 4043, 4047, etc. This trend is expected to continue to grow in the coming years as increasingly stringent guidelines are dictated in regards to vehicle fuel efficiency (CAFE). The forecasts indicate that automakers will increase their use of aluminum from 148 kg (327 pounds) in 2009 to 249 kg (550 pounds) in 2025.

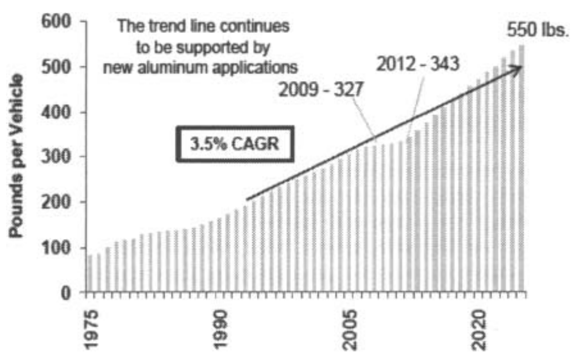


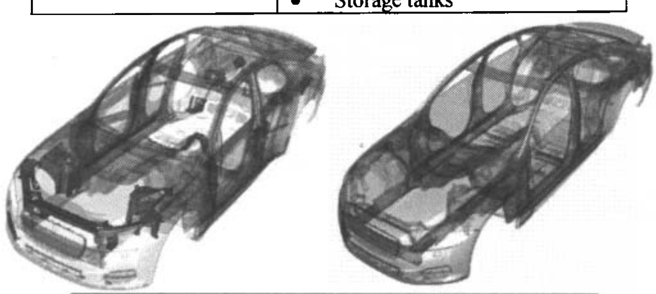
Figure 2. Aluminum Weight per Vehicle

There is no doubt that the utilization of aluminum within the automotive industry and the development of aluminum welding wire technology will continue to expand. Aluminum welding wire developments can be attributed to aluminum's attractive characteristics; i.e. comparatively light weight, high strength, versatility in extrusion and casting, and excellent corrosion resistance. Considering these physical properties, in conjunction with the increasingly important environmental issues such as improving fuel efficiency and superior recycling capabilities, there is no question as to why aluminum has become a popular choice of engineers and designers for a variety of automotive applications (see Figure 3). With the advancement of aluminum within the automotive industry, the necessity for developments in the area of aluminum welding wire and the production thereof becomes increasingly more important. Table III lists some of the most common aluminum welding wire alloys and their typical applications.

Global demand for technologically advanced aluminum wire rod, with high alloy content, has increased and is expected to continue to increase at a steady rate. However, the quantities currently required for each specific alloy are not yet sufficient to justify large Continuous Casting & Rolling (CCR) production lines, but are becoming sufficient to justify a more compact and more flexible line having a limited production range to better serve this highly specialized niche market.

Table III. Aluminum Welding Wire Alloys and Their Applications

Aluminum Alloy Welding Wire	Welding Applications
AA 4043	• For welding 6XXX series alloys, and most casting alloys • Automotive components such as frame and drive shafts • Bicycle frames
AA 4047	• Automotive components • Body panels • Heat exchangers
AA 5183	• 5XXX series alloys • Marine fabrication and repair • Cryogenic tanks • Shipbuilding and other high strength structural aluminum applications • Bicycle frames
AA 5356	• Automotive bumpers and supports • Structural frames in the shipbuilding industry • Bicycle frames • Formed truck panels
AA 5554	• 5454 base alloys • Automotive wheels • Transportation applications such as over-the-road trailers and rail tank cars • Chemical storage tanks
AA 5556	• 5XXX series alloys, such as 5083 and 5654 • Pressure vessels • Storage tanks



	Component Type	New XJ
	Stampings	88%
	Castings	6%
	Profiles	5%
	Other	1%

Figure 3. New Jaguar XJ Body Complete Overview

CCW Line Configuration

This paper will focus on the welding wire area and the technological solutions that are currently available with a system that was developed to facilitate the production of 3.2 mm aluminum alloy wire directly from molten metal.

The CCW line is comprised of the following equipment:

a) Combined Melting, Holding, and Tilting Furnaces: two furnaces to facilitate efficient melting, alloying and casting operations.
b) In-Line Treatment of Liquid Metal: Filtering and Degassing of the molten metal is necessary to produce aluminum alloys.
c) Casting Machine: equipped with a casting wheel having a diameter of approximately 1,100 mm and automatic pouring of the liquid metal. The copper ring mould has a cross sectional area of approximately 650 mm^2. The cast bar is solidified by a cooling system that permits fine regulations through computerized control that assures consistent repeatability of process parameters. Cast bar quality is optimized by a patented lubrication system of the rotating mould (ring and belt).
d) Sensor: facilitates perfect synchronization between the casting machine and rolling mill. (This device is intended to provide the fine adjustment of the mill speed while the overall synchronization is realized automatically by the electronic speed control.)
e) Pinch Roll: facilitates the transition of the cast bar from the casting machine to downstream operations.
f) Manual Bar Shear: to cut the cast bar in any convenient position between the casting machine and the rolling mill.
g) Cast Bar Straightener: utilized to straighten the cast bar before entry into the induction heater.
h) Milling machine: removes the eutectic segregation from the top and the edges of the cast bar when high magnesium alloys are cast.
i) Bar Induction Heater: utilized to re-heat the cast bar prior to entry into the rolling train in order to have the ideal temperature required by the particular aluminum alloy being produced to better facilitate the rolling operation.
j) Rolling Train: In order to provide the highest quality aluminum alloy, the rolling mill section is comprised of two rolling mills operating in tandem, one roughing mill followed by one finishing mill. The roughing mill provides higher reduction, while the finishing mill provides lower reduction and better control of the rod (wire) geometry. The roughing mill is equipped with 2-roll stands while the finishing mill is equipped with 3-roll stands that provide the classic triangle/round reduction sequence that does not require adjustment for the different alloys to be produced. The work rolls are made of tungsten carbide in order to insure long life. Work roll replacement is very quick and their calibration, using an optical projector, is not only very fast but also reliable as it is accomplished with the rolling stand completely assembled. Independent rolling mill emulsion systems for the roughing and finishing mills easily facilitate the use of different emulsion concentration levels according to the specific alloy being produced.
k) Quenching System: Independent quench chambers provide flexibility in reducing the wire temperature to the desired level (approximately 80° C) depending upon the alloy being produced.
l) Controlled loop wire take-up: The wire take-up has been specifically designed to continuously collect 'small' diameter, stiff mechanical aluminum alloys and to facilitate easy pay-off into downstream drawing processes. The take-up is a very critical part of the CCW line. The production of 3.2 mm diameter at the rate of 1.5 t/h implies a speed of approximately 19 m/s for the finished wire. The relatively high wire outlet speed, considering the outlet diameter, is the limiting factor for the production rate. Standard coil specifications that result from this take-up are as follows:

Outside Coil Diameter	1,300 mm (max.)
Height	1,500 mm
Weight	500 kg

m) Auxiliary Equipment: The line is completed with the necessary cooling and lubricating circuits for the various required operations including casting machine cooling water circuit, rolling stands oil lubrication circuit, gear transmission lubrication circuit, rolling process emulsion circuit, etc.

Aluminum Welding Wire Production

The CCW system, due to the relatively small bar size (≈ 650 mm^2) when compared to that of larger CCR lines for Electrical Conductors (up to 5500 mm^2), provides the welding wire producer with tremendous flexibility and ease in the production of these difficult welding wire alloys, not to mention a greater degree of quality control over the alloy itself.

Traditionally, and in a very general sense, welding wire products are produced in the following manner:

- Aluminum rod producers utilize continuous casting & rolling lines to make 9.5 mm aluminum alloy rod which is shipped to the various welding wire producers.
- The aluminum alloy rod is drawn via a rod breakdown machine from an inlet diameter of 9.5 mm to outlet diameters in the range of 5 mm to 2.5 mm. The outlet diameter depends upon the specific alloy and its mechanical characteristics as they relate to work hardening as a result of plastic deformation through the drawing process.
- The achievable outlet diameters will vary from alloy to alloy as a function of when intermediate annealing becomes necessary. In other words, what is the smallest diameter to which the wire can be drawn before it must be subjected to an annealing process?
- Ultimately, the aluminum welding wire industry and the associated welding machinery and welding processes demand very specific wire diameters. The most common wire diameters are 0.8 mm, 1.0 mm, 1.2 mm, 1.6 mm, 2.0 mm and 2.4 mm.
- The necessary intermediate annealing process(es) along the way not only adds a step to the welding wire manufacturing process, but also the associated costs and potential issues related to the intermediate annealing operation(s).

The Properzi CCW (Continuous Cast Wire) system allows the welding wire producers to skip the traditional rod breakdown wire drawing and associated intermediate annealing processes and go directly from molten metal to a wire size that is convenient for the welding wire producer; a diameter that synergistically fits within their current process; i.e. 3.2 mm, 4.3 mm, etc.. During the design phase of the CCW system, Properzi selected an outlet diameter of 3.2 mm in order to meet the above criteria. As it was conceived, the CCW line was manufactured and utilized to successfully produce various mechanical alloys while providing these process benefits. The CCW system provides a flexible production line that is able to produce all of the various aluminum welding wire alloys, as well as other mechanical alloys, at a rate of ≈1.5 t/h depending upon the specific alloy being cast.

The exit wire speed of the 3.2 mm wire is equal to approximately 19.2 m/s. This can be calculated using the formula shown below. While maintaining the same speed at the outlet, and configuring the CCW line in the same manner as described above, a new CCW line could provide a higher production rate; for instance 2.7 t/h if the market accepts an outlet wire of 4.3 mm.

$$M = \rho \cdot V \cdot A \cdot k$$

Where:

- M = production rate in kg/h
- ρ = density in kg/m^3
- V = speed of the wire in m/s
- A = cross sectional area of the wire diameter in mm^2
- k = the appropriate constant to homogenize all of the units

Table IV illustrates the production rates related to the production of 3.2 mm and 4.3 mm wire. Therefore, with a similar initial capital investment, there is an 80% increase in capacity for the production of very difficult mechanical aluminum alloys.

Table IV.

Exit Wire Diameter (mm)	Cross Sectional Area of Exit Wire Diameter (mm^2)	Exit Wire Speed (m/s)	Hourly Production Rate (T/h)
3.2 mm	8.04 mm^2	19.2 m/s	1.5 T/h
4.3 mm	14.52 mm^2	19.2 m/s	2.7 T/h

Table V shows a brief comparison of the mechanical characteristics of the wire produced with the CCW system with those provided by international standards, where available and applicable.

Conclusions

How and why can the CCW line serve this niche market?

- Welding wire alloys are mainly produced in the most technologically advanced countries; Europe, North America, and Japan.
- The production of 9.53 mm (3/8") aluminum rod has shifted, and continues to shift, from the more technologically advanced areas of the world to those areas where electrical power and manpower (labor) are less expensive.
- The production of aluminum remelt forms has not shifted in a manner congruent with that of the aluminum rod.
- The automotive brain trust, where the specialized aluminum parts are designed and manufactured, continues to be located in these same technologically advanced areas mentioned above.
- At the current time, the technologically crucial aluminum parts of the automobile are manufactured in the technically advanced regions of the world and shipped to the developing areas of the world for assembly. However, all the welding operations, testing and certification of these parts takes place before they are shipped.
- It is also critical that the welding wire suppliers remain in close geographic proximity to where the aluminum parts are designed and manufactured.
- How will this continue to happen if the aluminum rod producers continue to shift their production elsewhere in the world? As this shift continues, the CCW system will allow the welding wire producer to start from aluminum ingots and manufacture top quality aluminum alloys. It will provide the flexibility and ease to change from one alloy to another thereby facilitating the production of all the aluminum alloys destined for mechanical applications mentioned earlier, especially the welding wire alloys.

Table V. Aluminum EC Grade Alloys, Mechanical Alloys and Welding Alloys (Ø = 3.2 mm)

Alloy	Standard	Tensile Test (N/mm^2)	Elongation % Min. 250 mm	Tolerance on the Diameter (%)
1350 H19	ASTM 230 M	160	1.7	+/-1
	CCW	160	2.1	+/-1
6101 F	ASTM B317	220	15	+/-1
	CCW	180-195	15-17	+/-1
6061 H 13	ASTM B316M	150-210		+/-1
	CCW	180-200		+/-1
5051 H38	ASTM B221	260-290	2-4	+/-1
	CCW H38	280	5	+/-1
5052	ASTM B316 M	215-255	3	+/-1
	CCW H38	300-320	4.5-6.5	+/-1
4043	AWS A5.10-92	--	--	--
	CCW	170-180	13	+/-1
4047	AWS A5.10-92	--	--	--
	CCW	210-220	13-16	+/-1
5154	AWS A5.10-92	--	--	--
	CCW	340-370	8	+/-1
5356	AWS A5.10-92	--	--	--
	CCW	270-330	15-20	+/-1

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