Aluminum Wire in Metallizing

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Aluminum Wire is one of the primary consumables in today’s vacuum metallizing industry for flexible packaging and other applications. Typically when problems are encountered, the aluminum is often overlooked based on the past history and experience that suggests the likelihood of a defect is low. However, the characteristics of the aluminum wire do have the potential to create problems during the metallizing process. These characteristics can also be controlled to optimize the metallizing process. The aluminum wire has the potential to affect the uniformity of web coatings, boat life as well as the transmission rates of the final product. A brief background on the processes involved in producing the aluminum wire as well as the key characteristics of this wire and their impact will be discussed.

Aluminum:

The unique combination of properties makes aluminum a very versatile material for applications ranging from automotive to construction to electrical and most importantly metallizing. Aluminum is light in mass yet some alloys have strengths greater than structural steel. Other properties that make aluminum attractive include the high corrosion resistance, barrier properties, electrical conductivity and reflectivity.

Approximately 60% of aluminum is mined with the remainder being recycled. Aluminum is refined from bauxite ore using the Bayer Process. The ore is crushed and mixed with sodium hydroxide and “digested” under high temperature and pressure. Aluminum oxide is then evaporated and crystallized to remove the residues that may be present in the ore. The aluminum oxide is then reduced using an electrolytic cell, resulting in aluminum that can be sent to a melting furnace. The aluminum is then mixed with desired alloys to achieve the desired final chemistry mixture and characteristics. The aluminum is then cast into ingots for transportation and handling.

Recycled aluminum is melted in a gas fired furnace and then refined to remove impurities. After desired refining has occurred the molten aluminum is cast into rod or other configuration for future processing.

Aluminum is categorized by the chemical makeup or purity. Each grade is designed for specific desired properties. These grades are designated by a four-digit code that identifies the alloying elements:
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| 1xxx | >99% pure  
Applications: electrical / chemical  
Major Impurities: Fe and Si |
| 2xxx | Alloyed with **Copper**  
Require heat treatment for properties (similar to mild steel)  
Application |
| 3xxx | Alloyed with **Manganese**  
Not heat treatable  
Applications: high strength |
| 4xxx | Alloyed with **Silicon**  
Application: welding / brazing |
| 5xxx | Alloyed with **Magnesium**  
Not heat treatable  
Application: high strength |
| 6xxx | Alloyed with **Silicon & Magnesium**  
Heat treatable  
Applications: |
| 7xxx | Alloyed with **Zinc**  
Heat Treatable  
Applications: very high strength/stress |
| 8xxx | Alloyed with **Tin** |

The 1xxx series aluminum is the most common and often referred to as the 1000 series. This is the purest of the alloys and comprised primarily/exclusively of aluminum. With in this series the 10xx group is un-alloyed and contains natural impurity limits of various elements. The remainder of the series is comprised of 11xx, 12xx and 13xx that have special controls for one or more the impurity elements. Typical grades used in the metallizing industry include 1080, 1100, 1188, 1199 and 1350.

The other series 2000 through 8000 are highly alloyed and designed for specific applications and properties. These are rarely used in the metallizing industry.

The impact of the chemistry (grade) on the metallizing process / product is not necessarily clear. In general the common believe was that the higher purity our result in a more uniform deposition layer with enhanced water vapor and oxygen barrier properties. In 1977 a study did confirm that a 99.5% purity aluminum did outperform the 99% purity material (1>…). However, the differences in materials with purity levels
greater that 99.5% was negligible with one exception. The exception was with the 1188 grade (99.88% pure) with significantly better WVTR and OTR that other grades tested. The exact cause for this performance difference is unclear and could be related to the possibility of the purity actually exceeding the limits set for the grade.

Another key consideration involves the useful boat life. There is a correlation between the aluminum purity and the useful boat life. The impurities (silicon, iron, and others) comprise a significant component in the slag that builds up in the boats during operation.

**Aluminum Wire:**

Aluminum is supplied to a wire mill as rod. This raw material is typically purchased in a 3/8” (0.375”) or 9.5mm coil. The rod is a wound coil of aluminum that has either been cast to size or rolled. During the manufacturing process of rod, each batch is assigned a unique lot or heat number. This heat/lot of aluminum will then be processed into the final rod state. The coils produced from a single heat/lot will have a common chemical makeup. From heat to heat (or lot to lot), the chemical makeup of the aluminum may vary within the ranges allowed for the particular grade.

The aluminum rod is then cold-drawn to achieve the desire final wire diameter. This is accomplished by drawing through a series of tapered carbide or diamond dies. Each die will reduce the wire diameter between 20% and 30% per die. Typically wire used in metallizing will use 10-15 dies to achieve final size. Depending on the specific alloy and desired final properties, the process may involve heat treatments either prior to drawing, as an intermediate step or following drawing. The drawing process requires a lubricant to allow the aluminum to be pulled through the dies. This lubricant can be either be dry or liquid form. In the case of metalizing, this lubricant is subsequently cleaned from the wire by a variety of methods (either in-line or during a subsequent processing step). At the completion of the drawing process, the wire is packaged onto large spools for handling and further processing.

**Tempers:**

As the wire is processed, the aluminum will undergo cold-work that results in increased strength and hardness with an overall decrease in ductility. The “temper” of the wire is a designation that refers to the degree processing involved. A wire drawn approximately 75% from an annealed product while keeping the temperatures below 125°F is given a designation of H-18. An annealing cycle will revert the material back to its fully soft state and designated as an “O” temper. Processing that results in a wire with tensile strengths half way between the “O” and H-18 temper are designated as H-14. Similarly the tensiles between annealed and H-18 are designated from zero to eight.

With in the metallizing industry the typical tempers are H-18, H-16 and H14 with the typical wire diameters of 0.062”, 0.072” and 0.092”. The desired temper is typically chosen from past experience and will directly impact the operation of the metallizing process. The harder tempers (H-18) will have a more defined/stiff cast and will payoff
into the boats in with a certain arc. The softer tempers are easier to work with but will also tend to walk or wander before striking the boat.

During the wire production of the various tempers below H-18, the aluminum is heat treated/annealed at predetermined steps within the process (depending on the desired temper). This annealing process does not involve a protective atmosphere and thus results in a slight oxide layer on the surface of the wire. Depending on the final draw step, the amount of this layer will vary. Theoretically during the metallizing process, this oxygen can be released and influence the barrier properties. The actual mechanics of this are not clearly understood but previous work did find the water vapor barrier properties were consistently better on an H-14 vs. an H-18 tempered wire.

**Cleanliness & Spooling:**

For wire in the metallizing industry, the typical final package involves the wire perfectly spooled onto a plastic spool that will later be loaded into the vacuum chamber. This process takes the wire from the large spools and re-spool the wire onto the final plastic spools in a closely controlled process. This process involves closely controlling the incoming wire tension, traverse, pitch as well as wire cast as the spool is wound.

The spooling and wire cleanliness are the both potential sources of problems in the metallizing process. There are several factors involving wire cleanliness as well as spooling that must be considered.

During the drawing process, drawing oil is used as a lubricant. The wire must be subsequently cleaned and spooled for use in the metallizing equipment. If the wire is over-cleaned, the surface will tend to gall/stick to itself and prevent the perfect spooling of the wire. The spooling process is dependant on the cleaning process. The metallizing process demands extremely clean wire as well as perfectly spooled wire. Thus a balance is required to achieve a level of residual lubricant that will allow for perfect spooling as well as minimize problems in the metallizing operation. Wire with heavy residual lubricant will result in spitting from the boats as the oil/lubricant vaporizes.

Another potential source for oil carry through is related to possible wire surface damage that could occur during the wire drawing process. Aluminum is a very soft metal and is susceptible to scratching. It is possible to form a deep scratch that could entrap oil and then be smoothed over. This would ultimately be released during the evaporation process.

Within the spooling process, the wire is wound onto plastic spools. The geometry and consistency of the spool can significantly impact the quality of the wind. The spool flanges must be straight and true. If the flanges are not straight and true, the spool interrupts the pattern of the wire lay and prevents a perfect pattern. The plastic spools themselves are produced in an injection-molding operation. Burrs or overflows will also displace the wire during the winding operation and prevent a perfect pattern.
In some cases, spools can be re-used within limits. The spools must first be cleaned to remove any deposited aluminum or surface contamination that could result in downstream problems. During the spooling operation, the flanges of the spool experience pressure from the wire. After multiple uses, the flanges of the spools can weaken and actually bow out. This change in geometry can result in edge gaps in the first couple layers of wire.

During the winding process, opportunity exists that could result in a variation in wire diameter. A change in wire diameter will also negatively impact the ability to properly spool/wind. Several precautions are taken to minimize the chance of variation. These often include the use of diamond dies during the drawing process as well as controls in the re-winding operation.

The wire itself is wound onto the spool under tension to produce a tight package. The cast of the wire is larger than the spool and will unravel if the wire is let loose. A tight cast is possible but would require additional forces to be applied to the wire during the re-spooling operation as well as in metallizing process. These additional forces would increase the opportunity for diameter variation, tangling/feed difficulties as well boat issues. With the larger cast size, it is important that the wire be kept under some back-tension to avoid/prevent the strands becoming loose and increasing the opportunity for tangling. Even during the metallizing process, it is important to keep some back tension or drag on the wire/spool in the form to prevent the wire from becoming loose.

Conclusions:

Aluminum is a flexible versatile material that has a wide range of applications. Within the metallizing industry, as with many others, controlling the variables/characteristics is important. The selection of these characteristics can optimize the film properties.

The chosen alloy can impact the properties of the final film. As expected, the high purity alloys perform well, while other alloys may optimize the film barrier properties. Lower purity alloys can result in decreased boat life due to slag buildu.

Feed tube plugging can also be minimized by adjusting the wire diameter. A larger wire diameter will reduce the opportunity of the feed tube plugging up, but can lead to issues in the boat. Increased diameter can result in increase a change to the wire-boat intersection point as well as increased wandering. The impact of this can be controlled/minimized by adjusting the temper of the wire.

From a metallizer’s perspective, there are several variables that can not be controlled. These involve chemical variation, wire cleanliness, and spooling payoff. Individually these variables have the potential to negatively impact the metallizing process. In most cases, these are controllable by the wire producer.

Wire cleanliness can result in a variety of issues. This will primarily manifest itself in or at the boat during the metallizing process. An oily residue will result in spitting during
the melting process. Other contaminates can also lead to spitting, slag, as well other coating issues.

The spooling of the wire also can have a significant impact during the metallizing process. Improper spooled wire can result in a tangle or snag, resulting in inconsistent coatings and requiring venting of the vacuum system to correct. Spooling issues are typically the result of poorly spooled wire, spool quality/condition, as well as the back-tensioning during use.

There are many characteristics of aluminum and of wire that must be controlled to ensure a quality consistent metallized product. Ultimately these characteristics must be selected while considering the specific equipment and application involved.

**Bauxite**: Bauxite is the ore that is mined in for the production on aluminum.
**Aluminum Alloys in Metallizing:**

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<th>GRADE</th>
<th>AL</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
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<tr>
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<td>.005</td>
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<tr>
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<td>Si+Fe = .95</td>
<td>.05- .20</td>
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**Aluminum Rod Coil:** The aluminum is either cast or rolled to finish size. Coils typically weigh approximately 5000 to 7000 pounds.
**Drawing Dies:** The tapered draw surface is either a carbide or diamond material. Typically each die is used to cold draw the material approximately 25-30%. Multiple dies are used in the drawing process to achieve the final wire diameter.

**Plastic Spools:** Spools are typically injection molded plastic. The parameters of the spool include the arbor (hole size), flange (side), barrel (center surface) and the traverse (distance between flanges).
**Spooling of Wire:** Wire is perfectly wound onto the plastic spool.

**REFERENCES**

Aluminum Standards and Data 2003, The Aluminum Association, Washington DC

World–Aluminum.Org, International Aluminum Institute
