The Ageing Process for Extruded Aluminum Profiles

by Al Kennedy

Abstract

Extruded aluminum profiles in the Al-Mg-Si family are typically "aged" in order to improve the mechanical properties of the alloys. Ageing will occur naturally with time, but artificial ageing by heat treatment is preferred because it is not possible to store the production on the floor for long periods. In this paper we review why this process is performed; what equipment is used and how it should be operated and maintained; and what quality tests are used to verify the results of the process.

While this process is often referred to as "age hardening," the desired properties are higher ultimate tensile strength and yield stress. Hardness is a side effect that is discussed because it is more easily measured.

Natural Ageing

The precipitation process is quite complex and involves the solubility of inter-metallic clusters that precipitate within the alloy. Left at room temperature, the Al-Mg-Si alloys commonly used in extrusions will gain in strength over a period of 100 to 500 hours (illustration1).

However, this process of "natural ageing" is not practical due to the logistics problems and time delay. The floor space required for storage for 4 days' production is not practical, and the demand for fast deliveries also will not allow for natural ageing.

Artificial Ageing

Precipitation ageing is accomplished much faster at higher temperatures:

These charts from the paper *Precipitation Aging* by R.W. Hains show that maximum properties are achieved quickly under controlled temperatures and time. A common process for ageing alloy 6063 is at 185°C for 4 to 5 hours.

**The Process Cycle and Parameters**

From these and similar references it is not difficult to define the ideal process parameters of time and temperature for ageing extruded profiles. Most problems that occur are caused by non-uniformity of temperatures throughout the oven and throughout the load.

Most ageing is done in batch-type ovens with hot air circulation to provide heat transfer by convection. Uniform heat transfer requires that the heated air is in contact with all of the load, and that the air temperature is uniform. These simple rules are often ignored; following are some extreme examples of bad practices.
Loading the Oven

This extruder is ageing bundles of heavy profiles with no space for hot air to pass through the profiles. Note the center bars in each bundle --- how can heat reach these pieces, and how can they reach the same temperature as the pieces on the outside?

All of the heated air passes over the load, not through the load. It will take a very long time for this load to reach temperature.
Notice how these extrusions are spaced to allow room for the heating air to pass through the load to transfer heat. The extrusions are also stacked to the top of the oven, so there is no air by-passing the load over the top of the load.

The baskets have "fingers" to allow separation of the extrusions between layers, which protects the profiles and allows better ageing.
The Cycle: Heat-Up and Soak

The standard procedure specifies a soak time, which begins after the entire load has reached the required temperature. A common specification for the load is to reach temperature within one hour, with an accuracy of ±3°C.

It is important for all of the load to reach temperature before beginning the soak cycle. However, it is not practical to attach thermocouples to all points of the load for every cycle, so it is necessary to know the typical heat distribution throughout the oven. It is more practical to control the cycle by the temperature of the hot air and not by the temperature of the extrusions. The age oven must be surveyed with thermocouples placed throughout the loads several times in order to learn the characteristics of the oven --- that is, which points are likely to be hottest and which ones less hot. This information tells when the actual soaking cycle can begin. In some cases where precise ageing is required for some products, these can be placed in the hottest part of the oven.

Temperature Surveys

A new oven must be surveyed to determine its patterns of temperature distribution, and the oven should be re-surveyed periodically, typically at least every year (as recommended by Mr. Ram Ramanan of Alcan²). The suggested locations of thermocouples for the survey are shown in the following illustration:

These are suggestions for the first survey, but results may suggest additional locations for later surveys.

The thermocouples may be attached to a multi-point chart recorder, or used with a personal computer through a Multiple I-O plexer interface.

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Note that Temperature variations will depend on the loading pattern as well as oven configuration. Very long ovens with end flow are likely to have non-uniform temperatures.

**What is the Best Oven Configuration?**

Here the engineer has some difficult decisions to make when specifying an age oven:

- The longer flow pattern of end flow ovens results in higher efficiency as there is more contact time for heat transfer to the profiles. However,
- The longer the flow direction the greater will be the temperature drop in the hot air, so there is less uniformity.
- With end flow there is usually more opening area in the profiles for hot air to pass through the load.
- Cross flow will result in better uniformity of air temperature because of the short travel distance. However,
- Thermal efficiency will be less with cross flow as there is less contact time between hot air and profiles.
- With cross flow there is usually less open space for air to pass through the load and therefore less contact of the hot air with the center part of the load.
- With cross flow, when part of the load profiles are not full length, more of the air can bypass the load.

What is the best solution? The engineer must evaluate the mix of profiles to be aged and consider how the load will be arranged --- that is, where is space for the heating air to pass through the load and not by-pass it?

The cross-flow design is preferred by some, but my own preference is for end flow with special provisions. To solve the problem of temperature uniformity I recommend that longer end flow ovens be fitted with either multi-zones, or else reversing air flow. To me this is the best of both worlds, and it costs less and requires less floor space.

![Figure 9-3: Types of End Flow Age Ovens](image)

Of these examples, the double length, single zone has the least uniform temperature patterns.
With a cross-flow oven, loads like this one will not allow hot air to pass through the load. If part of the load is not full length, the hot air may pass around the load instead of through it.

**Testing the Results of Ageing**

The ageing process is often referred to as "Age Hardening," but the purpose of ageing is not to make the profiles "hard" but to increase the properties of *ultimate tensile strength* and *yield strength*. Testing for these properties requires preparing a sample coupon of a particular shape and testing it in a tensile testing machine. However, testing these properties is difficult and not practical for routine testing on the production floor in most cases. For this reason most extruders use a simple hardness tester such as Webster or Rockwell to confirm the ageing process.
Mr. Bob Werner presented a comparison of various test methods for quality control of the ageing process. He concluded:

CONCLUSION

The round robin data can provide guidance for extruders who are obliged because of their capabilities to utilize hardness measurements rather than mechanical property (tension) test methods for material evaluations. It is recommended that wherever possible mechanical property test procedures be employed because they are more precise and meaningful.

The ability to identify with precision a -T5 temper versus a -T6 temper is difficult with hardness measurements. While one can discern between -T5 and -T6 with tensile strength property evaluations, it is necessary to perform a chemical analysis to identify different alloys. Tensile strength properties alone are not capable of achieving this separation.

The hardness test method's precision deteriorates significantly with 6063-T5 material due to its relative softness. The Barcol test is the most precise. Second choice would be the Rockwell E method but care is required to avoid the anvil effect. Webster hardness based upon its high relative standard deviation of precision of the test method is not recommended.

Extruders are cautioned to utilize hardness property measurements with care because they are subject to a significantly wider variation than one encounters with tensile strength type measurements.

The tensile strength, yield strength and elongation methods are suitable for more precise evaluation of a material's properties. The various hardness methods, as has been recognized earlier by metallurgists and engineers, are not desirable to be used as the ultimate means of assessment of an alloy's mechanical properties.

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