6xxx alloys: Optimized heat treatment sequences for unique customer benefits

The 6xxx-Series alloys represent a well known compromise in overall properties, such as tensile strength, tensile elongation, fatigue strength, corrosion resistance, formability and weldability. These are the reasons why the Al-Mg-Si alloys are used for many very different applications. The wide range goes from automotive and aerospace parts to casings of electronic devices and sports equipment.

Comparison of alloy characteristics

Depending on the actual application the specific customer requirements in terms of material properties vary significantly. For example, in the automotive industry growing demand for thinner gauges for further weight reduction pushes the existing 6xxx alloys to their limits. If higher strength levels are required, costumers may have to apply 2xxx or 7xxx alloys. These alloy systems offer higher strength levels, but require alternative forming processes to compensate lower formability, and alternative protection methods to compensate their lower corrosion resistance.

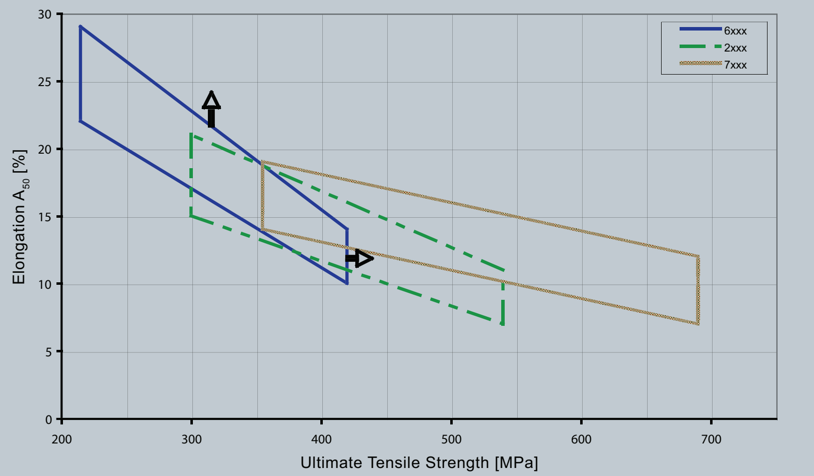

Fig. 1: Comparison of possible strength levels of 2xxx, 6xxx and 7xxx alloys.

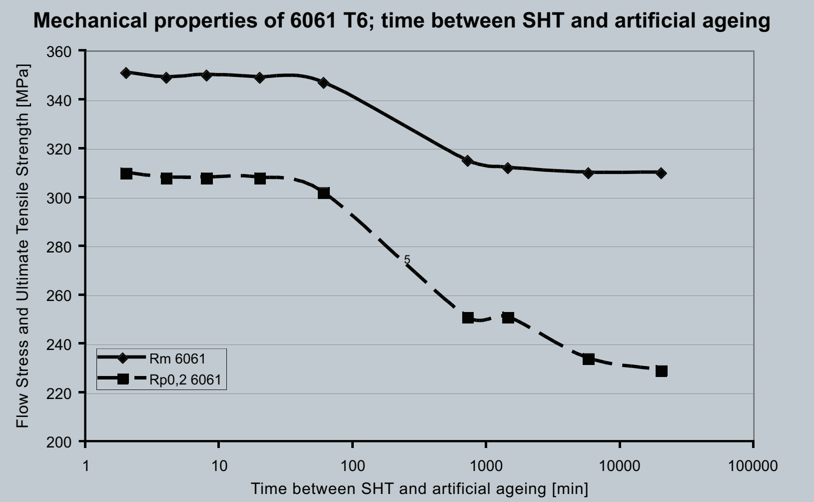

Fig. 2: Influence of waiting time between SHT and artificial ageing on mechanical properties in temper T6.

A schematic comparison of the three mentioned alloy groups is shown in figure 1. The schematic drawing indicates that the highest strength 7xxx alloys are superior in strength, but worse in elongation compared to the 6xxx alloys. As the arrows in figure 1 indicate, the goal of the presented development project is to enlarge the property window of 6xxx alloys towards higher strength or/and higher elongation. On the one hand higher ultimate tensile strength (UTS) may help to reduce the gauge of sheet metal components and on the other hand superior elongation levels at the same strength level enables more complex part geometries due to better formability at room temperature. In this article a modified heat treatment sequence for the alloy 6061 is introduced. This alloy is frequently used in the US market.

Theoretical Background

The mechanical properties of heat treatable sheet materials depend on various influencing factors along the complex processing chain. In the standard production chain hot and cold rolling steps are followed by solutionizing and artificial ageing treatments.

Artificial ageing of 6xxx alloys

The 6xxx – Series (Al-Mg-Si) of aluminium alloys belongs to the group of heat treatable alloys with Mg_2Si being the intermetallic hardening phase which precipitates in the Al-matrix. The understanding and control of precipitation during artificial aging is critical for achieving optimum properties in 6xxx alloys.

The potential for increasing strength and hardness of the Al-Mg-Si alloys is based on the increase of the solubility of magnesium and silicon in the aluminium matrix with increasing temperature. After quenching from solutionizing temperature the supersaturated solid solution is present at ambient temperature.

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In order to again reach thermodynamically stable conditions precipitates are formed. The main strengthening phases of the 6061 alloy are Mg-Si precipitates (Mg_2Si) and Si precipitates.

Experiments

To improve material properties within the standard production process three major parameters can be varied:

- Chemical composition within the EN or AA standard
- Hot/Cold rolling parameters
- Heat treatment parameter

In the present study the chemical composition of the alloy was kept constant at an adjusted AMAG 6061, the rolling parameters were fixed at standard production parameters and all attention was focused on the heat treatment processes.
In an initial experiment in the lab the influence of the waiting time between solution heat treatment (SHT) and artificial ageing treatment was investigated. All samples were aged at 160°C for 10 hours and the results are shown in figure 2 on page 7.

The strength properties start deteriorating after roughly 1.5 hours waiting time at room temperature.

Modified processing chain

Following the above mentioned observations from the laboratory experiments AMAG`s standard processing chain was modified significantly by applying additional short heat treatment steps right after the SHT. These additional heat treatments are supposed to avoid the formation of GP-zones in the alloy 6016. The schematic temperature/time curve of the modified AMAG process is shown in figure 3.

After conventional SHT (before artificial ageing) the material condition is named T4. Since the processing steps and the resulting material properties vary from standard 6061-T4 material the temper including these short heat treatments is called 6061-T4*.

The solution annealing of the coils was done on a continuous heat treatment furnace (Figure 4) at temperatures between 540 and 580°C.

In order to freeze the super saturated condition after SHT the bands were quenched with water to room temperature rapidly. Up to this point the production flow is similar to the standard process for 6061-T4 material. Due to the additional heat treatment steps the temper changes from temper T4 to designated 6061-T4*. This article describes the different ageing behavior of 6061-T4 and 6061-T4* at 160°C.

Fig. 4: Continuous heat treatment (CHT) furnace for solutionizing treatment of coil material

Results

Figure 5 shows the evolution of the mechanical properties of 6061-T6 depending on the starting temper T4 and T4* as a function of the artificial ageing time at 160°C. It can be seen that the temper T4* material reacts much faster with an increase in strength to the applied heat treatment. Standard T4 material properties, however, initially drop before they rise again after approximately 30 minutes. After 400 minutes the T4* material has almost reached its maximum strength, whereas the T4 material's strength is still rising slightly with increasing time.

Most importantly it can be stated that the maximum strength level in UTS as well as in flow stress is roughly 50 MPa higher if AMAG 6061-T4* is applied than for standard T4 as starting material. Looking at the same result from a different angle the following can be stated: If a level for the flow stress of 250 MPa is sufficient, it can be reached with AMAG 6061-T4* within only 1hour of artificial ageing, while the standard T4 material requires a treatment of 15 hours!

The difference in T6 - strength levels based on the T4* and the T4 material is again in the range of 50 MPa, with the first being the better one. The tensile elongation and the yield ratio are good indicators for the bending properties and the deep

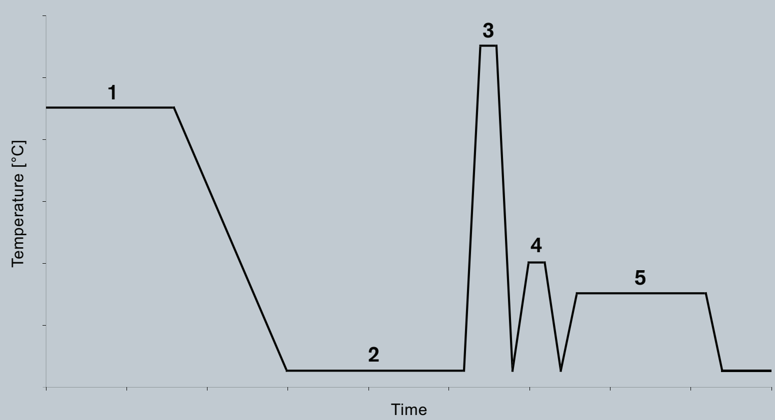

Fig. 3: Schematic temperature applied during production of modified 6061 with the additional heat treatment.
1-Hot rolling 2- Cold rolling 3- Solution annealing 4- Additional heat treatment 5-Hot ageing

drawability of a material. Higher values for tensile elongation and lower values for yield ratio let expect better formability.

As expected the tensile elongation decreases the longer the material is held at 160°C in the ageing furnace, because strength increases (Figure 6). The yield ratio of both materials rises continuously, with values for the material starting from temper T4* being significantly higher.

Summary and Outlook

The newly developed heat treatment process for 6xxx-alloys and the modified production facility at the AMAG rolling mill in Ranshofen allow the production of sheet metal products with novel and superior properties. The presented results show the high potential of AMAG 6061-T4* or the modified 6061-T6 regarding higher formability or higher strength. The important Figure 5 of the article can be interpreted as follows:

- If a strength level of 250 MPa for flow stress is sufficient for a component, then the new heat treatment sequence allows a reduction in ageing time by 90% (!!) compared to the standard T4 treatment. This is associated with enormous energy saving in production, combined with a reduction of CAPEX for new furnace capacity.

- If peak strength in T6 is required, then the material shows an increase of roughly 50 MPa both for UTS and yield strength when the ageing treatment starts from temper T4* compared to temper T4. This is equivalent to an increase in strength of roughly 20%.

- If a customer requires a tailored property-set in between, then the artificial ageing treatment can be adjusted accordingly. For example, artificial ageing for 4 hrs at 160°C would lead to an increase of about 30 MPa compared to the standard process. This is an increase in strength of more than 10%, but requires only a quarter of the standard ageing time.

The materials themselves are developed from a large amount of recycled aluminium combined with primary aluminium from AMAG`s Alouette Smelter, which uses only energy from hydro power. Saving natural resources during production of the materials and preparing them in such a way that the following component processing again requires less energy is a feature of AMAG 6061-T4* and the other 6xxx-T4* products. These materials are therefore members of the family of the newly developed **AMAG Green Alu Products**.

Bibliography

[1] Zelger, Ch., Oberhauser, P., Melzer, C., Pöschmann, D., Schulz, P.: Advanced 6xxx alloys for electronic applications, proceedings of EMC 2009, pp. 1419 – 1425, 2009

In this article only results of the development work for the alloy 6061 were presented. However, the new heat treatment sequence is applicable to all other members of the 6xxx-family of age hardening Al-Mg-Si alloys. Results on the important structural materials alloy 6082 and alloy 6013 will be presented soon.

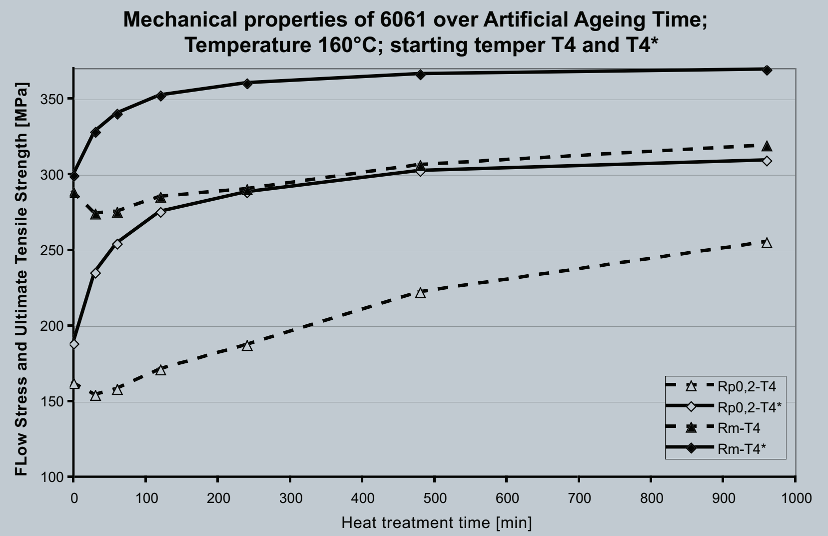

Fig. 5: Heat treatment response of 6061-T4 and 6061-T4* to variations in artificial ageing time at 160°C.

Fig. 6: New hot ageing furnace for coils

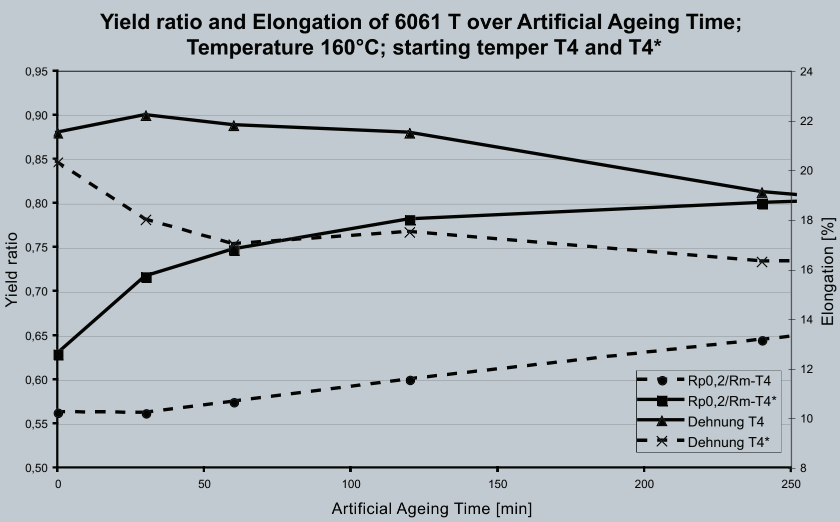

Fig. 7: Yield ratio and tensile elongation of 6061-T4 and 6061-T4* as a function of artificial ageing time at 160°C.