RECENT J. (2024), 74:190-193
https://doi.org/10.31926/RECENT.2024.74.190

Research on the Influence of Heat Treatment Parameters on the Properties of 6000 Series Al Alloys

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Abstract
6000 Series Al alloys are aluminium alloys with magnesium and silicon exhibiting high formability and excellent weldability, making them suitable for a wide range of applications. Due to its versatile characteristics, the 6082 aluminium alloy continues to be preferred in applications requiring balance between weight, strength and durability. Thus, this alloy remains an important pillar in the development of modern and sustainable technologies, contributing to innovations in the field of engineering and construction. The connection between the properties of the 6082 aluminium alloy and the heat treatments is essential to maximise its performance. This synergy between properties and heat treatments defines its use in demanding environments. The connection between the hardness of the 6082 aluminium alloy and the heat treatments is fundamental for achieving optimal performance in industrial applications. Hardness is an essential characteristic, influencing the resistance to wear, the behaviour under mechanical stress and the durability of the components.

Keywords
aluminium alloy, treatment parameters, hardness

1. Introduction

The 6082 aluminium alloy is one of the most widely used alloys in the industry due to its outstanding combination of mechanical properties, corrosion resistance and versatility [1]. Among its notable properties is its high tensile strength, making it ideal for use in mechanically stressed structures. The alloy also exhibits good fatigue resistance, making it suitable for components that bear varying loads over a long period of time. Another important advantage of the 6082 alloy is its corrosion resistance, providing increased durability in wet or corrosive environments [2, 4, 5].

To improve its performance, it can undergo specific heat treatments, such as solution immersion quenching and ageing, which have a significant impact on its hardness. During solution immersion quenching, the alloy is heated to a high temperature to dissolve the intermetallic compounds. This is followed by rapid cooling, which "freezes" the structure in its supersaturated state, creating a matrix that can later be ageing hardened by compound precipitation [3].

This stage allows the formation of fine particles which disperse in the aluminium matrix, contributing significantly to the increase in hardness. Thus, the hardness of the 6082 alloy can be increased from its initial state to significantly higher values, making it ideal for applications that require increased wear resistance [6].

2. Experimental research

The aim of the research was to study the influence of heat treatment parameters on the possibility of improving the hardness of 6082 alloys.

The 6082 aluminium alloy was used to carry out the experimental research, and its chemical composition according to EN-AW-6082 Si1MgMn is presented in Table 1.

Table 1. Chemical composition [%] according to EN-AW-6082 Si1MgMn [7]

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	Al
0.7-1.3	<=0.5	<=0.10	0.4-1.0	0.6-1.2	<=0.255	<=0.20	<=0.10	0.05	residue

The samples subjected to heat treatment were cut from a 50 mm thick plate whose determined chemical composition is presented in Table 2.

Table 2. Determined chemical composition

Material	State	Chemical composition [%]								
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ni	Ti
6082	T651	1.13	0.37	0.09	0.65	1.01	0.13	0.09	0.01	0.03

The cut samples were 15×15×20 mm. They were divided into three batches with different heat treatment temperatures and times.

The heat treatment programme is presented in Table 3.

Table 3. Applied heat treatments

Material	Heat treatment			Brinell Hardness [HB]
	Quenching temperature [°C]	Ageing temperature [°C]	Holding time [h]	
6082	530	150	0.5	66.2
		170		62.9
		190		62.4
	540	150	0.5	74
		170		83.3
		190		70.2
	550	150	0.5	90.7
		170		91.7
		190		104

Figure 1 shows the evolution in degrees of the hardness depending on the applied heat treatment.

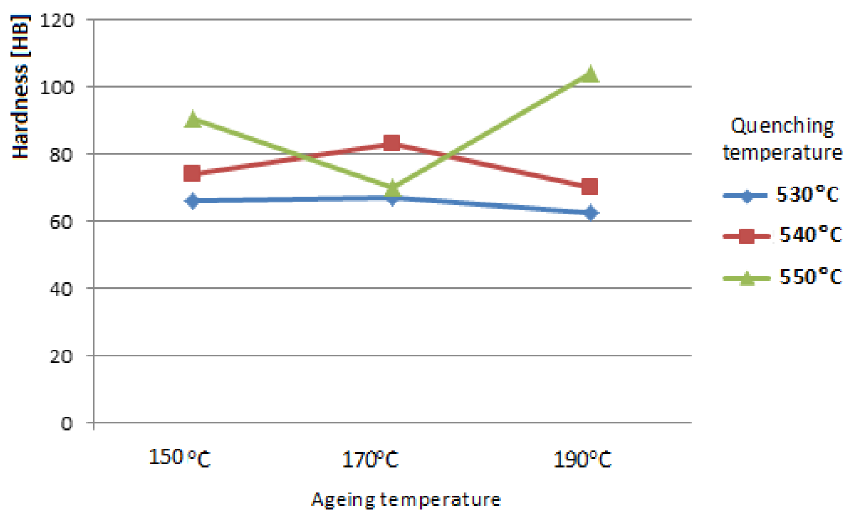


Fig. 1. Hardness variation

There was found that the hardness values of the samples quenched at 530 °C are approximately linear regardless of the ageing temperature and below the value provided by the national standard, which is explainable as this temperature is below the one recommended for the quenching of these alloys.

For the samples quenched at 540 °C, the maximum hardness value is obtained after ageing at 170 °C – a temperature slightly lower than the one recommended by the standards in force, which provide a temperature of 177 °C for ageing – a value which complies with the requirements of the national standard.

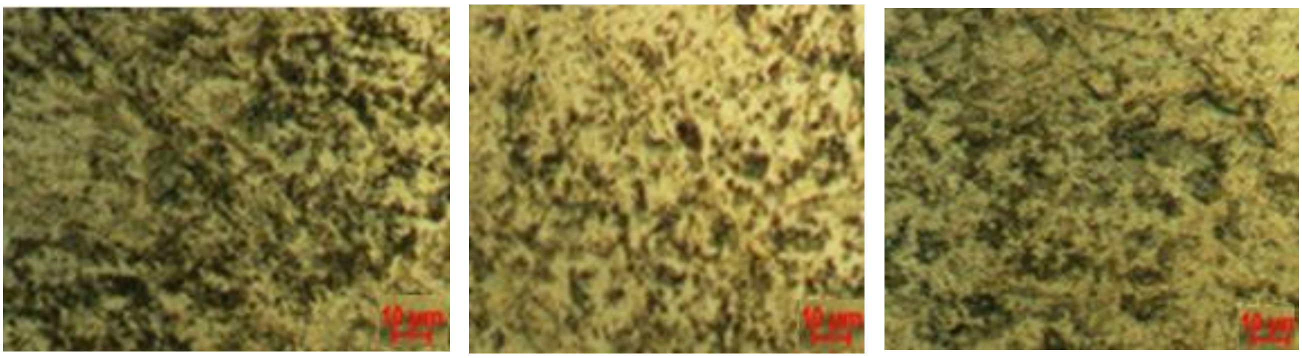
By increasing the quenching temperature to 550 °C – above the temperature recommended by the standard (540 °C) – hardness increases relatively significantly for all applied ageing options – the maximum being reached for an ageing at 190 °C.

There should be noted that the ageing holding time in all cases was of 30 minutes.

In conclusion, heat treatments are crucial for optimising the hardness of the 6082 aluminium alloy. By carefully controlling the quenching and ageing processes, there can be obtained hardness values that significantly improve its performance, adapting it for applications that require increased strength. This interdependence between heat treatments and hardness makes the 6082 alloy a valuable material in various industries.

The quenching and ageing of the 6082 aluminium alloy involves several phases that influence its structure and properties. These processes are essential for optimising mechanical characteristics such as strength, hardness and ductility.

Figure 2 shows some structures obtained following heat treatments as examples.



Quenching at 530 °C/water Ageing at 170 °C/30 min/air. HF etching. 50x

Quenching at 540 °C/water Ageing at 170 °C/30 min/air. HF etching. 50x

Quenching at 550 °C/water Ageing at 170 °C/30 min/air. HF etching. 50x

Fig. 2. Structures obtained following a heat treatment

In the first phase, the 6082 alloy is heated to a specific temperature to allow the intermetallic compounds formed by silicon and magnesium to dissolve in the aluminium matrix. This leads to the formation of a solid solution which is then rapidly cooled stabilising the solid compounds and preventing the formation of uncontrolled phases.

Afterwards, the material is subjected to artificial ageing. This stage allows the formation of fine precipitate particles (usually Mg2Si), which disperse uniformly in the aluminium matrix. These precipitates contribute to the increase in hardness and tensile strength of the alloy.

As the ageing time increases, the precipitate particles increase in size through coalescence. This phase can negatively influence hardness, as larger precipitates become less effective in preventing the movement of dislocations. Time and temperature control in this phase is essential to maintain the desired properties.

3. Conclusions

An analysis of the hardness values after the application of heat treatments reveals the following developments:

- the temperature and duration of the heat treatment directly influence the hardness. If the temperature is too high or the treatment time is too long, the hardness can decrease due to the coalescence of intermetallic particles. Therefore, the precise control of these parameters is essential to maximise hardness and other mechanical properties;
- the high hardness of the 6082 alloy, obtained through heat treatments, makes it suitable for industrial uses;
- the average hardness of samples heat-treated at 530 °C for 30 minutes and subsequently subjected to the ageing process for 30 minutes varies between 62.4 and 66.2 [HB]. This indicates a relatively constant hardness in this configuration.
- when the quenching temperature is increased to 540 °C and the ageing holding time is of 30 minutes, the hardness varies between 70.2 and 83.3 [HB].

- at a heat treatment temperature of 550 °C, the average hardness varies between 90.7 and 104 [HB].
- the data obtained reveals that the hardness of the alloys is influenced by the quenching and ageing temperature, as the holding time is the same for the studied cases. The hardness variation can be used to adjust the properties of aluminium alloys according to specific requirements.

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