Influence of Technological Parameters on Ageing of Aluminium Alloy AW-2024

Jiri Sobotka, Pavel Solfronk, Michaela Kolnerova, David Korecek
Faculty of Mechanical Engineering, Technical University of Liberec. Studentská 1402/2, 461 17 Liberec
Czech Republic. E-mail: jiri.sobotka@tul.cz, pavel.solfronk@tul.cz, michaela.kolnerova@tul.cz, david.korecek@tul.cz

Right after the ferrous alloys, aluminium alloys represent the most wide spread used constructional materials of these days. The main reason of such utilization rests mainly in their specific weight, availability, good mechanical properties and corrosion resistance. To enhance their mechanical properties is there, at majority of technically used aluminium alloys, applied thermal treatment. Wrought aluminium alloys are generally processed after the solution annealing and before their natural or artificial hardening. However, in light of the formability is the own ageing process quite undesirable due to strong decrease of the material formability properties. In this paper is evaluated the time change of the aluminium alloy AW-2024 mechanical properties after the solution annealing in dependence on different storage time before forming. Such change of the mechanical properties was evaluated by means of the static tensile test.

Keywords: Aluminium Alloy AW-2024, Hardening, Solution Heat Treatment, Static Tensile Test, Formability

1 Introduction

Aluminium alloys of series 2000 represent quite interesting materials where copper and magnesium are the major alloying elements. These materials are widely used in many industries – including e.g. aerospace applications [1, 2]. Regarding their mechanical properties, these aluminium alloys are age-hardenable (mostly by natural ageing) and this material ability is very often used to achieve required mechanical properties [3, 4]. There are a lot of specifications, which pose quite strong requirements about their processing – mainly in light of processing times after heat treatment (mainly solution heat treatment) and quenching. Generally stated, there is presumption about strong increase of strength properties and decrease of ductility properties [5]. And just adequacy of some specifications was a topic of this paper.

The major aim of this paper was to evaluate influence of two different approaches during processing the aluminium alloy AW-2024 (thickness 2,010 mm). Firstly was evaluated processing time after solution heat treatment (SHT) and quenching and used times were as following: 5 min, 1 Hr, 2 Hrs, 5 Hrs, 9 Hrs and 24 Hrs. As a reason for such testing there was reality that in many aluminium processing companies exist specifications to process these aluminium alloys within 15 min after SHT and quenching. There is also mentioned that material can be leave in the freezer under -15°C, but not longer than 75 Hrs. And just this requirement (time in freezer) was used as the second tested influence.

Thus as a "boundaries" of mechanical properties in the case of aluminium alloys there are two totally different processing approach. Firstly there is processing of material right after solution heat treatment (SHT) and quenching and secondly there is processing of material after ageing. In Tab. 1 are summarized results from static tensile test right for these two limits. Mechanical properties measured just after SHT and quenching are in Tab. 1 taken as 100% and data measured from material after ageing (1 month) are compared to this base. Note that strength properties revealed quite a strong increase, but on the other hand ductility properties decreased much smaller than was expected. Graphically are these results in the form of engineering stress-strain curves shown in Fig. 2. In chap. 2 is subsequently evaluated the influence of processing time on the mechanical properties of tested aluminium alloy AW-2024.

Tab. 1 *Basic mechanical properties of tested aluminium alloy AW-2024 for different states of basic material (BM)*

Alluminium alloy AW-2024	**Strength properties**		**Formability properties**	
Basic mechanical properties and testing conditions for basic material	Proof yield strength $R_{p0.2}$ [MPa]	Ultimate strength R_m [MPa]	Uniform ductility A_g [%]	Total ductility A_{80mm} [%]
Right after SHT and quenching (within 5 min)	**129.6**	**327.8**	**17.23**	**17.36**
	100 %	100 %	100 %	100 %
After ageing (after 1 month)	**337.7**	**463.8**	**14.21**	**14.67**
	+160.6 %	+41.5 %	-17.5 %	-15.5 %

2 Influence of processing time after solution heat treatment (SHT) and quenching

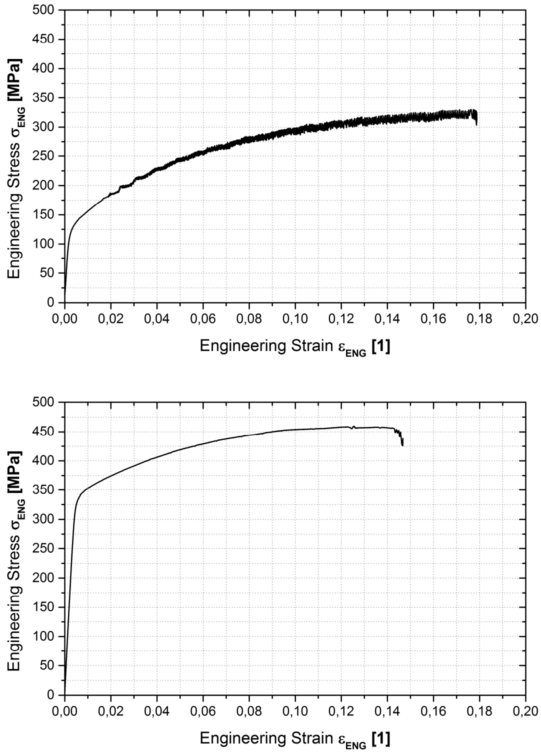

***Fig. 1** Engineering stress-strain curves of AW-2024 right after SHT and quenching (left) and after ageing (right)*

The first aim of this paper was to determine whether the requirement about fast processing time (from 30 min up to 2 Hrs) after solution heat treatment (SHT) and quenching isn´t too strict. That´s why there were used different processing times after SHT and quenching of aluminium alloy AW-2024 to perform static tensile test. Strictly speaking, these were as following: 1 Hr, 2 Hrs, 5 Hrs, 9 Hrs and 24 Hrs (1 day). Moreover, there were measured required mechanical properties right after SHT and quenching (within 5 min) and after long-term ageing (1 month) – see Fig. 1.

In Fig. 1 is demonstrated quite very interesting comparison – there are shown engineering stress-strain curves both for material right after SHT and quenching (Fig. 1 – left) and for material after ageing (Fig. 1 – right). Already just from this two curves there is evident a strong influence of ageing on the mechanical properties of aluminium alloy AW-2024. Strength properties changed quite a lot ($R_{p0.2}$ by 160.6% and R_m by 41.5%), but on the other hand formability properties didn´t decrease so much (approx. by 17%). However, the aim of this experimental part was to determine whether it is truly necessary to process tested aluminium alloy within 2 Hrs (in some specifications is even written 30 min) after SHT and quenching. According to expectations, all other engineering stress-strain curves from every applied processing times (1 Hr, 2 Hrs, 5 Hrs, 9 Hrs and 24 Hrs) should be found between curves shown in Fig. 1.

In Tab. 2 are summarized all major results determined by static tensile test in dependence on different processing times. There are written not only measured values, but also differences (in percentages) between used processing times where as 100% are always taken values measured 1 Hr after SHT and quenching. Already from these values is again obvious fact that there is a great change of strength properties in dependence on different processing times, but there is much lower change of formability properties. Moreover, in one case revealed the longer processing time even higher magnitude of total ductility than in the previous processing time (5 Hrs and 2 Hrs). Graphically are these results digestedly shown on the following page (Fig. 2 and Fig. 3).

***Tab. 2** Basic mechanical properties of tested aluminium alloy AW-2024 in dependence on different processing times*

Basic mechanical properties		**Processing time [Hrs]** (after solution heat treatment and quenching)				
		1 Hr	**2 Hrs**	**5 Hrs**	**9 Hrs**	**24 Hrs**
Proof yield strength	$R_{p0.2}$ [MPa]	**130.9**	**137.1**	**171.3**	**216.9**	**244.5**
		100 %	+ 4.7 %	+ 30.9 %	+ 65.7 %	+ 86.8 %
Ultimate strength	R_m [MPa]	**332.4**	**337.2**	**355.4**	**397.6**	**416.7**
		100 %	+ 1.4 %	+ 6.9 %	+ 19.6 %	+ 25.4 %
Uniform ductility	A_g [%]	**17.14**	**16.54**	**15.47**	**15.23**	**14.96**
		100 %	- 3.5 %	- 9.7 %	- 11.1 %	- 12.7 %
Total ductility	A_{80mm} [%]	**17.28**	**16.76**	**15.92**	**16.27**	**15.63**
		100 %	- 3.0 %	- 7.9 %	- 5.8 %	- 9.5 %

Stress-strain curves for all tested processing times are graphically shown in Fig. 2. There is clearly evident gradual ageing of tested material. This reality can be proved not only due to the achieved values, but also due to own shape of these curves. Note that so-called Lüders bands gradually disappeared as processing times increased (thus also ageing).

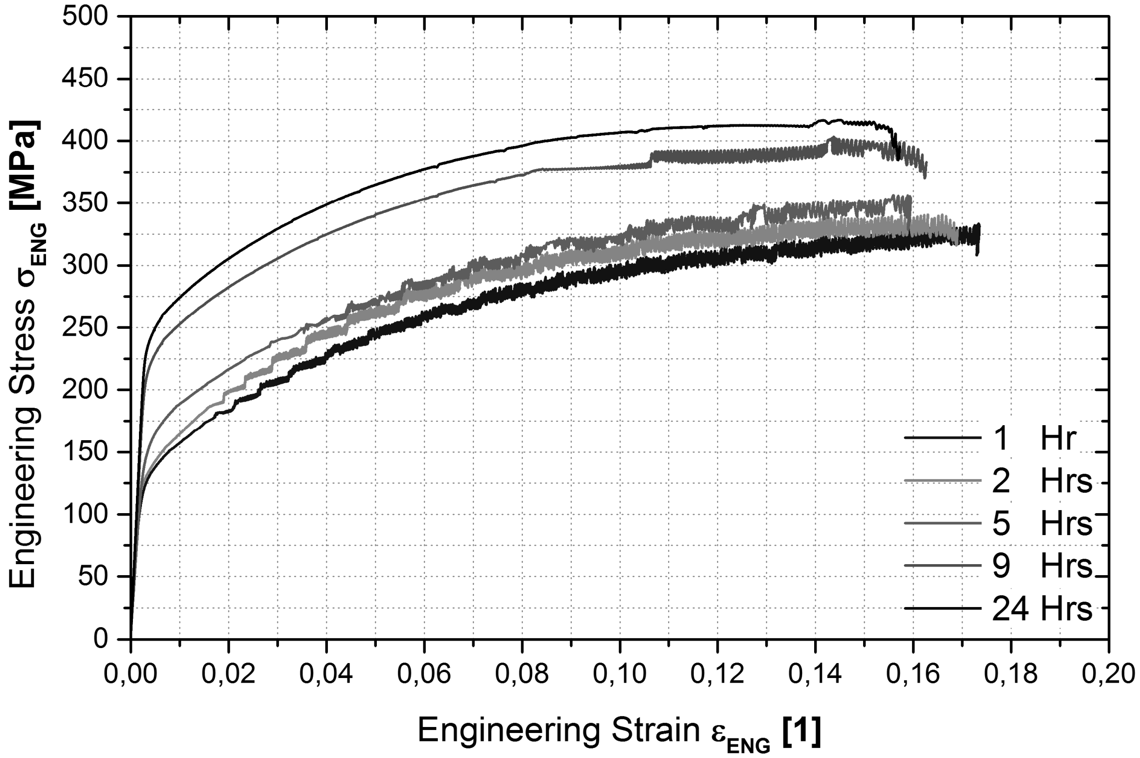

Fig. 2 *Engineering stress-strain curves for all tested processing times (1 Hr, 2 Hrs, 5 Hrs, 9 Hrs and 24 Hrs)*

All-important results concerning influence of processing times after SHT and quenching on the basic mechanical properties are digestedly summarized in Fig. 3. Strength properties (yield and ultimate strength) are continuously increasing. On the hand, in light of formability properties (uniform and total ductility) is such change quite very small (cca. 3,5 % for each processing time) – much smaller than there was expected.

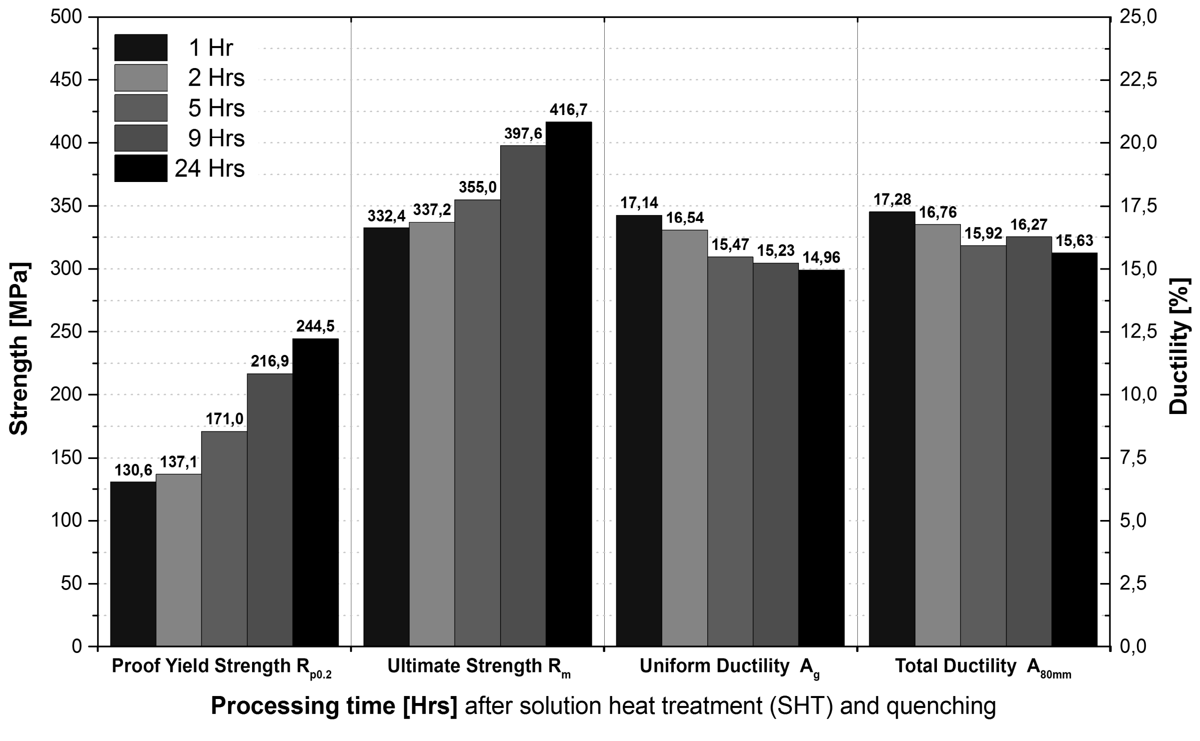

Fig. 3 *Processing times vs basic mechanical properties of tested aluminium alloy AW-2024*

3 Influence of time in freezer after solution heat treatment (SHT) and quenching

As the 2nd testing parameter, which can influence the final mechanical properties of AW-2024, there was time in freezer (after previous SHT and quenching). In this case, samples were placed in the freezer under temperature -15°C and after lapse of tested time (72 Hrs, 120 Hrs, 168 Hrs and 240 Hrs) were immediately measured. Many companies have an internal standard which set the maximal time in freezer as 75 Hrs (here the 1st used one). However, in this paper were used much larger time delay in the freezer – the maximal used one (240 Hrs) is more than 3-times higher than maximal time in freezer, which is commonly used in factories (72 Hrs).

In Fig. 4 are subsequently shown the stress-strain curves for all used times. There was not possible to place all of them in one graph, because they are very similar to each other. Neverthless, already from the graphical comparison is evident that there isn´t almost any influence on the final shape (and thus measured mechanical properties) of these curves. Note especially that shape, which doesn´t prove any influence of ageing under any time in freezer.

All tested basic mechanical properties (both strength and formability properties) in dependence on time in freezer are summarized in Tab. 3. There wasn´t proved almost any influence of time in freezer which can result as ageing of tested aluminium alloy AW-2024. Moreover, in some case were results a little bit better with increasing time in freezer. Nevertheless, such differences were primary given just from statistical evaluation of measured data. That is why in this table are not added differences in percentages, because it is not important in this case. On the next page are these data (both chosen stress-strain curves and mechanical properties) given again in the form of line and column graph.

More detailed stress-strain curves just for chosen times in freezer (72 Hrs and 240 Hrs) are shown in Fig. 5. As it was already proved by Tab. 3, there aren´t almost any changes in the basic mechanical properties. In Fig. 5 is shown the maximal tested time difference and it can be seen that both curves are almost the same.

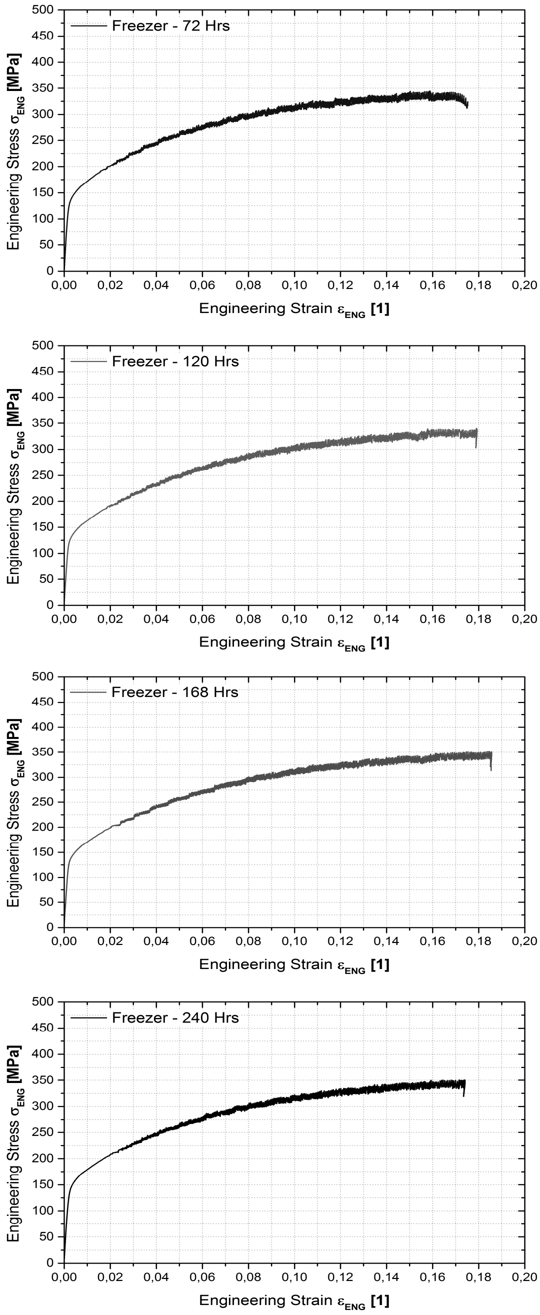

Fig. 4 *Engineering stress-strain curves for all tested times in freezer (72 Hrs, 120 Hrs, 168 Hrs and 240 Hrs)*

Tab. 3 *Basic mechanical properties of tested aluminium alloy AW-2024 in dependence on time in freezer*

Basic mechanical properties		**Time in freezer [Hrs]** (and subsequent immediate processing)			
		72 Hrs (3 days)	**120 Hrs** (5 days)	**168 Hrs** (7 days)	**240 Hrs** (10 days)
Proof yield strength	$R_{p0.2}$ [MPa]	**141.2**	**138.3**	**145.3**	**148.1**
Ultimate strength	R_m [MPa]	**342.6**	**341.9**	**349.3**	**349.6**
Uniform ductility	A_g [%]	**17.23**	**17.55**	**17.92**	**17.35**
Total ductility	A_{80mm} [%]	**17.52**	**17.61**	**18.42**	**17.49**

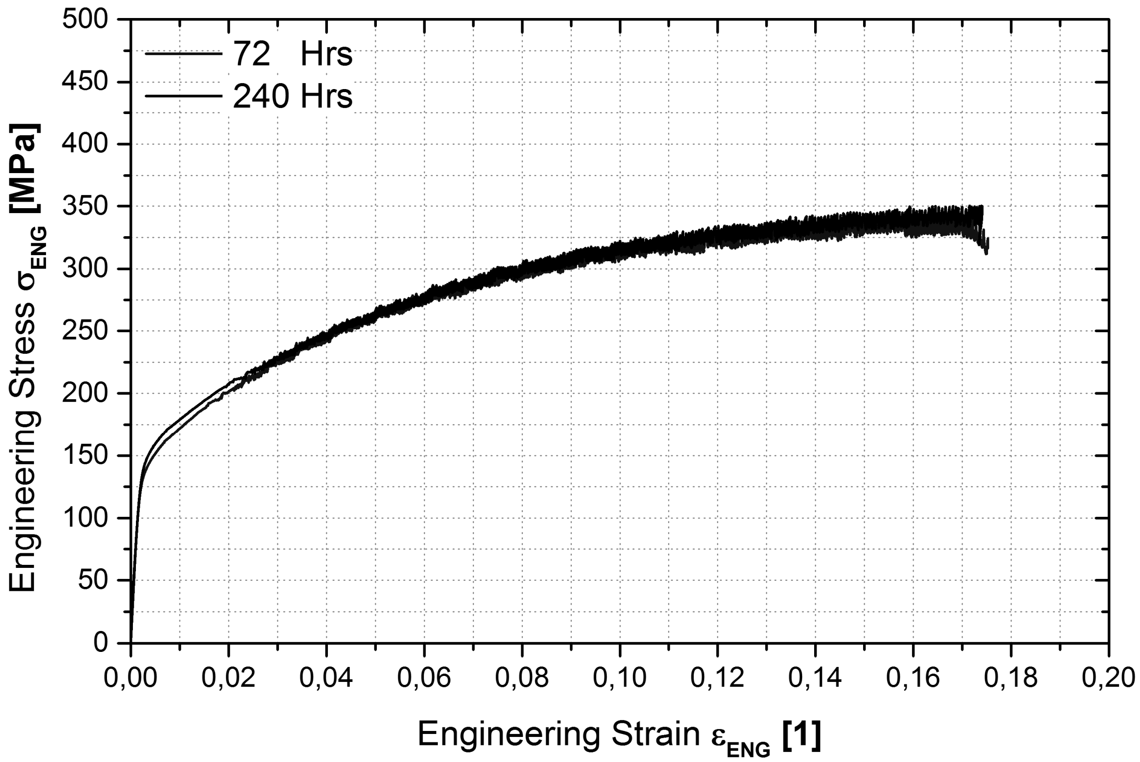

Fig. 5 *More detailed engineering stress-strain curves for chosen times in freezer (72 Hrs and 240 Hrs)*

Again, all important results concerning influence of time in freezer on the basic mechanical properties are given in Fig. 6. Note that all used columns graphs are within the given mechanical property almost “constant”. The maximal time difference in this case was 7 days (10 and 3 days) – it means more than 3-times higher than it is required by the standard. Finally, there can be stated that in light of time in freezer, there isn´t almost any influence on tested material.

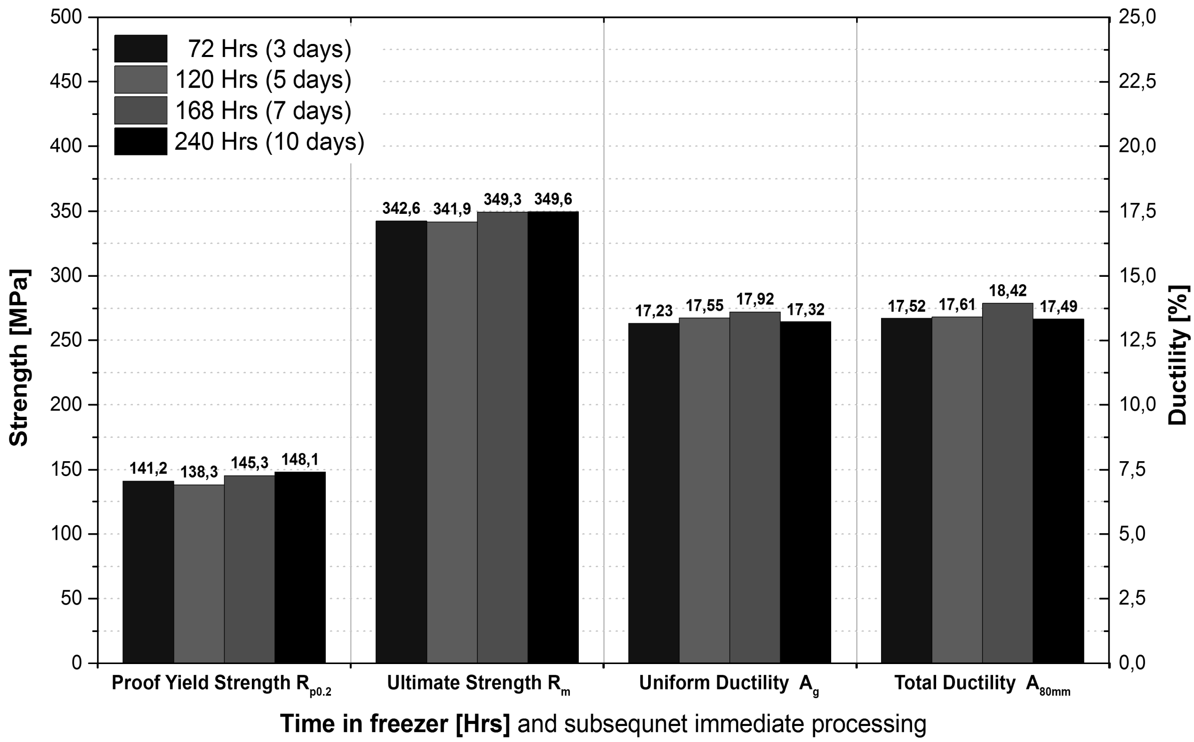

Fig. 6 *Time in freezer vs basic mechanical properties of tested aluminium alloy AW-2024*

4 Conclusion

Some requirements seem to be very strict about processing of materials. In this paper was tested aluminium alloy of 2000 series AW-2024 in light of processing times (after SHT and quenching) and time in freezer to verify such opinion.

In Fig. 7 are graphically illustrated both objects (influence of processing time and time in freezer). There are shown material properties in dependence on both processing time (1 Hr and 2 Hrs after solution heat treatment and quenching) and time in freezer (72 Hrs and 240 Hrs). Just for comparison are there also shown results for tested aluminium alloy AW-2024 after ageing (1 month). Major conclusions arising from these results can be summarized as following: in light of processing time there is its strong influence on the strength properties, but almost no influence on the formability properties and in light of time in freezer there isn´t almost any influence on all observed properties. Generally stated, commonly used specifications can be taken as feasible with respect to processing time and strength properties, but not so adequate in light of formability properties of AW-2024. Moreover, there isn´t almost any reason to follow strict requirements (processing after max 72 Hrs in freezer) regarding time in freezer.

Nevertheless, in this paper was measured only one aluminium alloy (AW-2024) under chosen technological parameters. There have to be perform more tests to verify these first results and also to make them more universal by testing also other wrought aluminium alloys - both in 2000 series and e.g. in 7000 series.

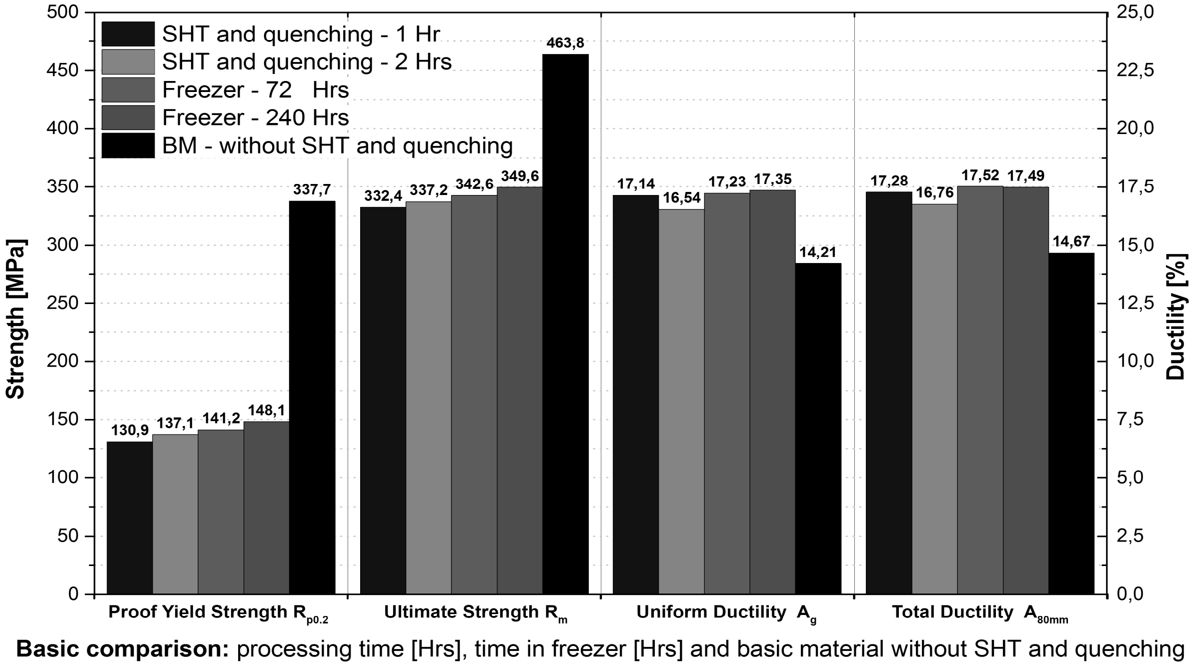

***Fig.** 7 Final graphical comparison of the most important results*

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