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Influence of Remelting AlSi9Cu3 Alloy with Higher Iron Content on Mechanical Properties

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Abstract

The paper deals with influence of multiple remelting on AlSi9Cu3 alloy with higher iron content on chosen mechanical properties. Multiple remelting may in various ways influence mechanical, foundry properties, gas saturation, shrinkage cavity, fluidity etc. of alloy. Higher presence of iron in Al-Si cast alloys is common problem mainly in secondary (recycled) aluminium alloys. In Al-Si alloy the iron is the most common impurity and with presence of other elements in alloy creates the intermetallic compounds, which decreases mechanical properties. Iron in the used alloy was increased to about 1.4 wt. %, so that the influence of increased iron content can be investigated. In the paper, the effect of multiple remelting is evaluated with respect to the resulting mechanical properties in cast state, after the heat treatment (T5) and after natural aging. From the obtained results it can be concluded that the multiple remelting leads to change of chemical composition and affect the mechanical properties.

Keywords: Al-Si-Cu, Remelting, Mechanical Properties, Heat treatment

1. Introduction

Aluminum alloys (Al-Si-Cu) are used to produce castings for the automotive and aerospace industries. The reason for their use is the low weight and good mechanical properties of the resulting components. Especially for the automotive industry is required to reduce the castings production costs. One possibility to achieve this goal is to use secondary alloys. Secondary alloys, in addition to economic benefits, are more energy efficient compared to production of primary aluminum. When using such alloys, it is necessary to find a compromise between the price and the resulting quality. The quality of the secondary alloy made from recycled materials can be affected in particular by the increased iron content. Our scientific team at technological engineering has been engaged in for several years studying the issue of increased iron content and its adverse effect.

Recycled or multiple remelted alloys are common materials used in foundry. It is a returnable material or technological scrap from foundry (gating systems, risers, ingots, etc.), which is used as a batch material to reduce costs. Often, when using such a material, it is not known or cannot be accurately determined how many times the material is remelted. This involves the changes of hereditary properties, which can vary from the number of individual remelts. The reason for examining the impact of multiple remelting is how they can affect mechanical characteristics and foundry properties, gas saturation, shrinkage, fluidity etc. [1-3].

Iron with other elements occurs in the form of various intermetallic phases, which have a negative effect on mechanical properties. In Al-Si-Fe-Cu alloys can be found in the form of Al_3Fe, Al_7FeCu_2, Al_8Fe_2Si, Al_5FeSi phases. These iron-based intermetallic phases reduce the tensile strength and elongation of alloys because are formed during solidification of the eutectic and can affect the fluidity and support porosity. Even the low content of iron in the alloy has an effect on ductility due to the exclusion of β-Al5FeSi phase, which is considered to be the most observed iron-based intermetallic phase in Al-Si alloys in the form of separately excluded needles of different lengths. These needles are often initiators of tension, resulting in tearing caused by the brittleness of the needles themselves.

Al-Si-Cu alloys belong to the heat treatable because intermetallic Al_2Cu phases can form, which allow hardening process. The aim of aging is to dissolve the phases again into the homogeneous solution α (Al) and their subsequent exclusion in the form of coherent or semicoherent formations, which increase the strength and hardness. This dissolution usually starts spontaneously at an ambient temperature immediately after cooling [4-6].

2. Materials and experiments procedure

The experiments were carried out in the foundry laboratory at the Department of Technological engineering - University of Zilina. As the experimental material was used foundry alloy AlSi9Cu3. Chemical composition with selected elements of the alloy is listed in Table 1.

The iron content of the AlSi9Cu3 alloy is approximately 1.08 wt. %. For further work, the iron content was increased to the level about 1.4 wt. %, so that the effect of increased iron content in multiple remelting could be investigated. Alloy was deliberately "polluted" by the master alloy AlFe10 at a temperature of 750 ± 5 °C. The chemical composition of alloy with higher iron content is shown in Tab. 2. For the experimental work was used 100 kg of alloy and melting process was carried out in in an electric resistance furnace. The alloy was subjected to multiple remelting. The process of remelting consisted of pouring ingots into prepared metal molds. After solidification and cooling, these ingots were used as batch for further melting without additional components addition. This process was repeated 6 times. Samples for mechanical properties were poured from the first melt (D1 as the reference sample) and from each second melt (D3, D5, D7), 12 pieces into a metal mold with a minimum temperature of 100 ± 5 °C and the casting temperature was in the range of 750 to 770 °C. The melt was not further modified, grain refined or purified. Before pouring, only oxide films on the surface of the melt were removed.

Table 1.
Chemical composition of the AlSi9Cu3 alloy

Elements	Si	Fe	Cu	Mn	Mg
(wt. %)	9,559	1,081	1,893	0,184	0,426
Elements	Ni	Zn	Ti	Cr	Al
(wt. %)	0,092	1,160	0,038	0,027	85,46

Table 2.
Chemical composition of the AlSi9Cu3 alloy after addition of Fe

Elements	Si	Fe	Cu	Mn	Mg
(wt. %)	9,347	1,416	1,741	0,178	0,427
Elements	Ni	Zn	Ti	Cr	Al
(wt. %)	0,094	1,162	0,034	0,025	85,50

3. Results

3.1. Evaluation of chemical composition

During multiple remelting, the chemical composition may be changed due to the burning process of certain elements. Changing the chemical composition has a significant effect on mechanical properties. To determine the chemical composition was used a spectral analysis. In Fig. 1 the graph shows the relationship between wt. % of iron and cast number. The graph shows a significantly increased iron content from 1.416 wt. % to 1.889 wt. %, an increase of approximately 25 %. Significant increase in wt. % may also be observed at chromium (Fig. 2), where for melt D7 grew by about 24% compared with melt D1. Both of the monitored elements create phases, which coarse by the number of remelting and on the examined sample create large flat formations, which this way affects wt. % monitored element.

Conversely, the influence of remelting causes decrease wt. % of magnesium and partly copper due to the burning off. In spite expectation of the higher burning off proces, the magnesium content dropped only 6.5% in the melt D7 (Fig. 3) and copper approximate by 6.2% (Fig.4) compared to the melt D1. Based on the results of the spectral analysis, it can be concluded that the manganese content (Fig. 5) and silicon (Fig. 6) are relatively stable after multiple remelting and no burning off occurs. In the graphs (Figures 1 to 6), the red line shows the maximum and yellow line show the minimum allowed amount of element in the AlSi9Cu3 alloy according to EN 1706. Due to remelting, the chemical composition changes but still remains within the allowed intervals of standards. The exception is copper, which already has a minor wt. % in the basic alloy, as specified by the standard.

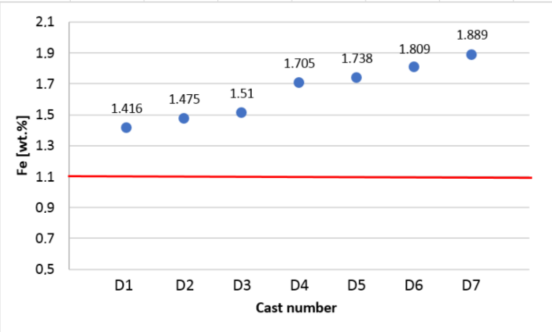


Fig. 1. Relationship between iron and melt number

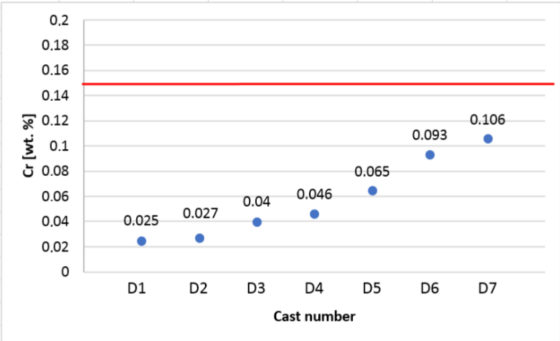


Fig. 2. Relationship between chrome and melt number

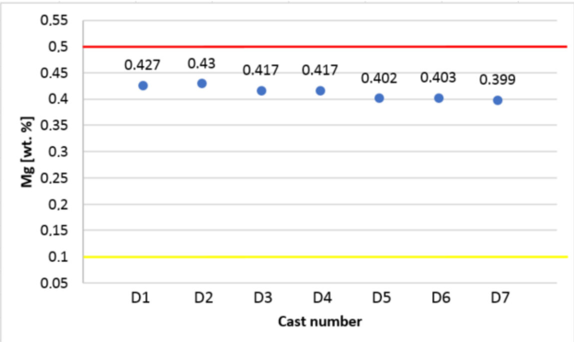


Fig. 3. Relationship between magnesium and melt number

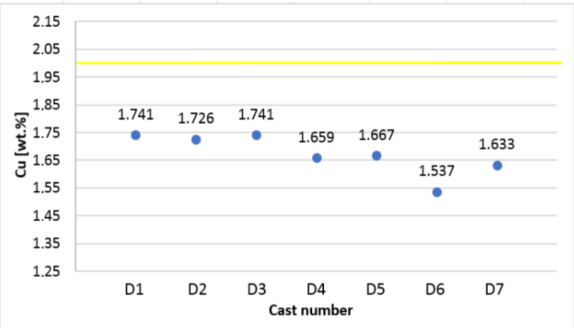


Fig. 4. Relationship between copper and melt number

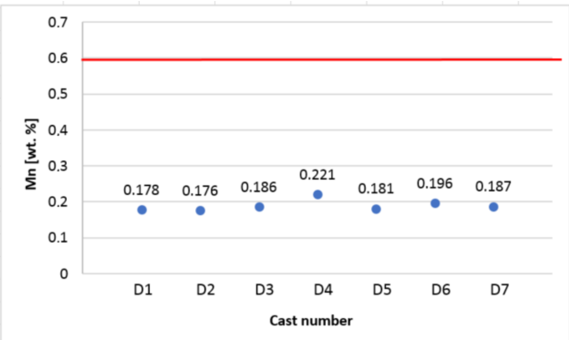


Fig. 5. Relationship between manganese and melt number

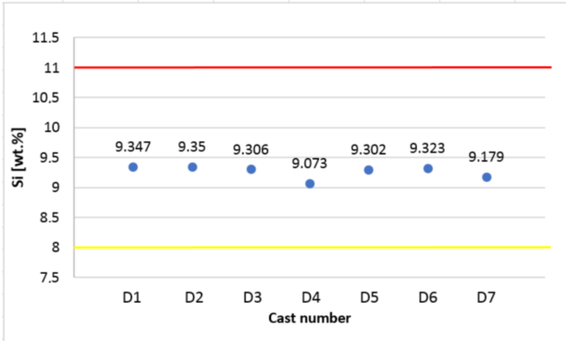


Fig. 6. Relationship between silicon and melt number

With increasing iron and chromium content due to remelting, it is likely that alloys with higher numbers of remelting will begin to appear sludge formations called "sludge" phases. How much of these particles will depend, in particular, on the amount of iron, chromium, manganese, which gives the called sludge factor:

$$SF = [\% Fe] + 2 \, . \, [\% Mn] + 3 \, . \, [\% Cr] \qquad (1)$$

The results of the calculation (1) of the sludge factor in dependent of the number of remelting are shown in Tab. 3

Table 3.
Relationship between sludge factor (SF) and cast number (CN)

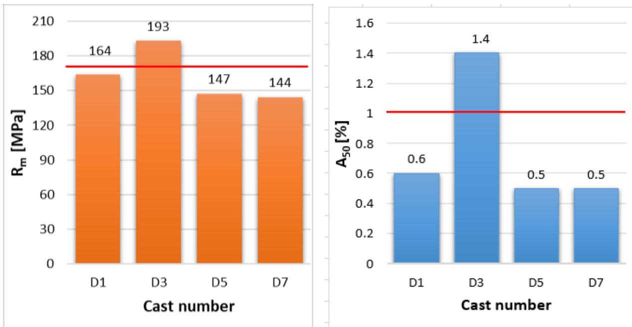
CN	D1	D2	D3	D4	D5	D6	D7
SF	1.847	1.91	2.002	2.285	2.295	2.48	2.89

3.2. Mechanical properties

Test samples for mechanical properties have been prepared for the tensile testing according to STN EN ISO 6892-1 and for Brinell hardness measurement according to STN EN ISO 6506. The tensile test was performed on a tensile machine WDW 20 ranging from 0-20 kN at a temperature of 22 °C. AlSi9Cu3 alloy belongs to heat-treatable and also to self-hardenable alloys. Heat treatment (T5) for this alloy consists of artificially aging at 200 ± 5 °C for 4 hours and cooling in water. The four bars were subjected to the tensile test after natural aging (about 160 hours at 20 °C) and the four bars were subjected to the test in a cast state, when no heat treatment was performed on them. The dependence of tensile strength (R_m) and hardness (A_{50}) on the number of remelting determines the average value of the four test bars.

Cast state

Fig. 7a shows the dependence of the tensile strength (R_m) in the casted state from the number of remelting. The highest tensile strength of 193 MPa was measured at melt D3. Influence of further remelting tensile strength dropped and the minimum value was reached at melt D7 (R_m = 144 MPa), which represents a decrease of 25 %. Fig. 7b shows the dependence of the elongation in the casted state from the number of remelting. The highest elongation was achieved again at melt D3 (A_{50} = 1.42%) and the lowest for melting D5 and D7 (A_{50} = 0,5). The red line in the graphs (Fig. 9 to 10) represents the minimum required value of alloys in casted state with a similar chemical composition in according with EN 1706.



a) b)

Fig. 7. Cast state: a) Relationship between tensile strength and melt number, b) Relationship between elongation and cast number

The effect of multiple remelting on Brinell hardness for samples in cast state is shown in Fig. 8. The AlSi9Cu3 alloy after the 1st melt (D1) shows HBW = 93, a similar hardness was measured for melt D7 and HBW = 94. The lowest measured value of HBW = 84 was at 3rd melt (D3).

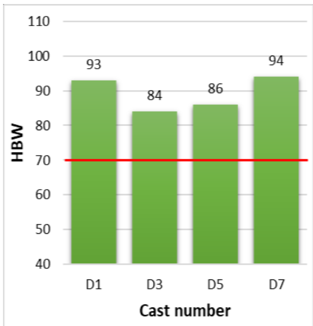
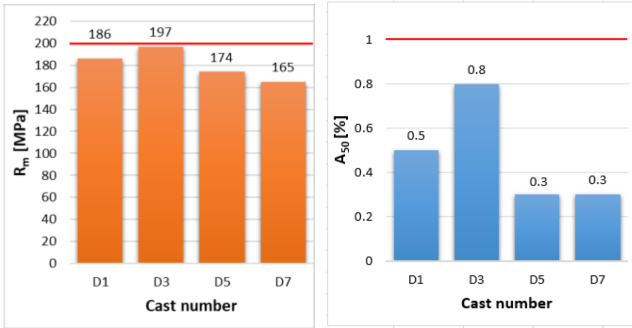


Fig. 8. Cast state: Relationship between Brinell hardness and melt number

Artificially aged (T5)

Measured values of tensile strength after artificial aging depending on the number of remelting are demonstrates in Fig. 9a. The maximum value was measured for sample D3 (R_m = 197 MPa). The sample of melt D1 reached R_m = 186 MPa and the minimum tensile strength after artificial aging was measured for sample D7 (R_m = 165 MPa). The results of the elongation after the heat treatment in dependence on the number of remelting are shown in FIG. 9b, where the highest value was reached for melt D3 (A_{50} = 0.8%) and the lowest for D5 (A_{50} = 0.3 %) and D7 (A_{50} = 0.3 %). The red line in the graphs (Fig. 9 to 10) represents the minimum required value of alloys after Artificially aged (T5) with a similar chemical composition in according with EN 1706.



a) b)

Fig. 9. Artificially aged: a) Relationship between tensile strength and melt number, b) Relationship between elongation and cast number

Fig. 10 shows the dependence of Brinell hardness on artificially aging from the number of remelting. The AlSi9Cu3 alloy after 1st melt (D1) shows HBW = 97, with subsequent remelting, the hardness dropped slightly to HBW = 90 (D3). A significant change occurred with the melt D5 (HBW = 111) and D7 (HBW = 108).

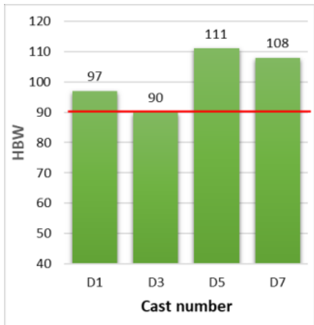


Fig. 10 Artificially aged: Relationship between Brinell hardness and melt number

Naturally aged

In Fig. 11a shows the dependence of the tensile strength (R_m) after naturally aging from the number of remelting. Melt D1 reached R_m = 182 MPa. Tensile strength at alloy after 3rd melt (D3) increased (R_m = 195 MPa). Further remelting was recorded to decrease to R_m = 141 MPa at 7th cast alloy D7. A similar course can also be observed with elongation (Fig.11b), where the highest value was reached for alloy D3 (A_{50} = 1.1 %) and the lowest for D5 (A_{50} = 0.4%) and D7 (A_{50} = 0.4%). The red line in the graphs (Figures 11 to 12) represents the minimum required value in accordance with EN 1706.

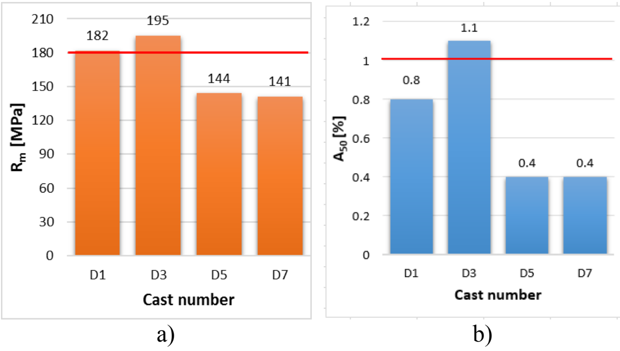


Fig. 11. Naturally aged: a) Relationship between tensile strength and melt number, b) Relationship between elongation and melt number

Fig. 12 it can be seen that the hardness did not change significantly due to the remelting. The maximum value was obtained for sample from melt D1 (HBW = 97) and minimum for sample from melt D3 (HBW = 91), which is only about 6% difference.

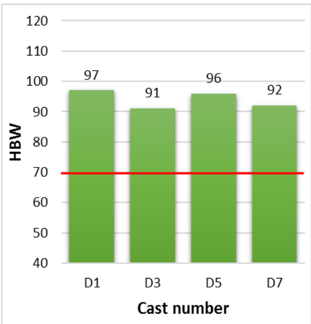


Fig. 12. Naturally aged: Relationship between Brinell hardness and melt number

Comparison of cast state, artificially aging and naturally aging

Tensile strength has the same course at all 3 different states. Maximum values were obtained at alloy after 3th melt (D3). Further remelting tensile strength has decreased and at minimum occurred for alloy after 7th melt (D7), probably due to the fact that in the structure of the alloy D3, the Fe-based phases are in the form of more favourable morphological formations and their size least disturbs the structure compared to the alloys D5 and D7. In Fig. 17, it can be seen that the influence of artificially aging on tensile strength has increased in all four cases compared to the cast state (only slightly in the alloy D3). From Fig. 13 can be also observed to be due to the naturally aging of alloys D1 and D2 there was no significant change in tensile strength compared to artificially aging. Naturally, aging for alloys D5 and D7 is no very effective, and measured values are similar to alloys in casted state.

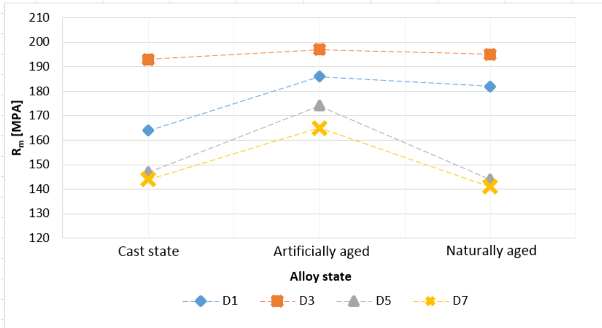


Fig. 13. Relationship between tensile strength and alloy state

As with tensile strength, even at elongations, the maximum values for D3 alloy were reached in all three states. The alloys D5 and D7 showed similar values (in all three states), what representing a minimum. On fig. 14 can be seen that the best values have been achieved by alloys in casted state. After artificial aging minimal decrease in elongations in all cases occurred. As a result of naturally aging a slight increase of elongations was observed compared to artificial aging, but the values as in the casted state have not been reached. Melt D1 achieved the best result after naturally aging.

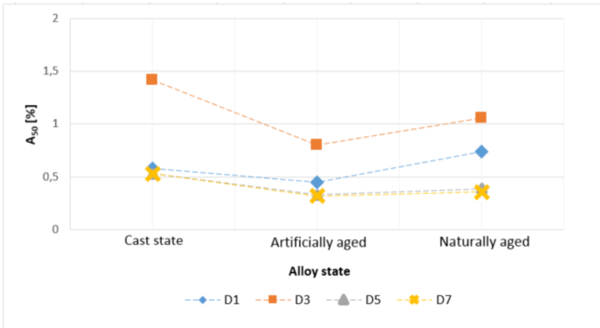


Fig. 14. Relationship between elongation and alloy state

The lowest hardness was measured at alloys in casted state (Fig. 15). After artificially aging for melt D1 and D3, there was a slight increase, and for melts D5 and D7 a rapid increase in hardness. The increase in hardness for melts D5 and D7 may be due to the presence of a large amount of iron phases and possibly also because of sludge phases in the structure (see Tab. 3), that exhibit high hardness. The hardness values of alloys D1 and D3 after naturally aging are almost the same as those after artificially aged, but the melts D5 and D7 shown a decrease. This is likely to be attributed to less effective naturally aging due to burning off Mg and Cu.

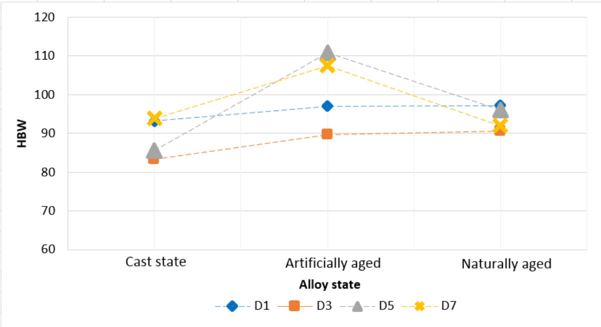


Fig. 15. Relationship between Brinell hardness and alloy state

4. Evaluation of results

Based on the experiments it can be concluded, that due to remelting was changed chemical composition, which is caused burning process of elements (Mg and Cu) and segregate of elements (Fe and Cr) to the bottom of melt because of high specific gravity.

The best results of tensile strength and elongation were achieved at AlSi9Cu3 alloy in cast state after 3th melt (D3) and influence of further remelting have decreased. The use of T5 heat treatment resulted in an increase of tensile strength to a maximum value for all melts. Conversely, the effect of T5 heat treatment on elongation results in a reduction in the resulting values to a minimum. This development can be attributed to the formation of the precipitating phase from the saturated solid solution due to heat treatment, which subsequently hardens the solid solution α, thereby increasing the tensile strength at the expense of the elongation. Tensile strength at melt D1 and D3 after naturally aging reached similar values to those after heat treatment of T5 but for alloys D5 and D7, a significant decrease in tensile strength was noted. Such a process is probably due to the fact that during the 5^{ft} and 7th remelting, magnesium and copper burning off occurs, thereby forming a smaller amount of intermetallic phases (Al_2Cu and Mg_2Si) that hardens the aluminium matrix, respectively iron-based phases were formed. Tensile strength values in accordance with the standard have been achieved for melts D1 and D3 after naturally aging and D3 in the casted state. Elongation in accordance with the standard was achieved only for melt D3 after naturally aging.

From Brinell hardness results, can say that the effect of remelting is changing values alternatively. The best results were obtained after the heat treatment T5 with higher number of remelting (D5 and D7). Also, we can conclude from the results that naturally aging did not greatly affect the resultant hardness. The minimum required value according to the standard exceeded all evaluated alloys. This fact can be attributed to the increased iron content and thus the greater number of iron-based phases occurring in the structure, which achieved higher hardness.

5. Conclusions

The influence of multiple remelting on the mechanical properties of aluminium alloys based on Al-Si-Cu is a complex issue and to better understand it is needed also knowledge of microstructural characteristics. This work, due to limited scope, focuses on mechanical properties and microstructural characteristics will be evaluated in subsequent publications.

From the obtained results, it can be stated that a significant change in mechanical properties occurs at the fourth remelting, when a significant decrease is recorded. At lower amounts of remelting, artificially aging and naturally aging are effective, but with an increasing number of remelting, the effectiveness of naturally aging decreases, and therefore artificially aging is better.

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