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Effect of Melt Holding Time on the As-cast Microstructure and Hardness of Aluminum Alloy 2618

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Abstract. The effects of the melt holding time on the type, quantity and morphological distribution of aluminum alloy 2618 were investigated by means of OM, XRD and SEM. And the influence of the melt holding time on the hardness of alloy was explored. The results show that the heredity of the microstructure of the master alloy is not completely eliminated when the melt holding time is less than 10 min at 740 ℃. And it will make Al9FeNi phase coarse needle-like, and segregate with Al7Cu2Fe phase at the grain boundary or inside the grain. Properly prolonging the melt holding time can change the shape of Al9FeNi phase from coarse needle-like to fine needle-like and make the distribution of Al9FeNi phase and Al7Cu2Fe phase more uniform. Aluminum alloy 2618 was melted at 740 ℃ for 30 min and then poured into graphite molds at room temperature, which can make Al9FeNi phase fine and uniformly distributed in the matrix. With the extension of the melt holding time, the size of the nonequilibrium crystalline phase is basically unchanged, but the grain size will be slightly coarsened. The hardness of the alloy showed a trend of first increasing and then decreasing with the prolongation of the melt holing time within 10~60min, and when the melt was held for 30min, the hardness of the alloy reached the maximum HRB value of Rockwell hardness within the range of this test. The maximum value is 48.62HRB, and the hardness distribution of the alloy is relatively uniform. Therefore, it is beneficial to refine the precipitated phase, reduce the macro segregation, and refine the grain and improve the hardness of the alloy, while alloy 2618 was poured into the graphite casting at room temperature with melting at 740℃ and held for 30min.

Keywords: alloy 2618; graphite mold casting; melt holding time; precipitated phases; hardness.

1. Introduction

With high heat resistance, aluminum alloy 2618 can be used to manufacture aeroengine impeller automobile turbocharger and other parts [1]. The main heat-resistant phases of aluminum alloy 2618 are S(Al2CuMg) and Al9FeNi. However, the melting and casting process in the actual production of aluminum alloy will directly affect the homogeneity of alloy composition. Moreover, it has significant influence on the morphology and distribution of the main strengthening phase. It can even promote the formation of heat-resistant phases such as Al7Cu2Fe, Al3Cu2Fe, AlCuNi or Al3(CuNi)2 and coarse primary crystal phase of Al9FeNi. However, the size and morphology of these refractory phases basically do not change during the subsequent heat treatment. All these will lead to insufficient heat resistance, and eventually lead to deformation in service at high temperature. Therefore, it is necessary to optimize the alloy casting process reasonably, which will improve the morphology and distribution of the main strengthening phase, avoid the formation of non-heat resistant phases, and further improve the high temperature performance of 2618 aluminum alloy. Wang Jianhua et al [2] studied the morphological changes of Al9FeNi phase under different melt overheating conditions. The results showed that the morphology and size of Al9FeNi was severely restricted by the overheating of melt, and the cooling rate played a decisive role in the primary crystal segregation of Al9FeNi. The influence of melting process and holding time on the size and distribution of refractory phases such as Al9FeNi and Al7Cu2Fe in the metal mold casting of aluminum alloy 2618 was explored by Zhu Zhenyu et al [3]. And the results showed that it was beneficial to obtain fine needle-like Al9FeNi, and promote the uniform distribution of refractory phases such as Al9FeNi and Al7Cu2Fe in the alloy matrix, with adjusting melting temperature, holding time and melting process.

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Although many scholars have done a lot of work on the casting process of aluminum alloy 2618, the alloy is prone to cracking in actual production due to coarse grains, uneven microstructure and even coarse crystals. And the heat resistance of the alloy decreases due to the formation of non-heat resistant phases, which eventually leads to deformation and other problems during high temperature service. All these make it difficult for aluminum alloy 2618 to meet the application requirements of national defense industry and military aviation technology. Therefore, this work intends to determine the optimal melt holding time by exploring the influence of melt holding time on the type, morphology and distribution of the precipitated phase in aluminum alloy 2618. And this work will provide technical guidance for the actual production of aluminum alloy 2618.

2. Experiment

Aluminum alloy 2618 was prepared from industrial pure aluminum, pure magnesium, Al-10%Fe and Al-50%Cu. Graphite crucible and well resistance furnace have been adopted as melting equipment. It is necessary to dehumidify the mold before pouring. The alloy 2618 casting rods were obtained by melting at 740℃ for 10 min, 20min, 30min,and 60min respectively, and then pouring into graphite molds at room temperature.

The chemical composition of aluminum alloy 2618 cast was determined by M-5000 direct reading spectrometer. The results showed that Cu (2.2%), Mg (1.41%), Fe (1.12%), Ni (1.07%), Si (0.05%), and the margin was Al. All the specimens of 10mm×10mm×10mm were taken at the same locations of the four experimental alloys via a line-cutting machine. The grain size, microstructure morphology, non-equilibrium crystal phase morphology under different melt holding time were observed and analyzed by using AE2000MET-S6 orthographic microscope and Zeiss sigma500 scanning electron microscope. XRD and EDS were used to characterize the phase of the alloy, and HRS-150 Rockwell hardness tester was used to test the hardness of the alloy specimens.

3. Results and Discussion

3.1 Microstructure and phase analysis of alloy 2618

XRD analysis was conducted on 2618 aluminum alloy with different melt holding time, and the results were shown in Fig.1. It can be seen from the figure that there are α-Al phase, S(Al2CuMg), Al9FeNi and Al7Cu2Fe phases in the 2618 aluminum alloy ingot, in which α-Al is the alloy matrix and the rest is the precipitated phase. In addition, it can be seen from Fig.1 that the peak strength of each precipitated phase basically remains unchanged with the extension of melt holding time.

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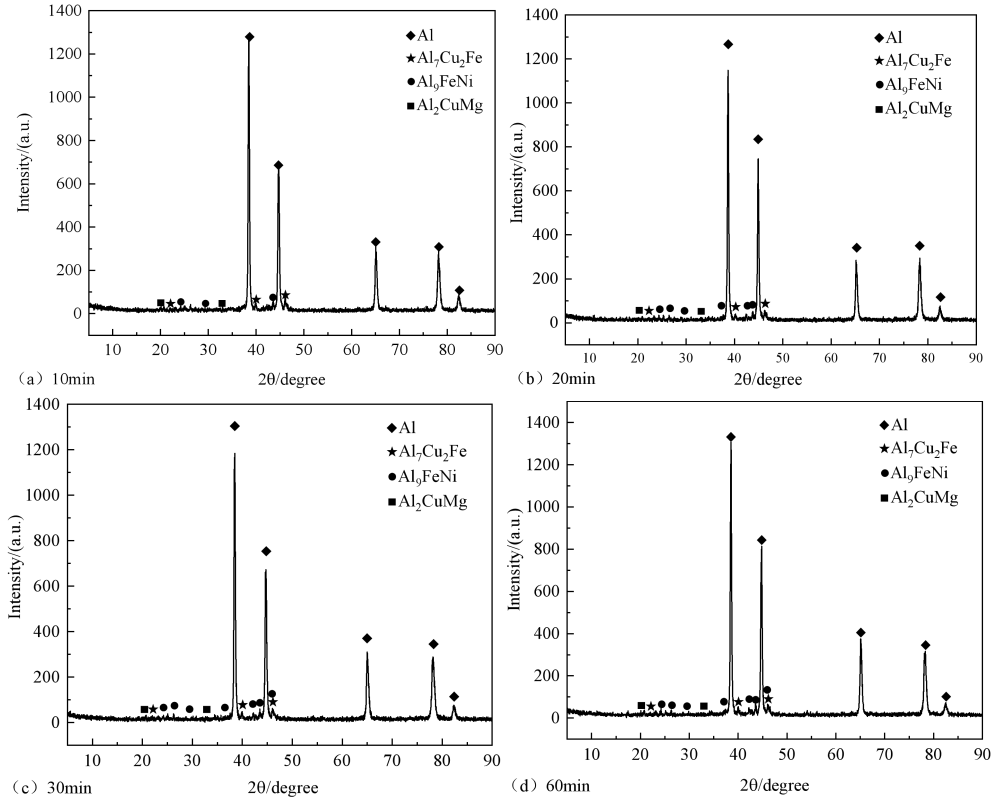

Figure 1. XRD patterns of aluminum alloy 2618 under different melt holding time.

Fig.2 shows the SEM and OM microstructure of 2618 aluminum alloy when the melt is held for 10min. The energy spectrum analysis results of positions A, B, C and D are shown in Table 2. By comparing Fig.2 and Table 2 with relevant literature, we can see that A is an unbalanced S (Al2CuMg) eutectic structure, C phase is Al9FeNi phase, B phase is Al7Cu2Fe phase, and D is α(Al) matrix. Surface scanning analysis was carried out on the microstructure of 2618 aluminum alloy ingot under different melt holding time, and the results are shown in Fig.3. As can be seen from the figure, the surface distribution of Mg element in the alloy is relatively uniform, while the distribution of other major alloy elements in the alloy has obvious segregation phenomenon. And Cu is mainly distributed in eutectic phase and massive phase, and Fe, Ni elements are mainly distributed in block and strip precipitate phase. The surface distribution of these elements can further provide experimental basis for the inferences of the precipitated phases of the alloy in Section 2.1.

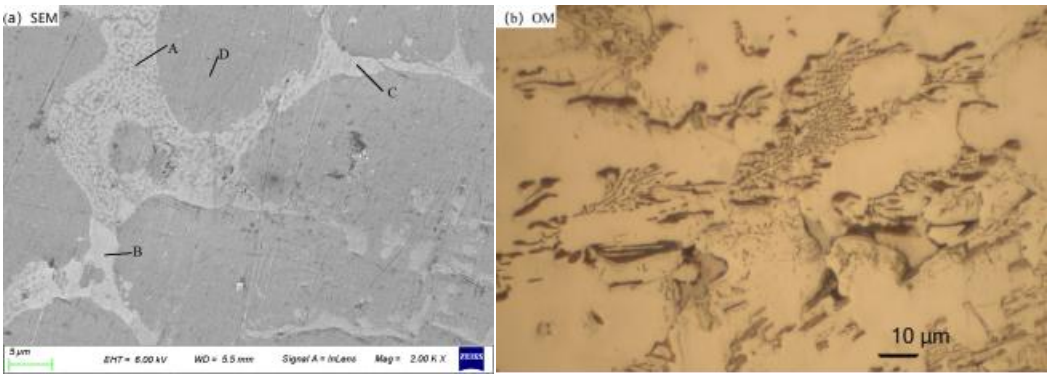

Figure 2. SEM and OM microstructure of 2618 alloy under melt holding for 10min.

3.2 Effect of melt holding time on precipitated phase

Fig.4 shows the as-cast macrostructure of aluminum alloy 2618 obtained by pouring aluminum alloy melt into graphite mold at room temperature after holding at 740℃ for 10min, 20min, 30min and 60min respectively. It can be seen from the figure that black reticular S(Al2CuMg) and second

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phases (precipitated phases such as Al9FeNi and Al7Cu2Fe) are distributed on the grain boundary of the alloy with four melt holding time. The S(Al2CuMg), Al9FeNi and Al7Cu2Fe phases are distributed at the grain boundary or inside the grain when the melt is held for 10min, and the distribution is very uneven with obvious segregation. The segregation of second-phase such as S(Al2CuMg), Al9FeNi and Al7Cu2Fe obviously reduced when the melt was held for 20min, and the distribution of precipitated phase is more uniform than that when the melt is held for 10min. The precipitated phases such as S(Al2CuMg), Al9FeNi and Al7Cu2Fe are not only obviously refined, but also more dispersed in the matrix under the melt holding time for 30min. The distribution of phases, such as S(Al2CuMg), Al9FeNi and Al7Cu2Fe, remained basically unchanged when the melt was held for 60min, but the precipitated phases coarsened slightly. Therefore, when the melt holding time is less than 30min, the distribution uniformity of precipitated phases on the alloy matrix gradually increases with the holding time prolonging. Furthermore, it can be seen from fig.4 that the grain size of the alloy at 30min is slightly smaller than that at 10min and 20min, but the overall change is not significant, while the grain size of the alloy at 60min is obviously higher than that at 30min. Thus, the grain size of the alloy is the smallest when the melt is held for 30min.

Table 1. Composition of phase in Fig.2 (at%).

Marks	Al	Cu	Mg	Fe	Ni
A	72.20	14.62	12.58	0.20	0.40
B	81.55	10.78	0.70	5.08	1.89
C	83.84	0.7	0.9	7.41	7.15
D	96.79	1.14	2.02	0.02	0.03

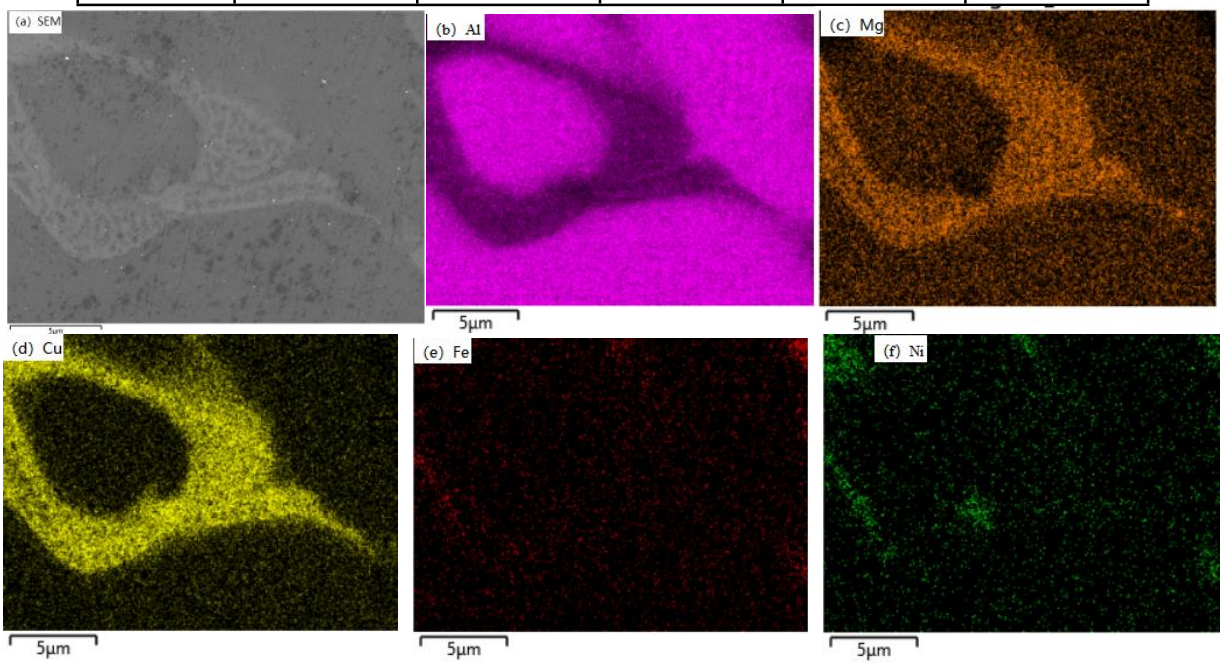

Figure 3. Surface distribution of 2618 aluminum alloy element under melt holding for 10min.

Fig.5 shows the as-cast macrostructure of aluminum alloy 2618 after melting at 740 ℃ for different time and pouring into graphite mold at room temperature. The honeycomb eutectic structure S(Al2CuMg) is large in size, with the maximum length of 132μm and the thickness of 42μm under the melt holding time for 10min. The Al9FeNi phase is mainly coarse needle-like, and the maximum length and thickness of the needle can reach 39μm and 10μm respectively, while the Al7Cu2Fe phase is fine and short. With the extension of the holding time to 20min, the honeycomb eutectic structure S(Al2CuMg) is effectively refined, and the maximum length and thickness are reduced to of 75μm and 26μm. At the same time, the Al9FeNi phase is still coarse needle-like, but the size of this phase is obviously refined, and the longest and thickest needle-like parts are only

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30μm and 7μ m, respectively. The Al7Cu2Fe phase has not changed obviously at the same time. When the alloy melt is held for 30min, the S(Al2CuMg) phase is finer, with the maximum length of 29μm and the thickness of 12μm. And the needle-like Al9FeNi phase is further refined, and the longest and thickest parts of the needle-like are only 8μm and 3μm, while the Al7Cu2Fe phase still remains unchanged. With the extension of the holding time to 60min, the morphology of S(Al2CuMg) phase in the alloy will not be affected basically, but the maximum length and thickness will increase slightly. The morphology and distribution of the precipitated phases Al9FeNi and Al7Cu2Fe basically do not change obviously, while the second phase coarsened slightly.

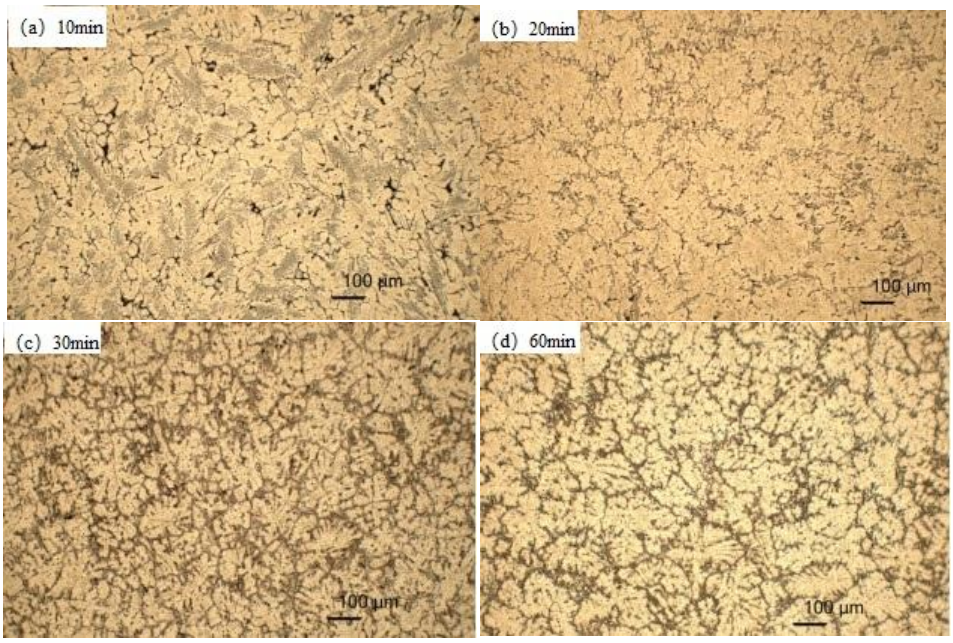

Figure 4. Low magnification microstructure of alloy 2618 as cast under different melt holding time.

This is mainly because the morphology distribution of refractory phases such as Al9FeNi and AlCuNi in 2618 aluminum alloy, which is related to the genetic phenomenon of raw materials. Generally, if there is an uneven structure in the alloy melt, the nonuniform structure will also appear after solidification of the alloy [3-4]. With the alloy melted at 740℃ and held for 10min, the coarser Al3Ni and Al2Cu phases can be completely dissolved, and the inheritability structural caused by these two master alloys can basically be completely eliminated. However, the coarser Al3Fe phase is still not completely dissolved due to the short holding time, so there are a large number of dispersed refractory particles Al3Fe in the aluminum alloy melt. And this makes it difficult to completely eliminate the inherit ability structural of the master alloy Al3Fe [5]. The inhomogeneity of chemical composition will force the AlFe3 particle and Fe-Ni atom group to act as the heterogeneous nucleation cores during the alloy crystallization, and they will grow up with obvious advantages, which eventually leads to the non-uniform precipitation of coarse refractory phases such as Al9FeNi and AlCuNi on the Al matrix. Therefore, the distribution of the second phase such as Al9FeNi and Al7Cu2Fe in the alloy matrix is not uniform, mainly concentrated at the grain boundary, with a small amount located inside the grain. At the same time, the macro segregation of the alloy is serious and the overall hardness of the alloy is low. With the increase of the melt holding time over 10min, the Al3Fe refractory particles and Fe-Ni atomic clusters in the alloy melt will dissolve more fully, and their sizes will gradually decrease or even disappear, so that the composition and structure of the alloy melt will be more uniform, and the structural heritability of raw materials will be gradually eliminated. During the subsequent cooling and crystallization process of the alloy, the nucleation effect is weakened, so the undercooling required for nucleation increased. Finally, the refractory phases such as Al9FeNi and AlCuNi will be uniformly precipitated on the Al matrix in the form of uniform nucleation [2]. The size of the refractory phases

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such as Al9FeNi and AlCuNi reduced obviously, the grains of the alloy are refined, and the properties of alloy were obviously improved. However, if the holding time of the alloy melt is too long, Fe-Ni atom clusters will collide and decompose continuously under the combined action of the fluctuation of melt structure, composition and disordered movement of atoms. And at the same time, a large number of atoms will re-agglomerate to form larger atom clusters, which will absorb the surrounding atoms and grow up, resulting in more obvious dendrite morphology, more uneven alloy structure and composition, so as to improve the ability of heterogeneous nucleation [6]. Accordingly, when the melt is held for 60min, the dendrite in the alloy developed, and it is difficult to refine Al9FeNi phase due to the difficulty of nucleation. All of these will lead to more and more obvious inhomogeneity of the structure and composition, so as to decrease the properties of the alloy.

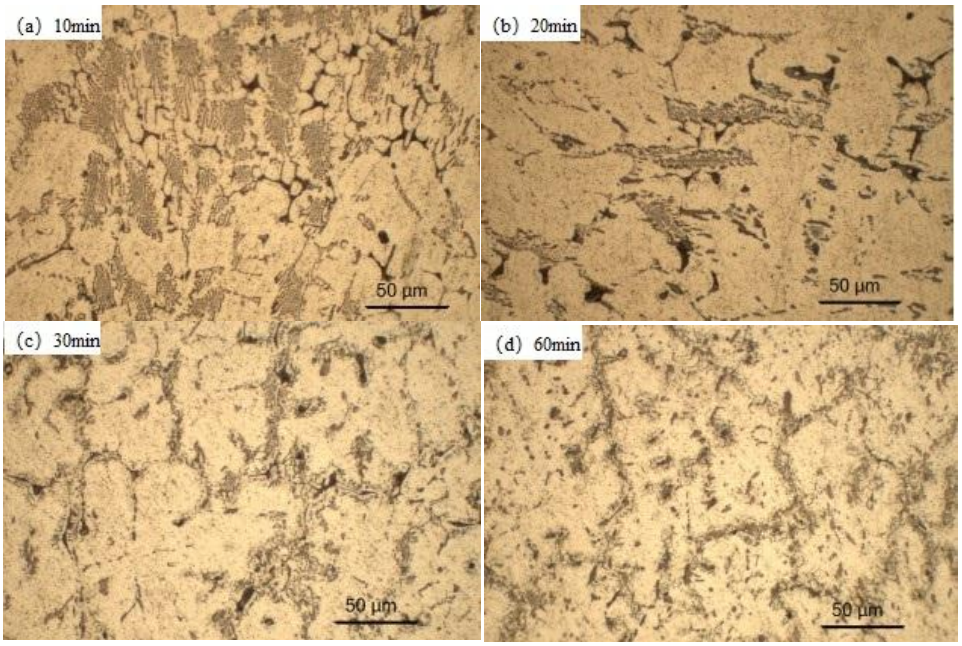

Figure 5. High magnification structure of alloy 2618 in as-cast state at different melt holding time.

3.3 Effect of melt holding time on hardness of alloy

Fig.6 represents the variation of hardness of 2618 aluminum alloy prepared under different melt holding time. It can be seen from the figure that with the continuous extension of the melt holding time in the range of 10 ~ 60min, the average hardness of 2618 aluminum alloy shows a trend of first increasing and then slightly decreasing. And the alloy hardness can reach the maximum value of 48.62HRB under the melt holding time for 30min, which is 9.64HRB higher than the average hardness of 10min, and 2.08HRB higher than that of 60min. In addition, Fig.6 also shows that the hardness of alloy is relatively evenly distributed, but the overall hardness is low, when the melt was held for 10min. When the melt was held for 30min, the hardness of the alloy was more concentrated and fluctuated equitably on both sides of the average hardness value. However, the hardness of the alloy was relatively dispersed when the heat was held for 20min and 60min. In conclusion, it is more appropriate for 2618 aluminum alloy when the alloy melt was held at 740℃ for 30 min. This is mainly because genetic phenomenon caused by raw material organization is eliminated and the alloy elements have more ample time to spread. All these are beneficial to obtain smaller grain size, more uniform composition, lighter macroscopic segregation and more balanced hardness distribution of the final alloy.

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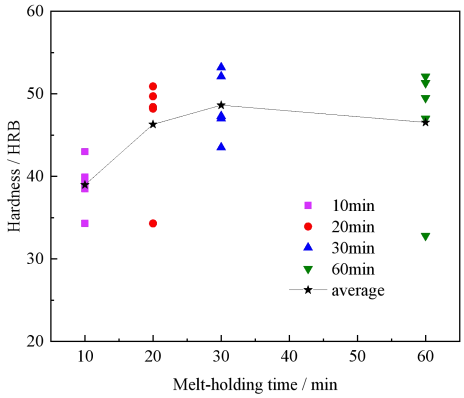

Figure 6. Hardness of the as-cast 2618 alloy at different melt-holding time.

4. Conclusion

The microstructure of 2618 aluminum alloy is mainly composed of α-Al, S (Al2CuMg) and Al9FeNi phases under different melt holding time after melting at 740℃ and pouring into graphite casting at room temperature. When aluminum alloy 2618 was held for 30 min at 740 ℃ and then poured into graphite mold at room temperature, the structure heredity caused by raw materials would be eliminated, and Al9FeNi phase was obviously refined, and its distribution was more uniform, and the morphology and size of other second phases remained unchanged, but the segregation phenomenon was effectively improved. With the further extension of the melt holding time, the distribution of the non-equilibrium crystalline phase is basically unchanged, but the grains and the second phase will be slightly coarsened. When 2618 aluminum alloy was melted and held at 740℃ and poured into graphite casting at room temperature, the alloy hardness showed a trend of first increasing and then decreasing with the extension of the melt holding time within 10~60min, and the Rockwell hardness HRB reached the maximum value of 48.62HRB within the test range when the melt was held for 30min. And the alloy hardness distribution is more uniform.

Acknowledgments

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