HOT-TEARING OF AL-LI ALLOYS IN DC-CASTING

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Abstract

To establish DC-casting technique of Al-Li alloys, hot-tearing characteristics were investigated first, then requirements for DC-casting were studied.

Hot-tearing characteristics of Al-Li alloys. Effects of Li content and grain-refiner addition on hot-tearing characteristics of Al-Li alloys were investigated by using hindered type hot-tearing test. In Al-Li binary alloys, the tearing tendency was decreased with increasing Li content, but was not improved by grain-refiner addition. In commercial Al-Li alloys, the tearing tendency was same as 2024 and 7075 alloys in the case of no grain-refiner added, but was not so improved by grain-refiner addition, while in 2024 and 7075 alloys improvement was remarkable.

Requirements for DC-casting of Al-Li alloys. The prevention of hot-tearing in the commercial Al-Li alloy ingots produced by DC-casting was studied. Tear started at the caved part of ingot surface which was contaminated by oxide. So study of prevention of hot-tearing was , first : to prevent the formation and mingling of oxides to improve smoothness of ingot surface, second : to improve the casting condition to reduce the stress by solidification shrinkage. On the former, molten metal surface was ventilated by Ar gas to inhibit the generation of oxide, and float shape was changed to reduce generation of oxide. On the latter, stress was reduced by decreasing casting speed , because the faster casting speed caused larger shrinkage.

Introduction

Al-Li alloys, as compared with the conventional Al alloys, have lower densities and higher rigidities, and yet, their strengths are equal to those of 2000 series alloys and 7000 series alloys. And therefore, they are being noticed as promising materials for structural member of aerospace application in the future, and research and developmental works for commercial use of these alloys are now being briskly progressed. Li, however, is an extremely active metal. For this reason, Li content in the Al-Li alloys causes the alloys to become highly reactive at the stage of molten metal, and this fact makes it difficult for the conventional melting and casting facilities to process these alloys into ingots.

At Alithium Co. Ltd., in order to establish the Al-Li alloys' melting and casting technologies, we have already installed an atmosphere controlling types high-frequency vacuum induction furnace in our plant and we now experiment practically all of DC-casting process with this furnace.

Since the Al-Li alloys are highly susceptible to occurrence of hot-tearing similarly to the cases of general high strength Al alloys, we anticipated possibilities of encountering with difficulties in preventing occurrence of tears on ingots in DC-casting process. Therefore, in this study, we principally tried to make quantitative evaluations on the Al-Li alloys' hot-tearing characteristics by conducting a series of tests. And also made studies on DC-casting of such alloys as 2090,2091 and 8090.

Hot-tearing characteristics of Al-Li alloys

By conducting a series of cast tearing tests, we tried to make quantitative evaluations of the Al-Li alloys' tearing characteristics. While several testing methods are available for hot-tearing characteristics including 'Ring testing method'[1] and 'Hindered type hot-tearing test'[2], etc., we have employed for this study 'Hindered type hot-tearing test[3),4] in accordance with a recommendation made by Ohya and others. In this study of ours we tried to clarify the quantities of such additives as Li and a rod type grain-refiner (Al-5mass% Ti-1mass%B), which are to take effects on the cast tearing characteristics of 0-3mass%Al-Li binary alloys and 2090, 2091 and 8090 commercial Al-Li alloys. Further, in order to provide data to be compared with those of the Al-Li alloys, we also made studies on 2024 and 7075 alloys, which are also high strength alloys and susceptible to the hot-tearing.

Testing methods

Given on Figure 1 is a typical illustration of the hindered type hot-tearing test mold. A casting mold of this type consists of 4 sections, and molten metal is to be poured into spaces which are surrounded by these 4 sections. A bar-type test piece (cast ingot) is stretched out on the both ends to be bound, and it is so designed that stresses are to be concentrated into the core located on the center of the test piece, where solidification

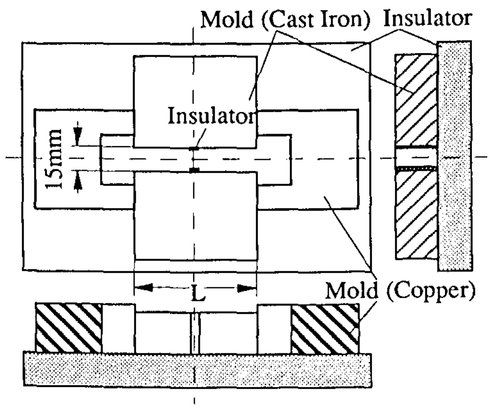


Figure.1 Hot - tearing test mold

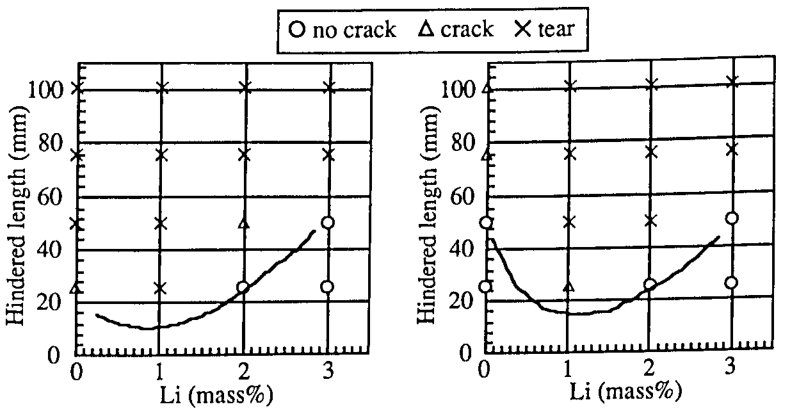
occurs at the end. By changing distance between the test piece's bound ends from 10 millimeters to 100 millimeters ,the susceptibility to tearing was evaluated from the standpoint of relations between the bound ends' distance and the occurrence of tears. Evaluations of tearing behavior were done in 3-step classification, that is, 'no cracking'(O), 'cracking'(Δ) and 'tearing'(X).

As for the testing conditions, alloys of the specimens used for these tests consists of the Al-Li binary alloys (0,1,2, and 3mass% Li), the commercial Al-Li alloys (2090,2091 and 8090) and the general high strength alloys (2024 and 7075). Further, the Al-5mass%Ti-1mass%B grain-refiner was added to alloys at the rates of 0mass%Ti, 0.01mass%Ti 0.025mass%Ti and 0.05mass%Ti.

Results

Al-Li binary alloys. Figure 2 shows effects of Li concentration on the hot-tearing characteristics. When the grain-refiner was not added to the alloys, the specimens of 1mass%Li became a little more susceptible to the tearing than those of 0mass%Li, but when Li concentration was further increased, the specimens became less susceptible to the tearing. An addition of the grain-refiner at 0.025mass%Ti improved the tearing characteristics of pure Al, but it did not improve the tearing characteristics of others, that is those of Al-Li alloys. By taking into consideration of the fact that crystallized grains were somewhat refined by an addition of the grain-refiner, it is conceivable that a tear-controlling effect by refining crystallized grains does not work much on the Al-Li alloys. However in this particular case the extent of refining was smaller than that of pure Al.

Commercial Al-Li alloys. Shown in Figure 3 are effects of additive quantity of the grain-refiner on the hot-tearing characteristics of 8090 alloy. Similar to the cases of the Al-Li binary alloys, an addition of the grain-refiner did not take an appreciable effect on control of susceptibility to the tearing. Further, similar tendencies were seen on Al-Li alloys other than 8090 alloy.



(1)Additional Ti : 0 mass%　　(2)Additional Ti : 0.025 mass%

Figure 2. Effect of Li concentration on hot-tearing characteristics in Al-Li binary alloys.

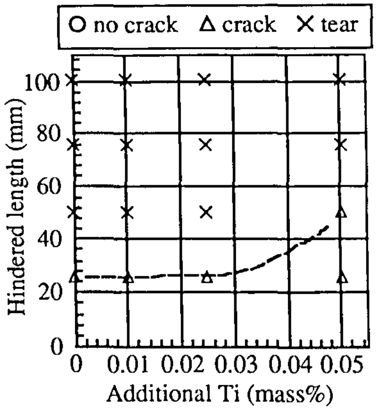


Figure 3. Hot-tearing characteristics of alloy 8090.

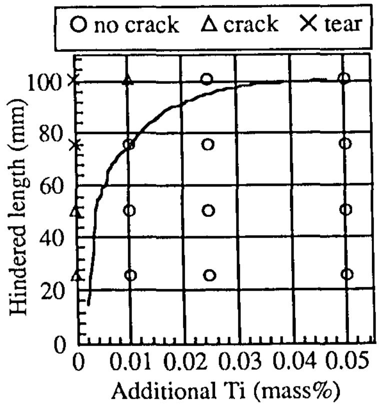


Figure 4. Hot-tearing characteristics of alloy 7075.

General high-strength alloys. Figure 4 shows a hot-tearing characteristics of 7075 alloys. While the tears easily occurred when the grain-refiner was not added, its susceptibility to the tearing was largely decreased by addition of the grain-refiner. And, an effect of the grain-refiner was larger than the cases of the commercial Al-Li alloys. A similar tendency was seen in the case of 2024 alloy. And therefore, we learned that the Al-Li type alloys are highly susceptible to the tearing. In addition, we could not help thinking that since it is not easy to refine crystallized grains of these alloys, it is difficult to improve its susceptibility to the tearing.

Requirements for DC-casting of Al-Li alloys

It was clarified that tears can easily occur on ingots of the Al-Li alloys during DC-casting process. In order to seek an effective measure to prevent occurrence of tears on ingots in casting process, we conducted a series of experiments in the process of DC-casting of sheet ingots and obtained the following results : At first, we carefully examined tears on DC-ingots in order to find out possible tear developing mechanism. As a result, we learned that oxides mingled into the ingot making dents on the surface and these dents caused tears to develop in the process of casting. And then, we thought that an effective way of preventing such tears from occurring on an ingot would be to provide the ingot with a flat and smooth surface. And therefore, we furthered our studies by concentrating our efforts on the following two points in particular : (1) In order to improve smoothness of the ingot surface, it is necessary to control development and mingling of oxides which become the starting point of the tearing. ; (2) In order to minimize internal stresses resulting from solidification and contraction, it is necessary to improve the casting conditions. With respect to the former, we modified the atmosphere-controlling method applicable to the inside of casting mold and also changed the molten metal distribution method, and as to the latter, we changed the casting speed. As a result, it became possible for us to prevent tears from occurring on an ingot during casting process.

Situation of tears occurrence

Depicted in Figure 5 is a tear-caused fracture on a DC-cast ingot. It shows that oxide coating which had formed in casting process have mingled with the cast ingot causing its surface to dent, and thus developed dents turned into starting points of cracks. In general, as a measure for preventing occurrence of tears, internal stresses are alleviated by controlling casting conditions. In the cases of Al-Li alloys, however, it is important to control formation of the tear-causing oxides and also to prevent the oxides from mingling in an ingot during casting process.

Prevention of formation/mingling of oxides

As Al-Li alloys are very active, it is necessary to cover the alloy in molten state with an inert (Ar gas) atmosphere. It, however, is difficult to cover the molten metal (in casting) with Ar gas completely. And, should it be thus covered, it becomes impossible to carry out the operations for removing the oxides from the metal. In addition, as a reaction between lubricant and molten metal generates smoke, it becomes necessary to remove it immediately.

Covering of molten metal surface with Ar gas. Figure 6 shows how to cover the molten metal surface with Ar gas. Initially, this was done simply by introducing Ar gas into a casting mold being used. Because of the smoke generated by a reaction between lubricant and the molten metal, a pressure was applied to exhaust the fume. However, as an excessive application of the fume exhausting pressure may end up in causing the level of cooling water to rise to the molten metal surface, we made this pressure a little positive externally.

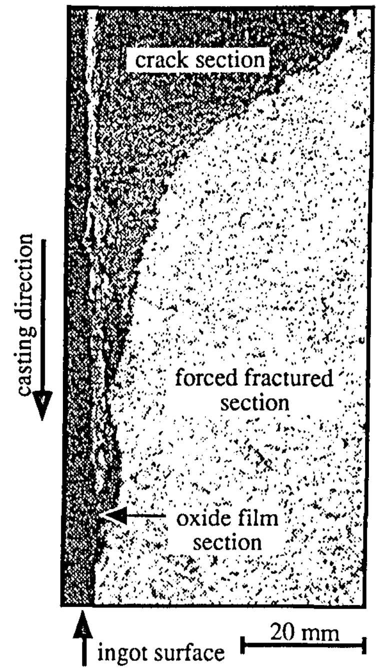


Figure 5. Photograph of crack part of DC-ingot (alloy 8090).

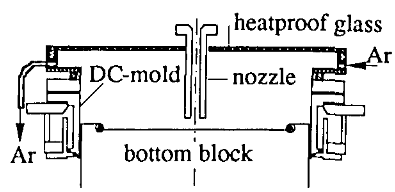


Figure 6. Mold cover

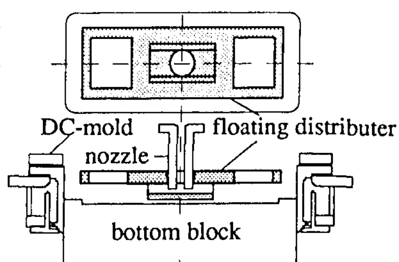


Figure 7. Floating distributer

Removal of oxides from metal surface. There is no possibility at all to remove the oxides forming on the surface of molten metal because of the Ar gas covering which prevents us from carrying out such operation on the metal surface. And therefore, as shown in Figure 7, we provided a dam on the floating distributor so that the oxides would not mingle with metal which is forming the surface of an ingot being cast.

Controlling of casting conditions

Figure 8 shows the casting conditions taking effect on distribution of thickness of a slab of 8090 Al-Li alloy. Although the contraction tends to become larger with the increase in casting speed, it turned out that flow rates of cooling water and molten metal take a very little effect on it. And therefore, it is considered that in order to lessen internal stresses, while a reduction in casting speed may be effective, changes in the flow rates of cooling water and molten metal would not take appreciable effect. In fact, in casting operations under these condition, the tears occurred only when an ingot was being processed at a high casting speed.

Datum of 2024 alloy is also shown in Figure 8. This datum indicates that its contraction is smaller than any one of those of the Al-Li alloys. These things seem to be proving the fact that the Al-Li alloys undergo larger internal stresses and are more susceptible to the hot-tearing.

Figure 9 shows the casting speeds having influences on solidification behaviors of slabs of 99.9mass% Al (pure Al). The casting speeds take effect on solidification behavior to such an extent that an ingot solidification tends to become faster with the increase in casting speed However, in the cases of the Al-Li alloys with additives of the grain-refiner, there were not appreciable differences in both macrostructure and microstructure on ingots being cast at these speeds.

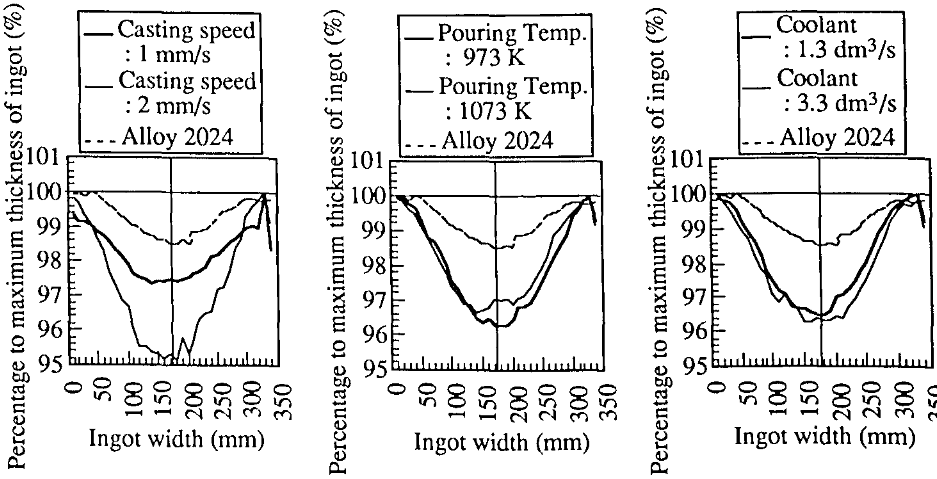


Figure 8. Distribution of ingot thickness in various casting conditions.

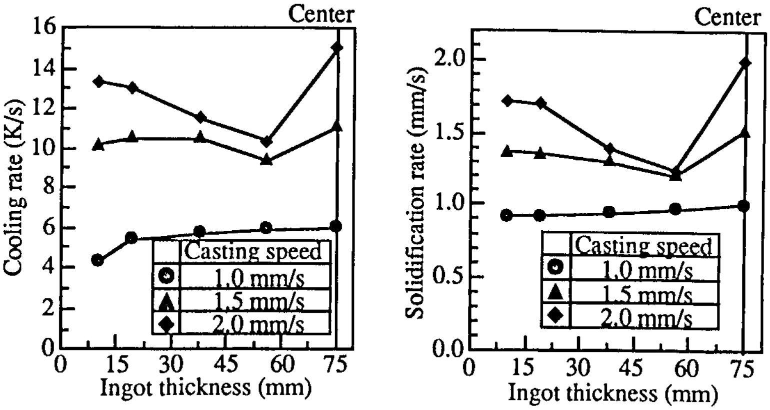


Figure 9. Influence of casting speed on solidification parameter (>99.9mass% Al).

Conclusion

Hot-tearing Characteristics of Al-Li Alloys

By using hindered type hot-tearing test, we conducted a series of experiments to clarify quantities of additions of Li and the rod type refining taking effects on the hot-tearing characteristics of the Al-Li binary alloys (0 to 3mass%Li) and the commercial Al-Li alloys (2090,2091 and 8090). In order to obtain data to be compared with those of the commercial Al-Li alloys, we also made, studies on such alloys as 2024 and 7075 which are also susceptible to the hot-tearing. And the results are as follows.

Al-Li binary alloys. When Li content was 1mass%, the hot-tearing characteristics were equal to that of pure Al, but it became less susceptible with the increase in addition of Li. While an addition of the grain-refiner to pure Al made an improvement on its susceptibility to the hot-tearing ,it did not take any effect on the Al-Li alloys. And the grain-refiner did not take much effect on refining of grains of the Al-Li binary alloys as compared with the effect on pure Al.

Commercial Al-Li alloys. In the case of absence of the grain-refiner, the hot-tearing characteristics of the commercial Al-Li alloys were equal to those of 2024 and 7075 alloys. After the grain-refiner was added, although the hot-tearing characteristics of 2024 and 7075 alloys were largely improved, there was not improvement on those of the commercial Al-Li alloys.

And, the grain-refiner did not effect refining of grains of the commercial Al-Li alloys as it did for 2024 and 7075 alloys.

Requirements for DC-casting of Al-Li alloys

As for DC-casting of the Al-Li alloys, we made studies on possible way of preventing occurrence of the hot-tearing by looking into the hot-tearing mechanism. And, these studies of ours brought about the following results.

Hot-tearing Mechanism. We carefully examined the tears on DC-cast ingots and discovered that the tears started developing from the section on an ingot where oxides had mingled in metal while casting process was going on. And therefore, we considered that in order to prevent the tears from occurring on an ingot being cast, it is necessary for us to take the following steps, that is firstly, we would have to improve the smoothness of the ingot's surface from which the tears start developing, and to this end, we would have to control formation of oxides in casting process and prevent thus formed oxides from mingling in the metal forming the ingot 'surface ; secondly, we should modify the casting conditions so as to reduce the internal stresses resulting from the solidification caused contraction.

Prevention of formation/mingling of oxides in casting. A DC-casting mold was provided with a covering so that the inside was filled with an Ar gas atmosphere, and then, an opening was provided to exhaust waste fume forcibly. Further, in order not to allow Ar gas to leak out from gaps between the casting mold and the ingot while ensuring a constant flow rate to maintain necessary atmosphere in the casting mold, the pressure in the casting mold covering was kept on a little positive side as compared with that of the outside. And by modifying the float to such an effect as to cover the major portion of molten metal, the formation of oxides was substantially reduced. Further, we also provided the float with a space for trapping the oxides.

Decrease in internal stresses. While a reduction in casting speed took an effect on the prevention of tearing, molten metal temperature and flow rate of cooling water proved not to take any effect. It is conceivable that with the increase in casting speed, contraction of an ingot becomes larger, that is, the faster, the larger. And we also cast 2024 alloy into ingots and confirmed that no tear occurred on these ingots. Contraction rates of the Al-Li alloys are considered to be higher than of 2024 alloy, and this may be one of the factors which make the Al-Li alloys more susceptible to the hot-tearing. Further, we also learned that with the increase in casting speed, the sump become deeper, and solidification parameters (cooling rate and solidification rate) tend to become larger.

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