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E. SYMPOSIUM ON ADVANCED MATERIALS AND PROCESSING

Fading of Al-5Ti-1B Grain Refiner of 0.081 and 0.115 wt. % Ti in AC4B Alloy Produced by Low Pressure Die Casting

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ABSTRACT

AC4B alloy (Al-8Si-2.4Cu) is one of the most desirable cast aluminium to be processed through low pressure die casting (LPDC). However, there are many problems, particularly shrinkage and porosity, that need to be resolved. One way to solve this problem is by using grain refiner. Another constraint is the duration of one cycle LPDC process of ~ 450 kg capacity may take up 4 hours, that causes fading. This research is aimed to understand the fading mechanism of Al-5Ti-1B grain refiner of 0.081 and 0.115 wt. % Ti during LPDC. Fading was observed through the changes of hardness, tensile strength and microstructure.

The results show that the longer the holding time, the lower hardness and the tensile strength of AC4B alloy. On the other hand, the longer the holding time, the higher the ductility and the secondary dendrite arm spacing (SDAS). This indicates that fading occurred before 1 hour. In addition, microstructure observation by using Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Analysis (EDAX) showed the presence of titanium in the alloy which indicates that titanium may act as the nucleant for solidification process.

Keywords
Grain refiner, fading, AC4B, LPDC, Al-5Ti-1B

1. INTRODUCTION

One way to improve the quality of aluminium casting products is by using grain refiner [1-3]. Grain refiner reduces grain size of aluminium casting by resisting the growth of columnar grains and promoting equiaxed grains [4-6]. The grain in aluminium casting can be refined by forming as much dendrites as possible during initial solidification, and maintain that they all grow at the same rate. This only can be achieved if the nucleation starts near to liquidus temperature, or minimum undercooling, by providing particles on which dendrites can readily nucleate and grow [3, 7-8].

There are several types of grain refiner available for aluminium alloys, such as aluminium-titanium, aluminium-titanium-boron master alloys, and titanium or titanium-boron containing salt tablets [7]. The aluminium-titanium and aluminium-titanium-boron master alloys are the most popular to use, such as Al-10Ti, Al-6Ti, Al-3Ti-1B, Al-5Ti-1B, Al-5Ti-0.6B, Al-10B, Al-5B, and Al-3B [9].

The mechanism of grain refinement is related to the nucleant particles which is contained in the grain refiner, i.e. TiB_2 or $TiAl_3$ particles. If titanium is present in the alloy at the levels greater than ~0.15 %, then on cooling, nucleation of $TiAl_3$ occurs before aluminium. Aluminium then nucleates on $TiAl_3$ reducing the undercooling and thus producing a smaller grain size [7,10]. When using aluminium-titanium-boron master alloy as the grain refiner, $TiAl_3$ particles will dissolve and introduce solute titanium in to the melt, while TiB_2 remains as a solid dispersion in the melt [6-7,11]. TiB_2 particles have the order of 0.5 to 5 μm. Although there is still a debate about precise nucleation mechanism, however, for wrought alloys it is generally thought that the mechanism involves nucleation of aluminium on layers of $TiAl_3$ which are formed and stabilised on specific facets of TiB_2 particles [7, 11-12].

The weakness of grain refiner is the fading that occurs within a period of time. Fading may be caused by settling, agglomeration and poisoning of nucleant particles [6-7]. The density of TiB_2 (4.5 g/cm^3) is larger than molten aluminium (2.3 g/cm^3), that makes the particles settle down the furnace [7,13-14]. Presence of borid particles may lead to agglomeration that speeds up the settling process. During the fast settling the large agglomerate also collides with the smaller one and becomes larger [6-7,13]. Agglomeration also occurs when TiB_2 combines with oxide film and make fast settling [15]. While poisoning of Al-5Ti-1B grain refiner is commonly caused by other elements such as silicon, zirconium, chromium, iron and tantalum [7-8,11-12,16]. When the melt has silicon content exceed 2 %, the coarsening effect will start and extend with the higher silicon content [17-18]. It is also known that addition of AlTiB grain refiner to zirconium containing melt would result quick poisoning. $TiAl_3$ layer can be displaced in the presence of zirconium and tantalum. The poisoning can happen by subtitution of element in $TiAl_3$ layer [7,12]. This research was purposed to study the fading mechanism of Al-5Ti-1B grain refiner in AC4B alloys produced by low pressure die casting (LPDC) process.

2. EXPERIMENTAL METHOD

The melting of AC4B was conducted in reverberatory furnace with the capacity of 500 kg at 810 ± 5 °C. Then aluminium was poured in to the preheated ladle and trapped hydrogen was eliminated by using Gas Bubble Floatation (GBF) for 8 minutes. Rod Al-5Ti-1B grain refiner was added at the begining of the GBF process, with the amount of 0.081 and 0.115 wt. % Ti. Molten metal was then injected through LPDC machine at 700 – 710 ^{o}C. Fading was observed through the changes of hardness, tensile strength and microstructure for a period of 0 – 2 hour. Samples were taken from thick and thin area of the component to see effect of heat transfer on grain refinement and fading.

3. RESULTS AND DISCUSSION

The microstructure of Al-5Ti-1B grain refiner is presented in Figure 1. The microanalysis of each position is tabulated in Table 1. There are white and grey phases as the matrix. Small white phase is found evenly distributed in the matrix. The white phase has 20.47 wt. % Ti and 53.91 wt. % B. By converting this value to atomic percentage, the white phase can be assume as TiB_2 particle. The similar method was also used to point 2 and 3, point 2 is AlB_2 and point 3 is AlB_2 combined with TiB_2. According to solute paradigm, boride and the other particles can act as nucleating subtrate[19].

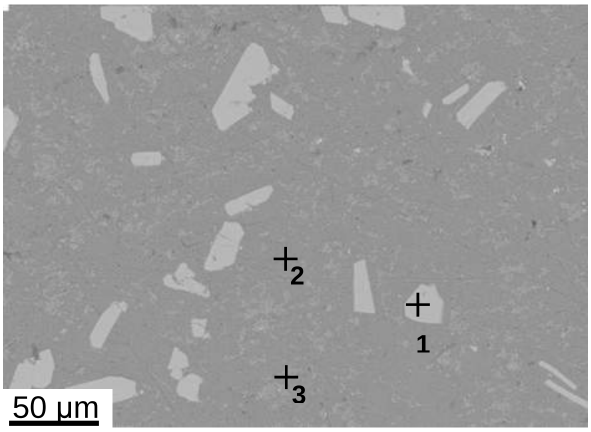

Figure 1. Microstructure of Al-5Ti-1B grain refiner.

Table 1. Microanalysis of Al-5Ti-1B grain refiner at positions shown in Figure 1.

Posi-tion	Content (wt. %)			Color	Phase
	Al	Ti	B		
1	25.62	20.47	53.91	white	TiB_2
2	36.43	0.34	63.23	grey	AlB_2
3	33.24	9.66	57.10	white	Al B_2 and TiB_2

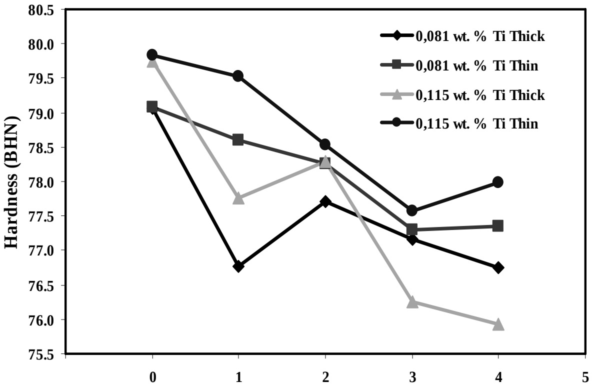

Figure 2. The effect of Ti addition and the sample position on the hardness of AC4B alloys produced by LPDC process for 4-hour period.

The change of hardness with the increase in holding time is provided in Figure 2. The hardness of thin section is generally higher than thick section due to higher solidification rate.

Samples with addition of 0.081 wt. % Ti at thick section shows that the longer the holding time, the lower the hardness of LPDC products. After 4 hours, the hardness dramatically decreased to 78 BHN. Similar trend was found for thin section, as well as for addition of 0.115 wt. % Ti.

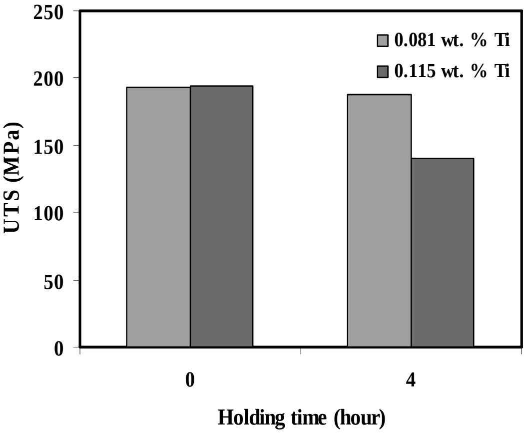

Figure 3. The change of ultimate tensile strength (UTS) of AC4B alloy produced by LPDC after 0 and 4 hours, with addition of 0.081 and 0.115 wt. % Ti.

The change of tensile strength of AC4B alloy produced by LPDC after 0 and 4 hours can be seen in Figure 3. This shows the declining of ultimate tensile strength for both 0.081 and 0.115 wt. % Ti after 4 hours. After 4 hours of LPDC process, the alloy with addition of 0.081 and 0.015 wt. % Ti underwent a decline in tensile strength for 5.6 and 54.1 MPa, respectively. The tendency in tensile strength is similar with that in hardness. Both hardness and tensile strength are parameters of resistance of materials to plastic deformation, so the values are generally proportional [20].

Microstructures of AC4B alloy processed by LPDC with 0.081 and 0.115 wt. % Ti addition are provided in Figures 4 and 5, respectively. It is clear that the dendrites are smaller in the thin section than those in the thick section. Both sections show that the longer the holding time, the larger the dendrites, confirming the results of hardness and tensile tests.

The secondary dendrite arm spacing (SDAS) was quantitatively measured and the results are presented in Figure 6. After 4 hours of LPDC, the size of dendrites in alloy with 0.081 wt. % Ti addition rises by 5.4 μm and 12.7 μm at thick and thin sections, respectively. Alloys with addition of 0.115 wt. % Ti also showed similar results, in which the size of SDAS increases by 14 μm and 7.7 μm at thick and thin sections, respectively.

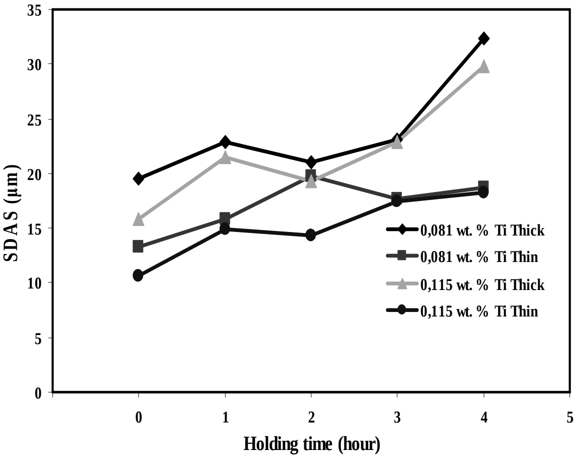

Figure 6. Change in secondary dendrite arm spacing (SDAS) in 4 hours in AC4B alloys added with 0.081 and 0.115 wt. 5 Ti in thick and thin areas.

The change of microstructure of AC4B alloy with addition of 0.081 wt. % using SEM and EDAX for 4 hours period is shown in Figure 7. The results of microanalysis of each point are tabulated in Table 2. The results show that the longer the holding time, the more sparsely distributed the Al_2Cu phase. This tendency is shown both in thick and thin samples. While the Al-Si eutectic phase tends to be coarser by the increase in holding time. The larger size of Al_2Cu, Al-Si eutectic phases and dendrites is correlated with the decrease in hardness and tensile strength of the alloys. Trace of titanium was observed for 0.64 % at point 5 of thick sample of 0 hour (Figure 7 (a)). This may indicate the presence of $TiAl_3$ particle at this point. Therefore, it confirms the mechanism of grain refinement by the presence of nucleant particles in the microstructures that seed the growth of dendrites in the molten metal.

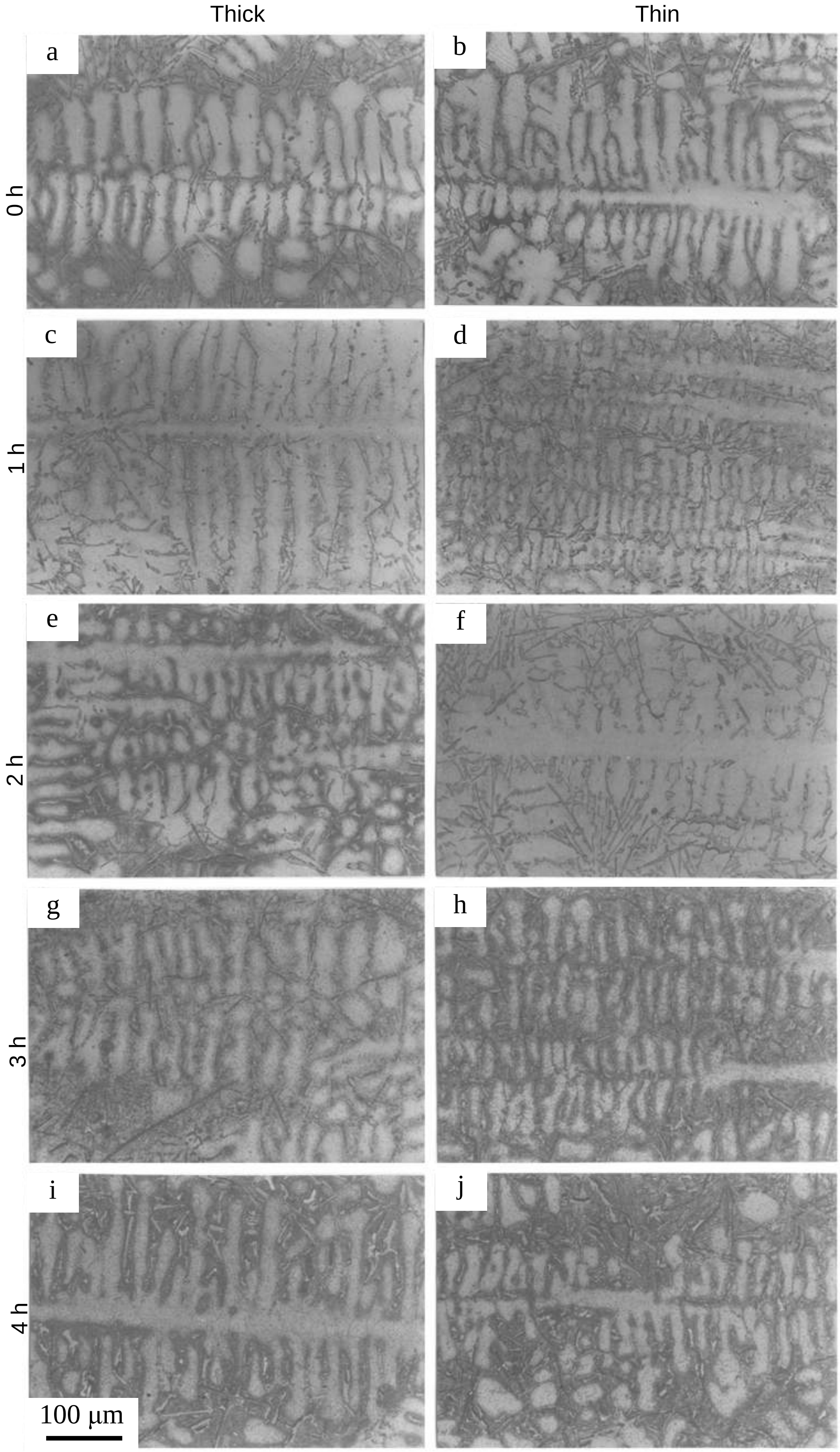

Figure 4. The change of microstructure of AC4B alloy with addition of 0.081 wt. % after (a-b) 0 hour; (c-d) 1 hour; (e-f) 2 hours; (g-h) 3 hours; (i-j) 4 hours, from thick and thin areas.

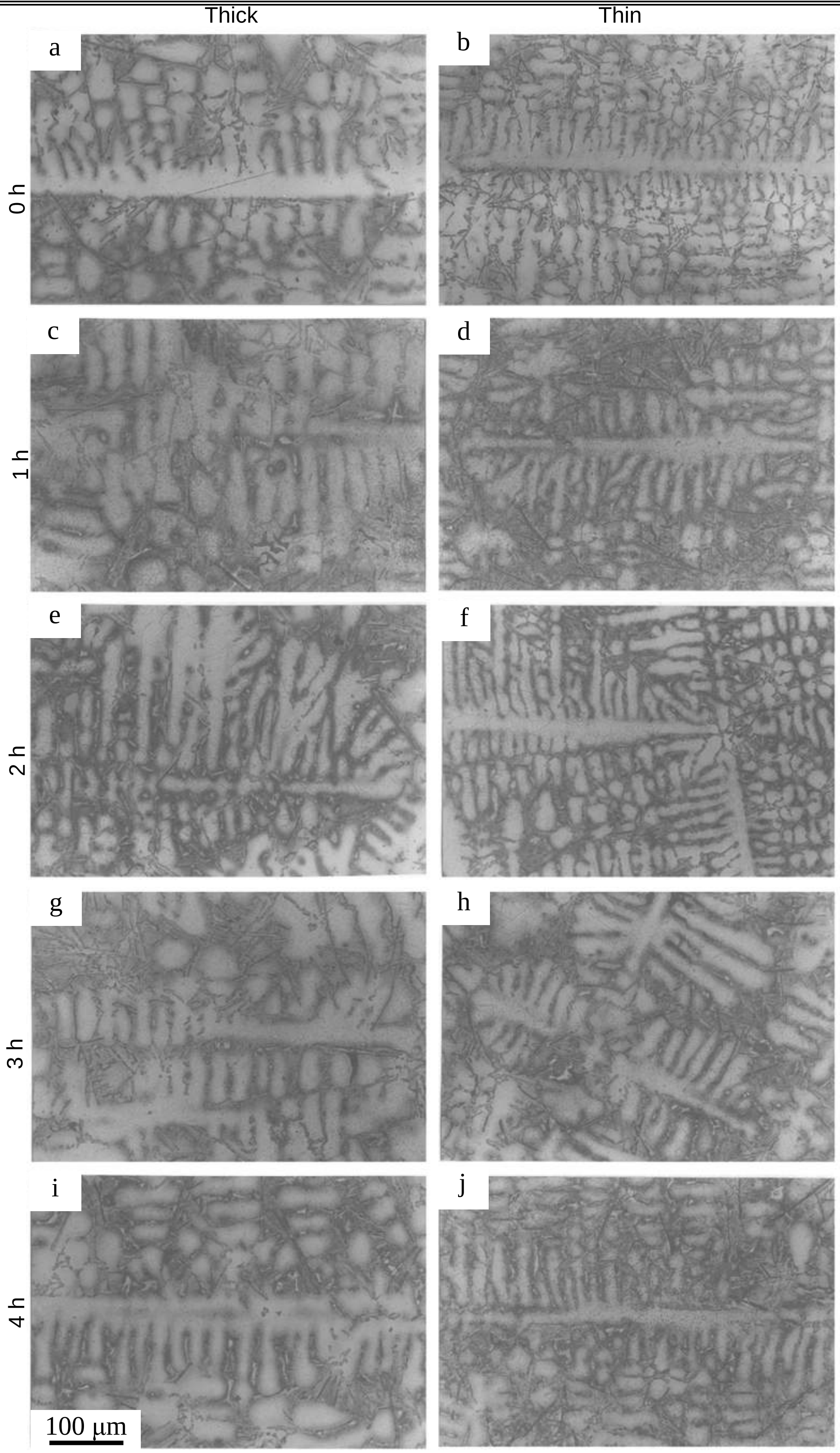

Figure 5. The change of microstructure of AC4B alloy with addition of 0.115 wt. % after (a-b) 0 hour; (c-d) 1 hour; (e-f) 2 hours; (g-h) 3 hours; (i-j) 4 hours, from thick and thin areas.

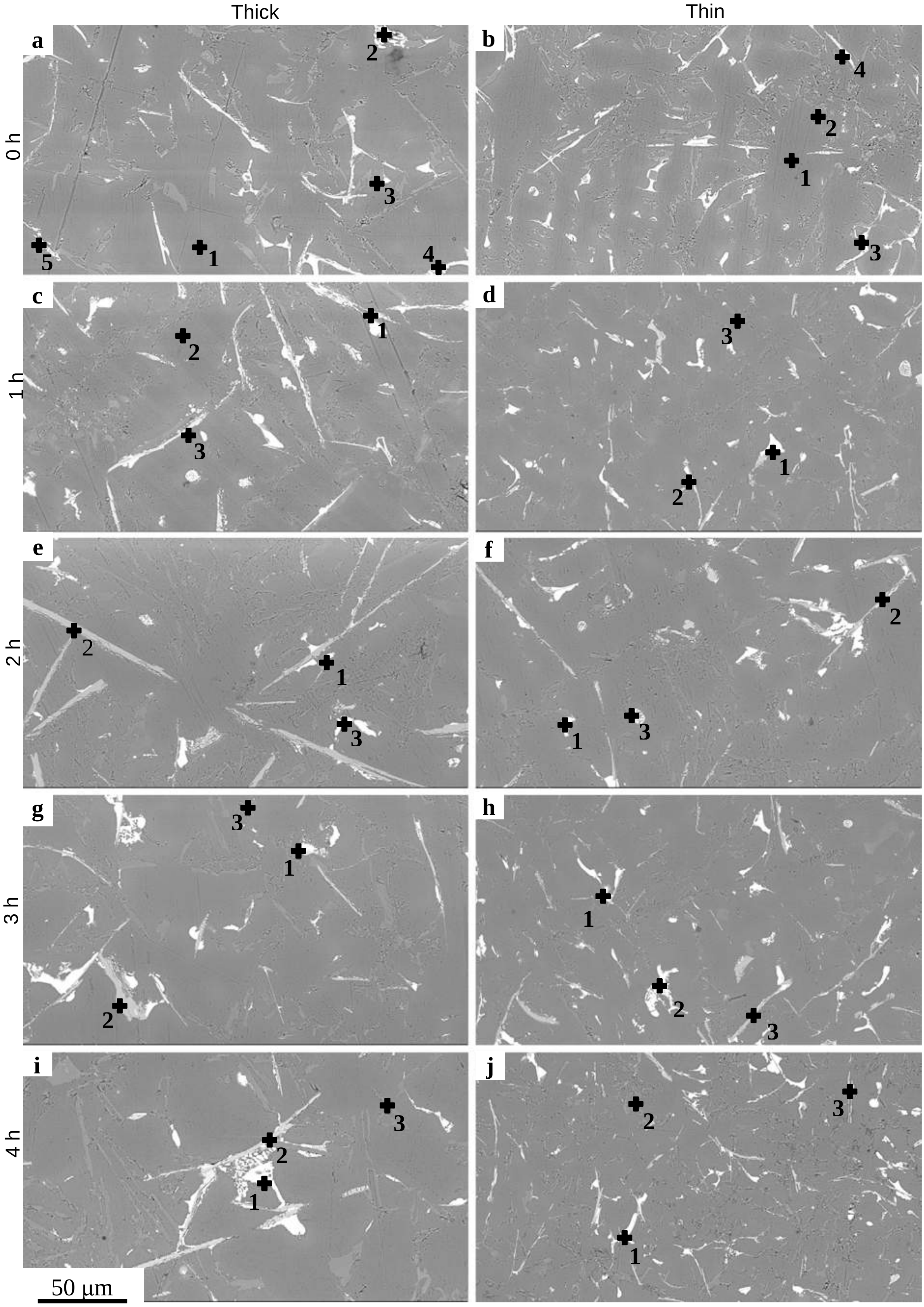

Figure 7. The change of microstructure (SEM) of AC4B alloy with addition of 0.081 wt. % Ti after (a-b) 0 hour; (c-d) 1 hour; (e-f) 2 hours; (g-h) 3 hours; (i-j) 4 hours, in thick and thin samples. The results of microanalysis of each point are tabulated in Table 2.

Table 2. Results of microanalysis of AC4B alloy with addition of 0.081 wt. % Ti at the points shown in Figure 7.

Sample	Point	Element (wt. %)			Color	Phase
		Al	Si	Cu		
0 hour, thick section	1	94.48	1.90	-	grey	Al
	2	64.88	2.74	29.36	white	Al_2Cu
	3	19.49	82.34	-	grey	Al-Si
	4	64.13	5.27	24.05	white	Al_2Cu
	5	57.66	11.65	16.18	white	Al_2Cu
0 hour, thin section	1	94.88	1.88	-	grey	Al
	2	15.24	80.60	-	grey	Al-Si
	3	91.05	0.95	7.27	white	Al_2Cu
	4	32.91	63.03	-	grey	Al-Si
1 hour, thick section	1	89.70	1.48	6.86	white	Al_2Cu
	2	94.80	2.00	-	grey	Al
	3	57.17	11.56	-	grey	Al-Si
1 hour, thin section	1	38.36	5.87	45.20	white	Al_2Cu
	2	59.15	14.91	21.82	white	Al_2Cu
	3	52.37	42.09	-	grey	Al-Si
2 hours, thick section	1	88.11	1.27	8.47	white	Al_2Cu
	2	60.53	11.68	-	grey	Al-Si
	3	42.71	0.51	56.26	white	Al_2Cu
2 hours, thin section	1	88.13	2.34	8.28	white	Al_2Cu
	2	72.20	22.63	-	grey	Al-Si
	3	93.84	1.76	-	grey	Al-Si
3 hours, thick section	1	70.22	11.91	11.48	white	Al_2Cu
	2	57.09	11.19	-	grey	Al-Si
	3	88.60	1.23	8.93	white	Al_2Cu
3 hours, thin section	1	87.10	1.36	7.59	white	Al_2Cu
	2	29.21	0.17	60.83	white	Al_2Cu
	3	93.93	1.59	-	grey	Al-Si
4 hours, thick section	1	30.04	0.19	59.94	white	Al_2Cu
	2	93.06	1.50	-	grey	Al-Si
	3	11.83	83.11	-	grey	Al-Si
4 hours, thin section	1	88.95	1.27	8.13	white	Al_2Cu
	2	88.63	2.34	7.62	grey	Al-Si
	3	87.95	1.16	9.16	white	Al_2Cu

4. CONCLUSIONS

1. The longer the holding time, the lower hardness and the tensile strength of AC4B alloy. On the other hand, the longer the holding time, the higher the secondary dendrite arm spacing (SDAS).
2. The examination using SEM and EDAX shows the presence of titanium that indicates the presence of nucleant particles, particularly $TiAl_3$.
3. The result shows that there is a fading phenomenon in AC4B alloys produced by LPDC process which occurred after 0 hour.

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