5.3.2 Tensile properties and microhardness

A. Ultimate tensile strength (UTS) and microhardness (Hv)

Table 5.3 presents strength and hardness values of the Al-Si-X samples that were machined from the segment “Plate” (Fig. 4.11). This Table displays that T6-treated Al-25SiCuMg (PT) alloy has the highest UTS and microhardness values; whereas, Al-20SiFe (PT) has the lowest values among all the alloys. The high UTS and hardness value of the Al-25SiCuMg alloy can be attributed to the solution and precipitation hardening derived from Cu and Mg. On the contrary, most of Fe added in Al-20SiFe transforms after thixocasting into large intermetallic particulates, due to low solubility of Fe in α-Al. Therefore, although Al-20SiFe (PT) has uniform dispersed Si and intermetallic particulates, the soft matrix of this alloy still make it weak.

From Table 5.3, T6 heat treatment was found to increase the tensile strength, ductility and microhardness of the Al-Si-Cu-Mg alloys. The ductility increase after T6 treatment is due to spheroidisation of the Si particles, comparing Fig.5.4 with 5.5 or Fig. 5.2 b with d. Furthermore, the strength increase is because of formation of a larger number of fine precipitates to strengthen the soft α-aluminum matrix. As compared with Al-25SiCuMg (IT) alloys, Al-25SiCuMg (PT) alloys in both as thixocast and T6 condition show obvious improvement in hardness and UTS, but decline in ductility behavior. The strength improvement is clearly derived from the drastic refinement in microstructure on Al-25SiCuMg (PT) (Fig. 5.2 b) compared with Al-25SiCuMg (IT) (Fig. 5.4 a).

The results of UTS and ductility presented in Table 5.3 closely correspond to those of P. J. Ward [35,36], who thixocast the hypereutectic Al-Si-Cu alloys using billets fabricated by spray-forming followed be extrusion. This may indicate the powder can be effectively consolidated after powder thixocasting. In our previous studies [111, 112] that revealing no debonding of powder particles observed on the fracture surfaces also verifies the consolidation. Nerveless, it is still worthy to noted that the UTS values of about 300 MPa obtained here are much lower than those obtained using techniques of powder forging or extrusion. In Table 5.3, the strength of Al-25SiCuMg (PT) in as-thixocast state is 224 MPa and that in T6 state is 304 MPa. However, the strength of hypereutectic Al-Si-Cu-Mg alloys fabricated by conventional powder forging can reach around 400-500 MPa [15].

The reason why powder thixocast Al-Si alloys have lower mechanical properties than traditional powder forged Al-Si alloys are attributed to the microstructural coarsening and Si particles aggregation during thixocasting. This is because that the extremely fine scale microstructures in the as atomized powders were almost destroyed after semisolid processing; in addition, there is no strain hardening effect by powder thixocasting. Besides, powder forging also takes an advantage in improving strength by strain hardening effect, however this effect is deficient in powder thixocasting. Nevertheless, powder thixocasting offers an alternative to powder forging when a complex part of the hypereutectic Al-Si alloys is fabricated in net shape forming.

The low ductility observed for the powder thixocasting specimens listed in Table 5.3 is beyond our expectation. Figure 5.6 shows typical stress-strain curves of powder-thixocast Al-25Si-2.5Cu- 1Mg specimens, indicating brittle behavior of these powder thixocast Al-Si specimens. This low ductility is suggested due to clustering of primary Si particles after thixocasting in Al-25SiCuMg alloys (Fig. 5.2 a), since fracture tends to initiate from or propagate through the Si particle agglomerates [36]. According to this reason, as Al-20SiFe (PT) shows less extent of Si clustering (Fig. 5.3b), it exhibits slightly higher ductility than Al-25SiCuMg alloys.

Table 5.3 Tensile properties and hardness of the Al-Si-X alloys (PT=powder thixocasting; IT=ingot thixocasting)

Materials	Heat treatment	Hardness (Hv, 100gf)	UTS (MPa)	Elongation (%)
Al-25SiCuMg (PT)	As thixocast	144	224	0.20
	T6	175	304	0.12
Al-25SiCuMg (IT)	As thixocast	108	205	0.35
	T6	152	254	0.28
Al-20Si5Fe (PT)	As thixocast	82	192	0.48
LM13	As cast	86	245	1.8
	T6	143	330	1.5

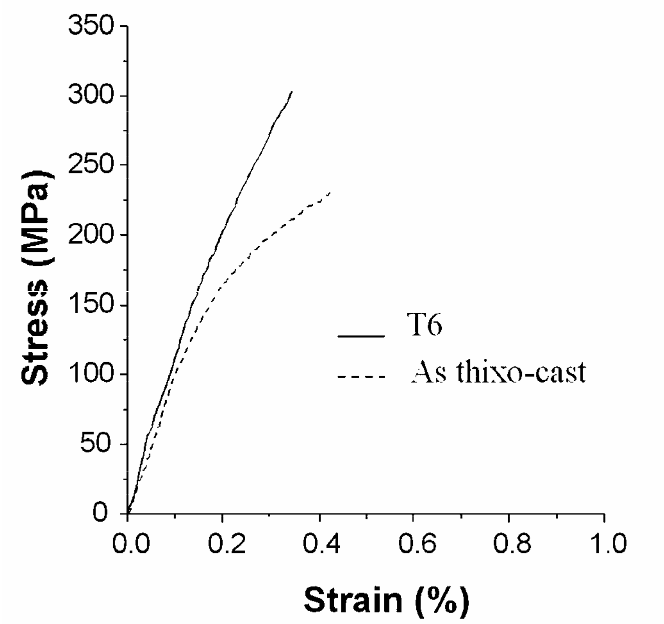


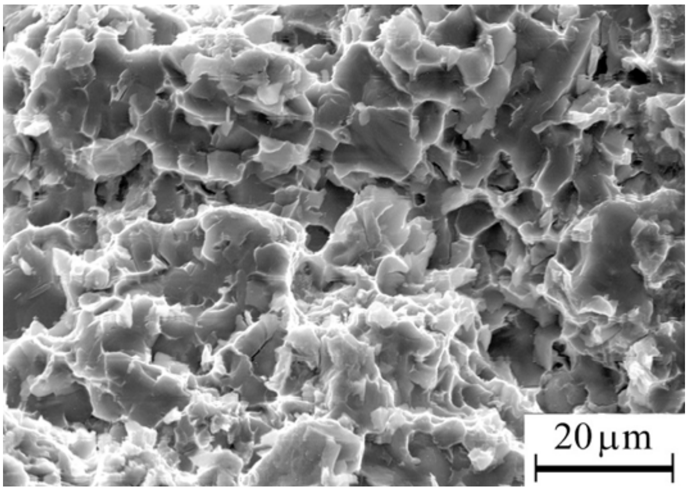
Figure 5.6 Typical stress-strain curves of Al-25Si-Cu-Mg (PT) Specimen were machined from the "plate" sections and fabricated using powders of size in 120~300μm and compacts consolidated at 550 ℃.

<u>*B. Fractographs*</u>

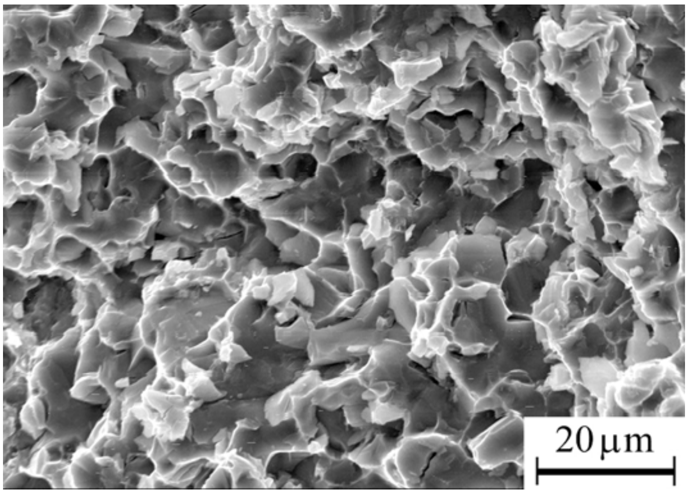
Figures 5.7 a and b show that tensile fractographs of Al-25Si-Cu-Mg (PT) in both as-thixocast and T6-treated states typically present only the small dimples and cleavage of silicon particles. In addition, since no deep, spherical large holes were found in these fractographs, no debonding of the Al-25Si-Cu-Mg powder particles can have occurred, indicating the powder was effectively consolidated after powder thixocasting.

Figures 5.7 c and d display micrographs of the cross-section beneath the fracture surfaces of the tensile specimens, showing several cleavage cracks in the Si grains. These cleavage cracks are nucleation sites of the fracture. Since the Si grains are both hard and brittle, they are the first to crack as tensile stress increases, generating the cleavage planes shown in Figs. 5.7 a and b.

The Si grains in thixocast specimens tend to aggregate near the α-Al grain boundary, as shown in Fig. 5.2 c. The cracks in the aggregated Si grains rapidly coalesce, as shown in Figs.5.7 c and d, which increase the velocity of crack propagation. The agglomerated Si grains in the specimens are believed to cause brittleness of these alloys, whose ductility is usually below 0.2%.

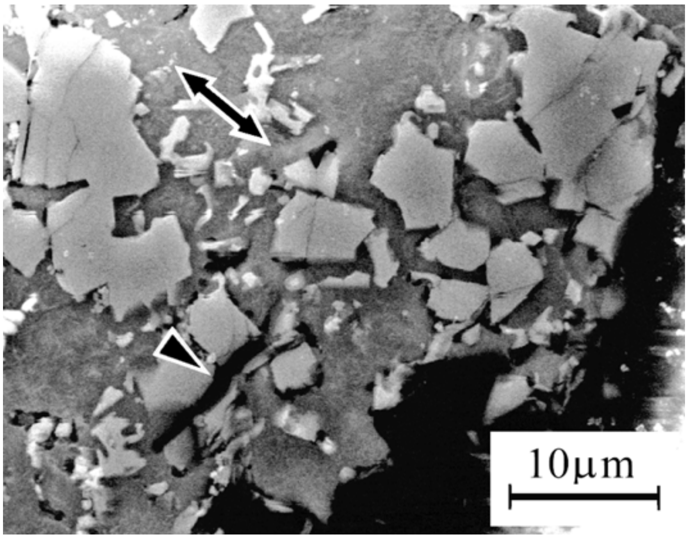


(a)

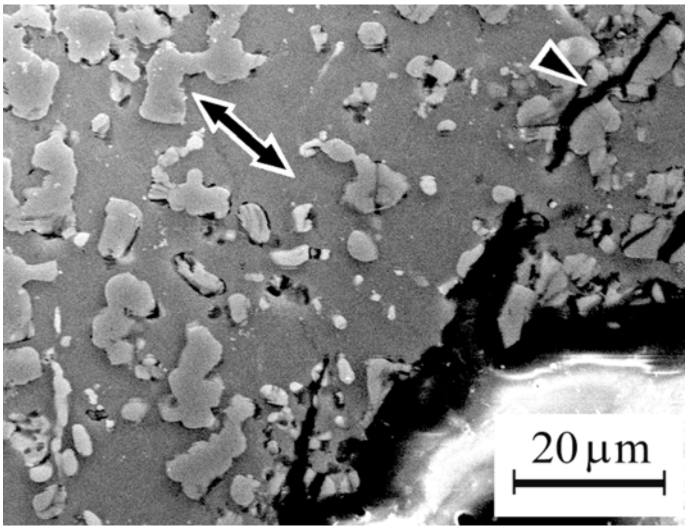


(b)

Figure 5.7   (continued)



(c)



(d)

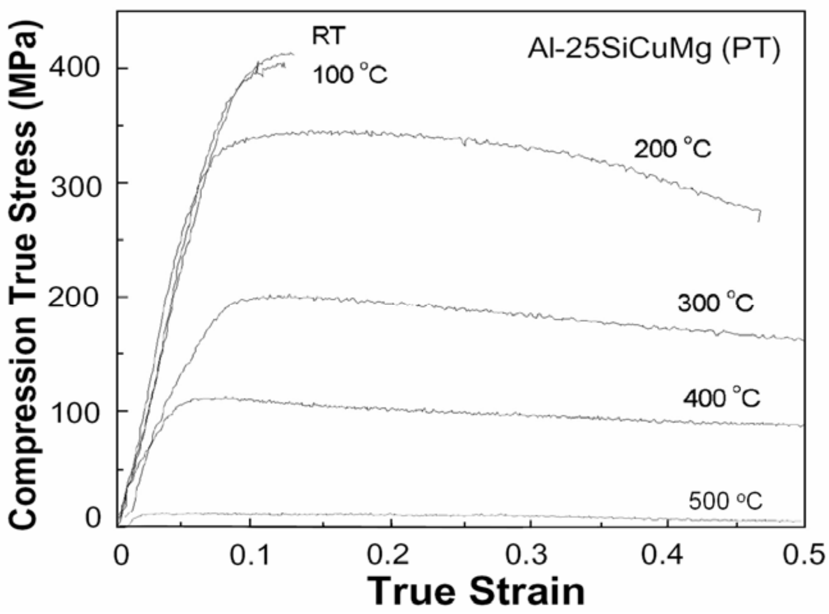
Figure 5.7 Tensile fractographs of the powder-thixocast specimens in (a) as-cast and (b) T6-treated state. Cross-section micrographs of these specimens beneath the tensile fracture surfaces are shown in (c) for as-thixocast and (d) for T6-treated specimens. Arrow←→indicated the tensile direction. The thixocast specimens were machined from the "plate" sections and fabricated using powders of size in 120~300μm and compacts consolidated at 550℃.

5.3.3 Compression strength at elevated temperature

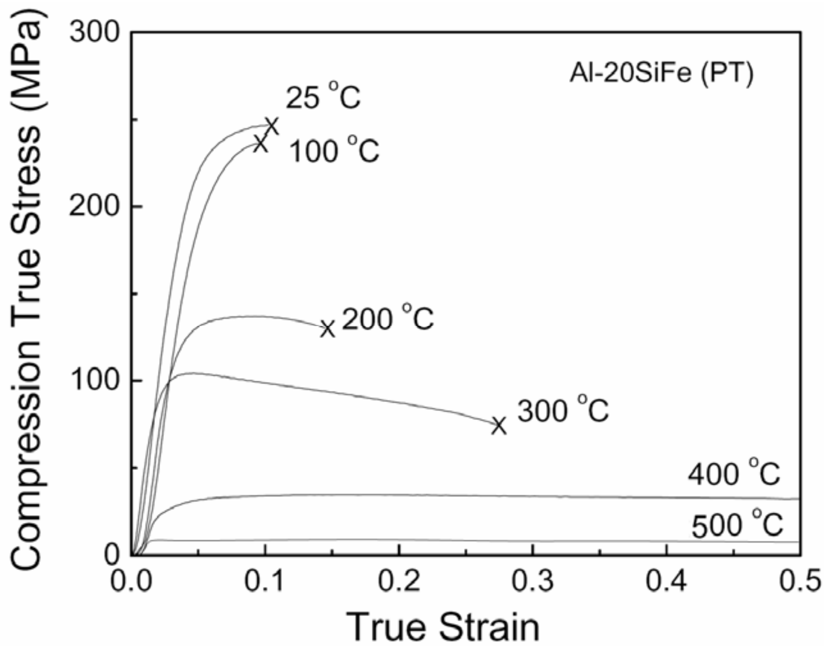
The elevated temperature compressive strengths of the as-prepared Al-Si-X alloys are shown in Figs. 5.8. The alloys have the sequence in the compressive strength to be: Al-25SiCuMg (PT)> Al-25SiCuMg (IT)>LM13>Al-20SiFe (PT). The sequence is the same as that when regarding their hardness values shown in Table 5.3.

Addition of Fe to an aluminum alloy was found to able to improve the high temperature strength through the precipitation of intermetallic phases of δ-Al_4FeSi_2 and β-Al_5FeSi during rapid solidification [23]. However, in this study, the Al-20SiFe (PT) alloy seems to have little such improvement in elevated temperature strength. This exception may be due to the grain coarsening of the intermetallic precipitates after powder thixocasting, since the primary Si particles of Al-20SiFe (PT) (Fig.2b) was found to be much coarser than those should present in conventional rapid solidified powders.

Figure 5.9 presents the compressive strengths of the Al-Si alloys at high temperature. Al-25SiCuMg (PT) alloy exhibited a much higher compressive strength than Al-25SiCuMg (IT) and LM13 alloys at low temperatures, revealing that the powder thixocast alloy possessed superior compressive strength at high temperature. However, the difference between the compressive strengths slowly disappears as the temperature increases (Fig. 5.9). When the temperature is 500 °C, Al the Al-Si-X alloys have similar low compressive strength of only 8 ~ 10 MPa.

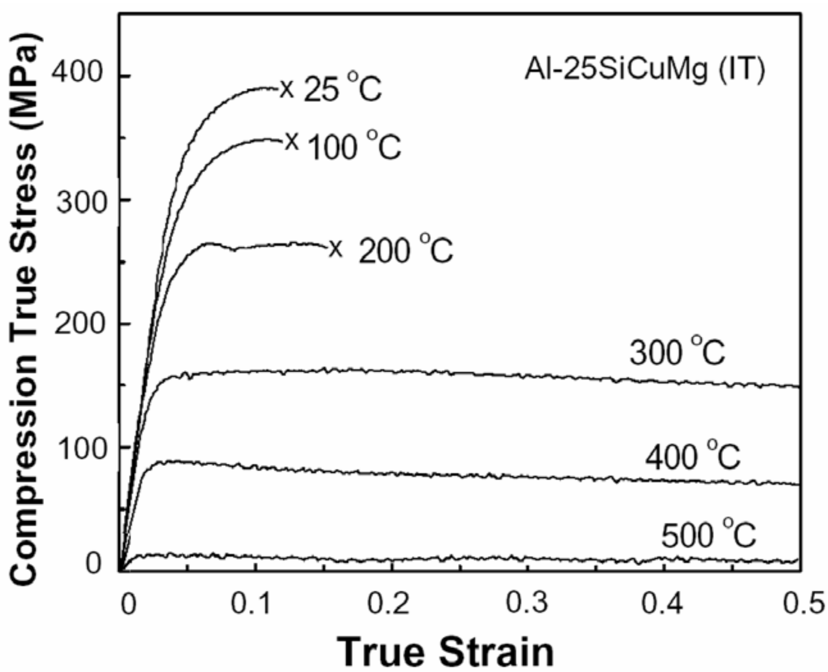


(a)

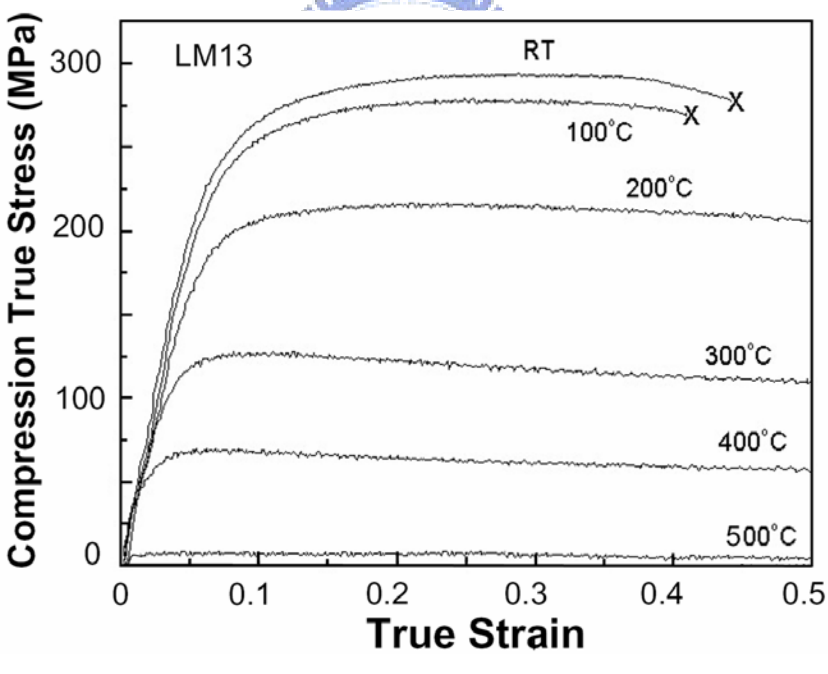


(b)

Figure 5.8 (continued)



(c)



(d)

Figure 5.8 Compressive stress-strain curves of as-prepared Al-Si-X alloys. (a)Al-25SiCuMg (PT), (b)Al-20SiFe (PT), (c)Al-25SiCuMg (IT), and(d)LM13 alloys.

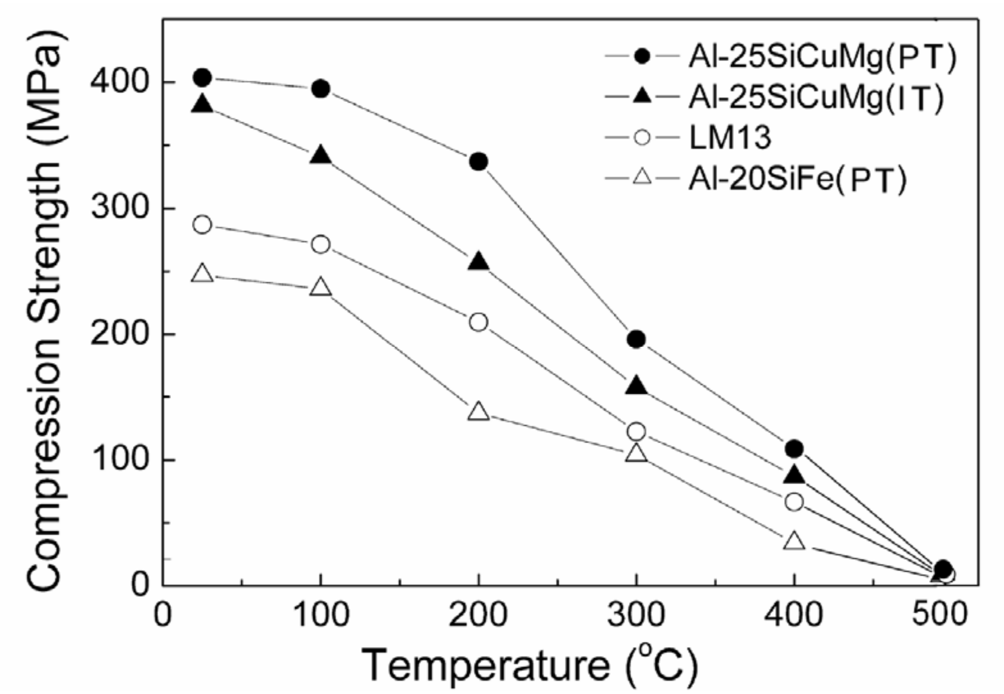


Figure 5.9 Compressive strength of the as-prepared Al-Si alloys varied with temperature.

5.4 Conclusions

1. The powder-thixocast samples have finer Si particle size and better strength than the ingot-thixocast samples.

2. The tensile fractographs of the powder-thixocast alloys show coexisting small dimples and cleavages of silicon particles. Furthermore, no decohesion of powder particles in tensile fracture surface were found, indicating an evidence of eliminating detrimental oxide interfaces after powder thixocasting.

3. The strength values of the as-thixocast and T6 specimens are 225 MPa and 304 MPa, respectively, which are close to those thixocast using feedstock made by spray forming followed by extrusion.

4. The reason that the powder thixocast Al-Si-X alloys have lower strength than those produced by powder forging is not only because the tendency of aggregation and coarsening of Si grains in the former case but also because that there are additional strain hardening effect in the latter case.