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Toughening Effect and Oxidation Behavior of MoSi₂-ZrO₂ Composites

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Objective

In this study, the influence of particle size and volume percentage of unstabilized ZrO₂-addition on toughening effect in MoSi₂-matrix composites were investigated. And, the negative effect of ZrO₂-addition on oxidation resistance of the composites was also observed. The aim of this study is to understand the both of positive and negative effects of ZrO₂-addition on the composites for reaching a comprehensive results.

Materials and Preparation

- The commercial Kanthal powder (KT-MoSi₂) with average size of 2.2 μm in diameter was applied for preparing the composites.
- The Five different USZ- ZrO₂-particle sizes between 0.74–5.6 μm and 10- 30 vol.% of <1 μm particles were used to prepare the testing materials.
- Composites were produced by two different powder metallurgical processes, including pressure-less sintering (PLS) at 1650°C in H₂ for 1 hour and hot-press sintering (HPS) at 1600°C in Ar under 52 MPa for 2 hours.

Testing

1. The hardness and fracture toughness were determined by using Vicker's indentation technique. And the fracture toughness was calculated by Anstis' equation.
2. The specimens were exposed in air under a temperature of 1400°C for 100 hours.
3. Backscattering electron images of SEM; EDS and XRD methods were applied for the analytical analysis.

Table 2. Marks of the MoSi₂ – 20vol.% ZrO₂ composites

Mark of sample	starting powder	sintering process
PLS – 1	KT-MoSi ₂ + SF-Extra	Pressure-less sintered
PLS – 2	KT-MoSi ₂ + DK-1	as above
PLS – 3	KT-MoSi ₂ + SF-premium	as above
PLS – 4	KT-MoSi ₂ + DK-2	as above
PLS – 5	KT-MoSi ₂ + DK-3	as above
PLS – 6	KT-MoSi ₂	as above

Table 5. Sintered density, room temperature hardness and toughness of five different ZrO₂-content composites prepared by PLS + HIP processes

Specimen	Sintered density (g/cm ³)	RT-Hardness (Hv, GPa)	RT-toughness (MPam ^{1/2})
HIP-1	6.31 (100%)	9.76 ± 0.20	4.50 ± 0.35
HIP-2	6.34 (100%)	9.64 ± 0.22	6.40 ± 0.35
HIP-3	6.17 (99.5%)	9.13 ± 0.25	5.65 ± 0.54
HIP-4	6.16 (99.5%)	8.96 ± 0.15	6.13 ± 0.41
HIP-5	6.16 (99.5%)	9.00 ± 0.20	5.79 ± 0.24

Table 3. Marks; compositions of KT-MoSi₂ + C208-ZrO₂ composites prepared by PLS + HIP processes

Mark of sample	Starting powder (vol. %)	Sintering process
HIP-1	90 vol. %KT-MoSi ₂ + 10 vol. % C208	Hot Isostatic Press
HIP-2	85 vol. %KT-MoSi ₂ + 15 vol. % C208	as above
HIP-3	80 vol. %KT-MoSi ₂ + 20 vol. % C208	as above
HIP-4	75 vol. %KT-MoSi ₂ + 25 vol. % C208	as above
HIP-5	70 vol. %KT-MoSi ₂ + 30 vol. % C208	as above

Conclusions

1. The particles of less than 1 μm usually generated the better results on sintered density, RT-hardness and RT-toughness of the composites, compared with the bigger particles.
2. The composites containing 15–25 vol.% USZ-particles showed a better toughening effect, compared to the composites having less or more particles.
3. External pressure of sintering process assisted the composites for a higher hardness, but slightly improved sintered density and toughness only. It means that the PLS process could be a practical and economical method for producing MoSi₂-ZrO₂ composites in industry.
4. A deteriorated oxidation resistance of MoSi₂-ZrO₂ composite compared to its monolithic counterpart is due to the formation of the porous oxide layer of ZrSiO₄+SiO₂ mixture and a retarded Si diffusion.
5. Therefore, an alloying addition for further forming a protective oxide layer is necessary on developing this type of composites.

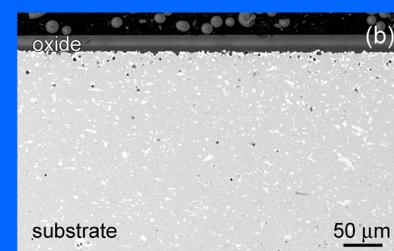
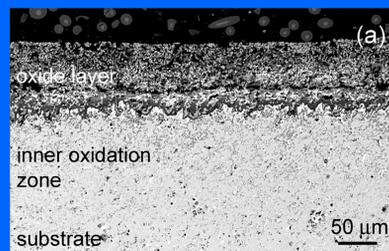


Fig.1 (a) shows the typical microstructures in the oxidized composite and monolithic specimens. The oxidized composite is characterized with a thick oxide layer and an inner oxidation zone with thickness of 110 μm and 200 μm respectively.

Fig.1 (b) the monolithic MoSi₂ exhibits an excellent oxidation resistance due to a protective silica scale with an average thickness 25 μm, which is under one fourth of that in the composite counterpart. No inner oxidation occurs in the sub-interface region.

Table 1. The starting powders of ZrO₂ used for preparing MoSi₂ – 20vol.% ZrO₂ composites

Commercial mark	SF-Extra	DK-1	SF-Premium	DK-2	DK-3
Average size (μm)	0.74	0.87	0.96	2.13	5.65

Table 4. Sintered density, room temperature hardness and toughness of MoSi₂ – 20vol.%ZrO₂ composites by PLS process

Specimen	Sintered density (g/cm ³)	RT-Hardness (Hv, GPa)	RT-toughness (MPam ^{1/2})
PLS-1	6.07 (98%)	7.82	5.79
PLS-2	6.13 (99%)	7.80	6.89
PLS-3	6.08 (98%)	7.48	5.63
PLS-4	6.02 (97%)	6.97	4.61
PLS-5	5.89 (95%)	6.01	4.06
PLS-6	6.07 (97%)	9.19	3.09

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