Thermodynamic and kinetic compatibility of nanoscale nonmetallic particles with metallic materials in casting and welding technologies

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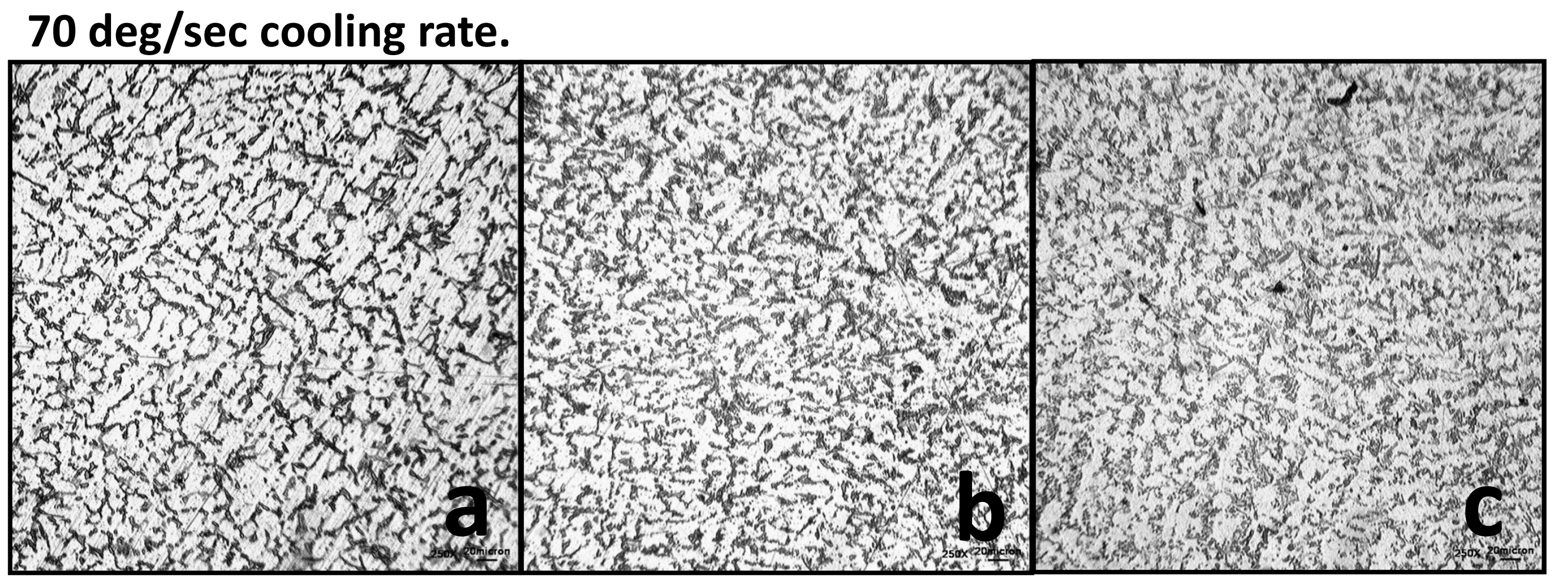
Objectives and Methods

The usage of non-metallic nano-scale particles is expedient for effect at the crystallization of a metal melt, within processes of foundry and welding technologies, and formation of protective and functional coatings. The approach includes the theoretical thermodynamic CALPHAD calculations and experimental studies (microstructure and thermal analyzes, mechanical and functional testing) to discover features (environment, time-temperature range, secondary phases, distribution) of the nano-scale particles' effect on the mechanical and functional properties of cast items, metallic coatings, and welded joints. The important thing is discovering the conditions of chemical compatibility of the components of such composite structure, including thermodynamic and kinetic compatibility because of the material heterogeneity.

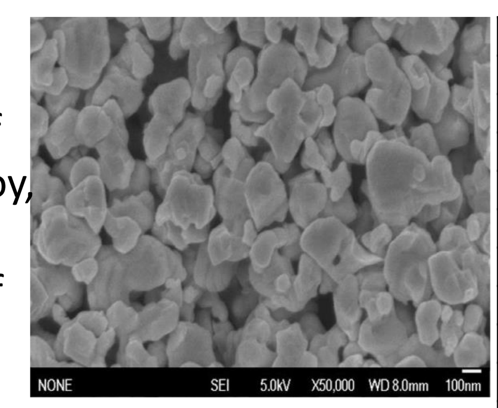
Results

There were discovered number of the aluminum alloys systems: 5183, 4047, 4043, 1100, 5356 and 7075 to be modified by non-metallic microstructure modifiers to improve characteristics of its welding joints. Particularly for 4th series (Al-Si) aluminum alloys with Si content more than 5 wt. % and Al10SiMg alloy, is promising to improve its welding joints by highly dispersed nano-scale tungsten carbide introduced into melt at conditions of inert gas (argon) or covering flux. Correspondent to thermodynamic calculations, DSC and microstructure analysis 5 wt. % and higher silicon in aluminum alloy completely blocks formation of the aluminum carbide, phase equilibrium shifts towards formation of the tungsten silicide and silicon carbide, both of these compounds are highly stable in aluminum melts and form fine grain type microstructure for cooling rates from 8-10 deg/sec up to 70 deg/sec, these rates are correspond to melt crystallization conditions during arc and electron beam welding processes. Welds of the 4th series (Al-Si) aluminum alloy content from 5 wt. % of Si can be hardened with highly dispersed particles of tungsten carbide (WC). TiC also be used for hardening aluminum alloys with Si content lower than 1 wt %. The higher silicon concentration of the melt leads to the formation of the titanium silicides (TiSi, $TiSi_2$) into the melt as a result of TiC reaction.

The result of Al10SiMg alloy melt modification by nano-cale 1 wt. % of tungsten and titanium carbide modifiers. Solidification accrued at 70 deg/sec cooling rate.

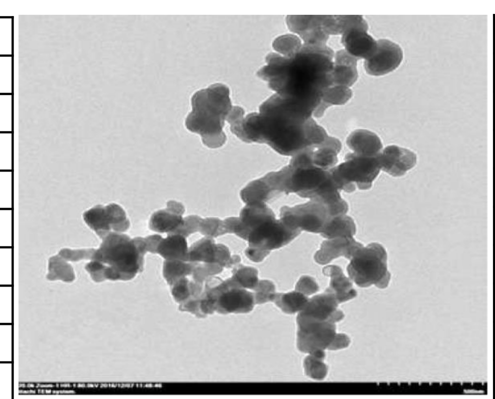


a - microstructure of as cast Al10SiMg alloy, x250;
b - microstructure of modified Al10SiMg alloy with titanium carbide, x250;
c - microstructure of modified Al10SiMg alloy with tungsten carbide, x250.



Tungsten carbide
WC - 99,5 wt. %;
APS - 200 nm;
ρ - 15.6 g/cm³

	wt. %
WC	99.0
T.C	0.28
F.C	0.1
Mg	0.001
Mn	0.001
Ti	0.001
Na	0.001
Al	0.001
Fe	0.002
Ca	0.001
Mo	0.001
Co	0.001
Cu	0.001
Cr_3C_2	0.1
VC	0.18
O	≦0.1



Titanium carbide
TiC - 99,9 wt. %;
APS - 50 nm;
ρ - 4,8 g/cm³

	wt. %
TiC	99.9
Fe	0.002
Ca	0.001
Mg	0.001
Cu	0.001
Mn	0.002
Na	0.001
Zn	0.001
Al	0.001
Ni	0.001
Pb	0.001
K	0.001
N	0.01
F.C	0.2
S	0.001
O	0.1

Conclusion

The study provides data to predict the impact of nanoscale powder usage corresponding to metallic base and the particles type. The results find the effects of nano-scale additions in the cast (aluminum alloys) and welding alloys (aluminum, steels), in the production of protective and functional (frictional) layers.