Lead Bismuth Eutectic (LBE) as thermal agent in concentrated solar power applications

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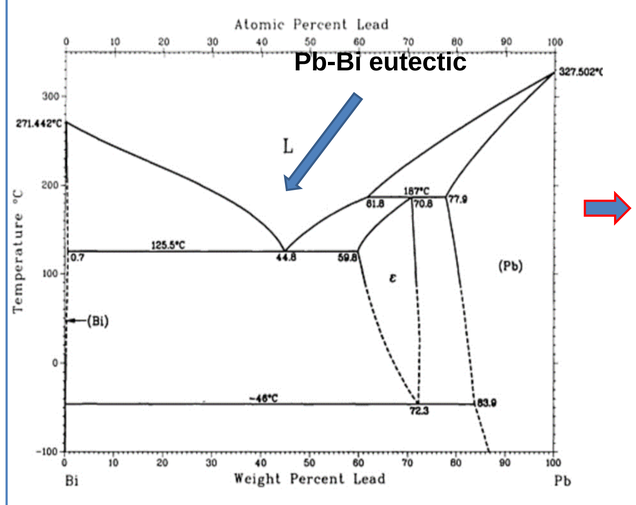
Abstract: Heavy liquid metals offer a wide range of uses in energy conversion systems due to their excellent thermal properties. Furthermore, the neutronic characteristics of different liquid metals make them appealing for fusion as well as Generation IV nuclear reactors. Concentrated solar power (CSP) systems, which can reach temperatures up to 800 ° C, have recently gained popularity. Lead Bismuth Eutectic (LBE), 44.5 wt% Pb + 55.5 wt% Bi, is one of the main candidates for solar thermal applications as liquid-metal coolant, due to its physical qualities such as high thermal conductivity, low melting point (~125 ° C) as well as high boiling point and low thermal expansion.
The process for synthesizing the LBE alloy by induction melting, as well as the structural properties and stoichiometry analysis of LBE, are presented. The structural properties were studied by X-ray diffraction, Scanning Electronic Microscopy (SEM), Energy Dispersive X-ray Analysis (EDX) and Differential scanning calorimetry (DSC).

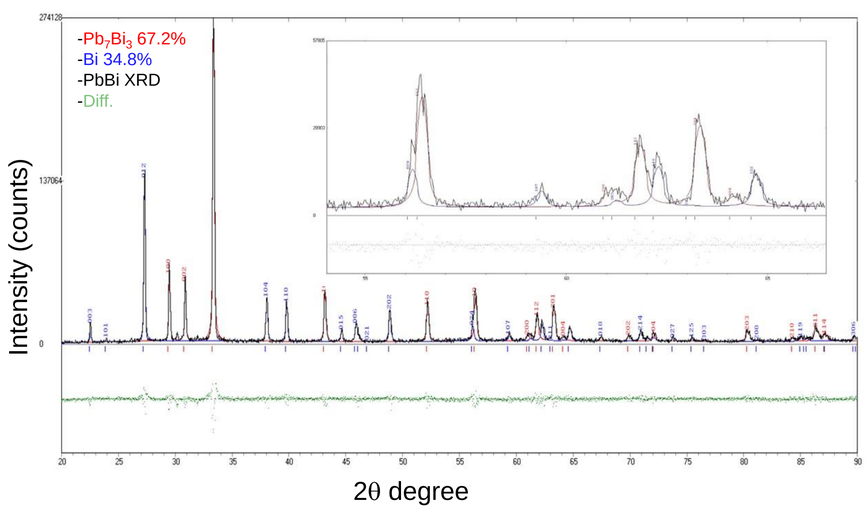
Experimental Details:

- Eutectic Pb-Bi ingot was prepared by induction melting of the starting components under a vacuum atmosphere.
- XRD investigation was performed using a Brüker D8 Advance X-ray diffractometer with Cu K_α radiation.
- The stoichiometry of our as-cast sample was investigated using the energy dispersive X-ray analysis (EDX).
- The homogeneity of the sample was investigated by using Scanning Electronic Microscopy.
- In order to find out the melting point of the LBE sample, a DTA measurement was performed.

Results and Discussions :

XRD Investigations:

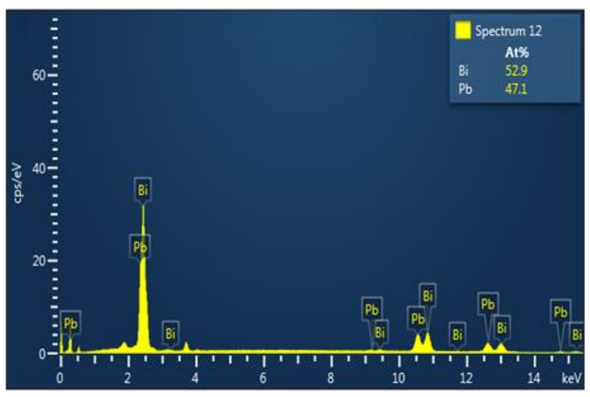


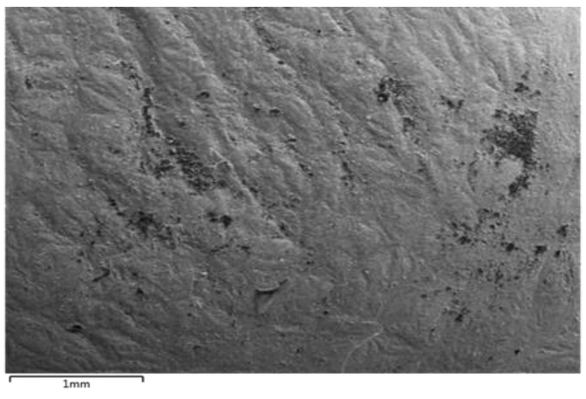


Structural phase	Space group	Lattice parameters(Å)	Lattice parameters from literatures (Å)	Phase concentration	XRD stoichiometry
ε-Pb_7Bi_3	194	a = 3.508 c = 5.808	a = 3.5058; c = 5.7959; [1]	65.2%	$Pb_{45.64}Bi_{54.36}$
Bi	166	a = 4.539 c = 11.871	a = 4.546 c = 11.862 [2]	34.8%	

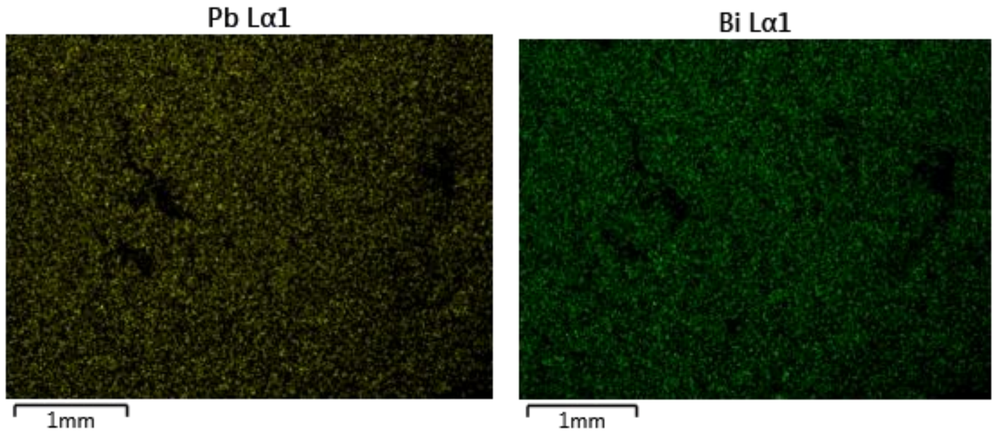
→ The Pb_7Bi_3 (hexagonal crystal structure) and Bi (trigonal crystal structure) phases, respectively, confirmed by XRD studies, indicates that the eutectic Pb-Bi alloy has been formed.
→ The values of lattice parameters are in good agreement with the values reported in literatures.
→ The XRD stoichiometry ($Pb_{45.64}Bi_{54.36}$) differs slightly from the ideal stoichiometry ($Pb_{45}Bi_{55}$), which can be attributable to measurement errors.

EDX and SEM investigations:



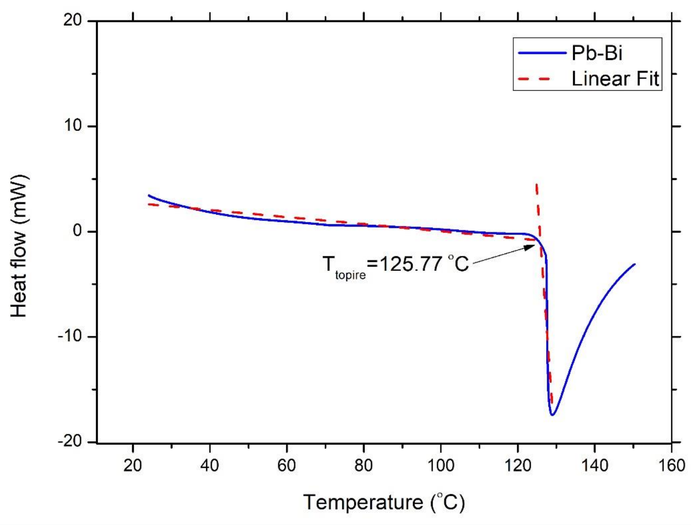


In terms of stoichiometry, the values obtained from EDX measurement and the XRD measurement are slightly different. Both methodologies have experimental measurement errors, which can explain for this discrepancy. On the other hand, in both situations there is less than a 4% deviation from the ideal ratio of the components.



The component elements are distributed uniformly throughout the SEM images. This indicates that the investigated sample is homogeneous.

DSC Investigations:



In the measured temperature range, a single endothermic transition can be seen on the DSC curve. The temperature at which this change occurs, according to the phase diagram, shows that the examined sample has transitioned from a solid to a liquid state, which is corresponding with the eutectic transformation of the Pb-Bi alloy. As a result, the melting point calculated using the tangent approach was 125.77 ° C. This value is close to the value of 125.5 ° C reported in the phase diagram for the Pb-Bi eutectic. The value of the melting point determined experimentally confirms that the stoichiometry of the studied sample is close to the real value of the Pb-Bi eutectic.

Conclusions:

- The crystalline structure investigated by XRD measurements, confirms the formation of the eutectic Pb-Bi alloy, by the coexistence of the Pb_7Bi_3 and Bi structural phases, in agreement with the phase diagram.
- The lattice parameters and phase concentrations were determined from the Rietveld refinements of the XRD diffractogram.
- The stoichiometry of the sample was determined by XRD and EDX measurements. The values of the stoichiometries obtained experimentally are within the limit of the accepted experimental errors, these being comparable.
- The homogeneity of the sample was demonstrated by SEM images.
- The value of the melting point determined from DSC measurements is close to the melting point reported in the phase diagram. This indicates that the stoichiometry of the investigated sample is close to the ideal value.

[1] S.E. Rasmussen, B. Lundtoft, "Crystal data for Pb7Bi3, a superconducting ε-phase in the Pb-Bi system", Powder Diffraction 2 (1986) 28.
[2] Wyckoff R W G, "Crystal Structures", (1963) p.7-83, Second edition. Interscience Publishers, New York, U.S.A.

Acknowledgment
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