engineering proceedings

MDPI

Proceeding Paper

Analysis of Mechanical Strength of Indium-Doped SAC 105 Lead-Free Solder Alloy †

Muhammad Sohail Hameed [1,*], Aneela Wakeel [1], Riffat Asim Pasha [1], Barkat Ullah [2] and Umair Ali [3]

[1] Department of Mechanical Engineering, Faculty of Mechanical & Aeronautical Engineering, University of Engineering and Technology, Taxila 74050, Pakistan; aneela.wakeel@uettaxila.edu.pk (A.W.); asim.pasha@uettaxila.edu.pk (R.A.P.)
[2] Department of Mechanical Engineering, COMSATS University Islamabad, Wah Campus, Wah Cantt 47040, Pakistan; barkat@ciitwah.edu.pk
[3] Department of Mechanical Engineering, CECOS University of Information Technology and Emerging Sciences, Peshawar 25000, Pakistan; umair@cecos.edu.pk
* Correspondence: miansohail910@gmail.com
† Presented at the Third International Conference on Advances in Mechanical Engineering 2023 (ICAME-23), Islamabad, Pakistan, 24 August 2023.

Abstract: The incorporation and doping of elements represent a widely used approach to enhance the solidity, integrity, and characteristics of pb-free solder joints. The present study summarizes the incorporation of indium and its impact on the mechanical aspects of the SAC105 pb-free solder alloy. To refine the mechanical impact of the solder alloy, the evaluation of samples were categorized into three groups: as-cast, low-thermal aged (at 125 °C), and high-thermal aged (at 180 °C). The tensile deformation data were obtained via the universal tensile machine (UTM). Investigational findings demonstrated the enhancement in mechanical characteristics, including ultimate tensile and yield strength of the solder alloy. The addition of 1 wt.% of indium to SAC105 led to a notable increase in ultimate tensile strength, rising from 29.6 MPa to 35.31 MPa, which corresponds to an approximate 19.30% increase over the initial value.

Keywords: lead-free soldering material; SAC105; UTM; ultimate tensile strength; indium-lead-tin-copper

check for updates

Citation: Hameed, M.S.; Wakeel, A.; Pasha, R.A.; Ullah, B.; Ali, U. Analysis of Mechanical Strength of Indium-Doped SAC 105 Lead-Free Solder Alloy. *Eng. Proc.* **2023**, *45*, 18. https://doi.org/10.3390/engproc2023045018

Academic Editors: Mohammad Javed Hyder, Muhammad Mahabat Khan, Muhammad Irfan and Manzar Masud

Published: 11 September 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Soldering is the process of joining metals by utilizing solder as a filler metal. For a long time, the electronics industry has used 63Sn-37Pb for component interconnection, owing to its outstanding and widely accepted qualities [1]. However, environmental and health considerations have resulted in limitations on the use of lead in the electronics industry [2]. Owing to the low recycling rate of electronics and the adverse effects of lead (Pb) on human health, its utilization in electronic components has been restricted [3]. Consequently, researchers have persistently worked to encourage the electronic industry to switch to lead-free soldering. The SAC family is the most effective and trustworthy alternative to conventional tin–lead soldering out of all lead-free solders [4]. Although, the SAC family consists of different doping compositions, which is to be considered as SAC305, SAC405, SAC105, SAC307, SAC396, and SA107 [5]. SAC305 is perceived as the most favorable choice among all these alternatives, while the concern of high cost is due to the high silver content [6]. The SAC105 is renowned for its suitability and attractiveness due to its cost-effectiveness and favorable thermal and mechanical properties [7].

Based on the existing literature, the primary focus of this investigation is to create a new, pb-free solder alloy (SAC105) infused with indium as a doping agent. Suchart Chantarmanee conducted a study on the mechanical characteristics of the (SAC305) pb-free solder [8]. Similarly, Sungkhaphaitoon et al. [9] investigated the impact of adding indium to SAC305 by the resulting hardness of the new alloy. In this study, the ultimate tensile

and yield strength of the solder alloy were investigated by adding indium as the doping element to SAC105 under various thermal aging temperatures.

2. Experimental Procedure

Tensile specimens of Sn, Ag, and Cu with the addition of In were prepared using the casting process. Figure 1 illustrates the raw materials used for the fabrication of the tensile test specimen. Raw materials in powdered form were imported from China with almost a 99.89% purity level of each element. Subsequently, the powders were carefully weighed using a highly precise scale and then mixed at 98% tin, 1.0% Ag and 0.5% Cu by weight. A ball milling apparatus was used for mixing these elements for 45 min to acquire a uniform composition of alloys using the inclusion of propanol and isopropyl alcohol (IPA). The complete composition of the preparing samples at various percentages by weight are listed in Table 1. The elements were subsequently poured into an alumina crucible and then positioned within a muffle furnace at 1250 °C to attain the ultimate melting point of each element. Subsequently, the liquefied metal was poured in a specially prepared die to obtain the tensile samples, as shown in Figure 2. In a similar way, the casting process is discussed by Umair Ali et al. to prepare the tensile specimens [6].

Figure 1. Raw materials were utilized in the preparation of samples: (**a**) tin, (**b**) silver, (**c**) copper, and (**d**) indium.

Table 1. The weight composition of doping elements.

Sr. No.	Alloy	Wt.%			
		Sn	Ag	Cu	In
1	SAC105	98.50	1.0	0.5	0.0
2	SAC105-1In	97.50	1.0	0.5	1.0

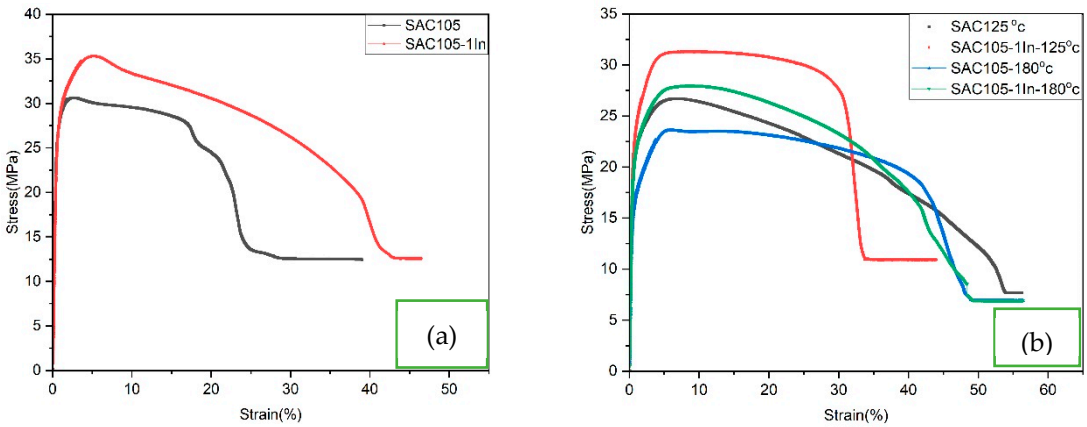

Figure 2. UTM curves (**a**) as a casted alloy and (**b**) thermally aged at 125 °C and 180 °C.

3. Results and Discussion

The reason for opting for a lead-free solder alloy was that the doping of an alloy to the pb-free soldering material has the capability to improve the characteristics of the SAC105 solder alloy. Figure 2 illustrates the stress–strain graphs observed during the tensile testing of SAC105 and SAC105+1In at a continual tensile rate of 0.5 mm/m at normal temperature. As a result, it has been observed that the addition of indium has increased the mechanical strength of SAC105. The highest strength of SAC105 was recorded with 1 wt.% of In. The yield strength (Y.S) was measured at 33 MPa, while the ultimate tensile strength (UTS) reached 35.31 MPa with 1 wt.% of indium.

Figure 2b demonstrates the deformation characteristics of specimens subjected to thermal exposure at 125 °C and 180 °C, respectively. The validation of the results and the comparison of the findings with the existing literature were undertaken. The corresponding outcomes were documented by M.H. Mahdavifard et al. [10], as well as H. Fallahi et al. reported the effect of indium upon the mechanical characteristics of the non-toxic solder alloy [11]. The study conclusion corelates and best matches with the previous findings and also makes a comparison of the indium-doped and without indium alloy. In this way, the findings were validated.

ASTM Standard

The ASTM Standard B32 especially deals with solder alloys having a melting zone less than 430 °C, which was followed in the preparation of the cast tensile specimen. The tensile test was performed by using a UTM at the tensile rate of 0.5 mm/m. Figure 3 depicts the geometry of a casted tensile specimen.

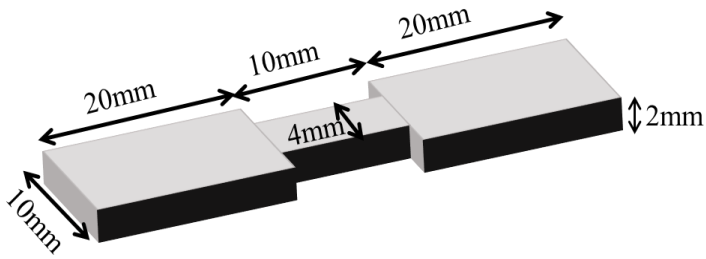

Figure 3. Geometry of casted tensile specimen.

4. Conclusions

The aim of this study was to examine the impact of indium on the mechanical characteristics of the SAC105 non-toxic solder alloy. Based on the empirical findings, the doping of indium could enhance the mechanical aspects of SAC105. In conclusion, it has been observed that the ultimate tensile strength of the indium-based SAC105 pb-free solder alloy exhibits the maximum UTS in comparison to all the other alloys that have been synthesized. Although the UTS decreases as the thermal aging increases, it is important to note that the mechanical properties of the indium-based alloy exhibited superior strength in comparison to both the undoped and aged SAC105.

Author Contributions: Conceptualization, M.S.H.; methodology, M.S.H. and U.A.; validation, M.S.H.; writing—original draft preparation, M.S.H.; writing—review and editing, M.S.H. and B.U.; supervision, A.W. and R.A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Available on request.

Acknowledgments: The author wishes to express his heartful appreciation and gratitude to Muhammad Abid for the support and facilitation to perform the UTM testing at COMSATS University, Islamabad Sahiwal Campus.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fazal, M.A.; Liyana, N.K.; Rubaiee, S.; Anas, A. A critical review on performance, microstructure and corrosion resistance of Pb-free solders. *Meas. J. Int. Meas. Confed.* **2019**, *134*, 897–907. [CrossRef]
2. Aamir, M.; Muhammad, R.; Tolouei-Rad, M.; Giasin, K.; Silberschmidt, V.V. A review: Microstructure and properties of tin-silver-copper lead-free solder series for the applications of electronics. *Solder. Surf. Mt. Technol.* **2020**, *32*, 115–126. [CrossRef]
3. Sun, L.; Zhang, L. Review Article: Properties and Microstructures of Sn-Ag-Cu-X Lead-Free Solder. *Adv. Mater. Sci. Eng.* **2015**, *2015*, 639028. [CrossRef]
4. El-Daly, A.A.; Hammad, A.E.; Fawzy, A.; Nasrallh, D.A. Microstructure, mechanical properties, and deformation behavior of Sn-1.0Ag-0.5Cu solder after Ni and Sb additions. *Mater. Des.* **2013**, *43*, 40–49. [CrossRef]
5. Ma, H.; Suhling, J.C. A review of mechanical properties of lead-free solders for electronic packaging. *J. Mater. Sci.* **2009**, *44*, 1141–1158. [CrossRef]
6. Ali, U.; Khan, H.; Aamir, M.; Giasin, K.; Habib, N.; Awan, M.O. Analysis of microstructure and mechanical properties of bismuth-doped SAC305 lead-free solder alloy at high temperature. *Metals* **2021**, *11*, 1077. [CrossRef]
7. Yang, T.; Chen, Y.; You, K.; Dong, Z.; Jia, Y.; Wang, G.; Peng, J.; Cai, S.; Luo, X.; Liu, C.; et al. Effect of Bi, Sb, and Ti on Microstructure and Mechanical Properties of SAC105 Alloys. *Materials* **2022**, *15*, 4727. [CrossRef] [PubMed]
8. Chantaramanee, S.; Sriwittayakul, W. Effects of Antimony and Indium Addition on Wettability and Interfacial Reaction of Sn-3.0Ag-0.5Cu Lead Free Solder on Copper Substrate. *Mater. Sci. Forum* **2018**, *928*, 188–193. [CrossRef]
9. Sungkhaphaitoon, P.; Chantaramanee, S. Effects of Indium Content on Microstructural, Mechanical Properties and Melting Temperature of SAC305 Solder Alloys. *Russ. J. Non-Ferrous Met.* **2018**, *59*, 385–392. [CrossRef]
10. Mahdavifard, M.H.; Sabri, M.F.M.; Said, S.M.; Rozali, S. High stability and aging resistance Sn-1Ag-0.5Cu solder alloy by Fe and Bi minor alloying. *Microelectron. Eng.* **2019**, *208*, 29–38. [CrossRef]
11. Fallahi, H.; Nurulakmal, M.S.; Fallahi, A.; Abdullah, J. Modifying the mechanical properties of lead-free solder by adding iron and indium and using a lap joint test. *J. Mater. Sci. Mater. Electron.* **2012**, *23*, 1739–1749. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.