Solid State Phenomena
ISSN: 1662-9779, Vol. 330, pp 71-76
doi:10.4028/p-ux638q

Submitted: 2021-08-25
Accepted: 2021-11-22
Online: 2022-04-12

The Influence of Diffuse Element in Solid-State on Dissimilar Joint between Semi-Solid Cast 7075 with 6061 Al Alloy by Diffusion Welding

Chaiyoot Meengam[1,a*], Yongyuth Dunyakul[2,b] Suppachai Chainarong[1,c] and Dech Maunkhaw[2,d]

[1]Faculty of Industrial Technology, Songkhla Rajabhat University, Songkhla, Thailand

[2]Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Srivijaya, Songkhla, Thailand

[a]Chaiyoot.me@skru.ac.th, [b]Dyongyuth@gmail.com*, [c]Suppachai.ch@skru.ac.th, [d]Dechmaunkhaw@yahoo.com

Keywords: Diffusion Welding; SSC 7075 Al Alloy; SSC 6061 Al Alloy; Dissimilar Joint

Abstract. The purpose of this research was to study the diffuse element and mechanical property of Semi-solid casting (SSC) 7075 and 6061 Al alloy from diffusion welding (DW). The results found that Zn elements were successfully diffused. Mg_2Si and $MgZn_2$ intermetallics were precipitated from plate-like shape to flake shape. The high bonding temperature and bonding time caused diffuse elements distributed throughout the material. The mechanical property showed that the maximium average tensile strength was 76.80 MPa from bonding temperature at 723 K and 120 min bonding time. The hardness in bonded line was around 63 HV to74 HV.

Introduction

Semi-solid casting of aluminum alloy is a novel material that was developed to solve problems from traditional casting by Wisutmethangoon et al. [1]. Especially, Gas Induced Semi-solid technique (GISS) is one method that has been invented by Wannasin et al. [2] to solve cracks, incomplete casting, voids, and shrinkage of castings. However, the α-Al matrix from semi-solid castings is constructed in globular shape [3]. The Al/Zn and Al/Mg alloys were produced by the semi-solid casting with GISS technology for application in the automotive industries due to their lightweight, excellent performance on corrosion resistance, creep behavior, and tensile strength. Nowadays, it shows that the use of Al alloy is increasing in automobiles especially for body structure, doors, hood, and decklid are bolted [4]. The Al alloys are being developed to support these automotive parts.

However, the optimal welding method for materials produced by semi-solid casting is challenging and interesting because its microstructure may change from globular shape to the dendrite structure in weld zone with fusion welding [5] and numerous defects after welding [6]. The diffusion welding is a solid-state welding. The welding temperature is around 0.5-0.8Tm, which heat input is lower than Tm (when Tm is the melting temperature of materials) [7]. This method has its own advantages on produced microstructures in bonded lines similar to those of the base metal, low distortion, ability to weld different materials, no filler rod, and no defects associated with fusion welding [8]. Moreover, the DW of both materials is difficult because the different Tm of the different materials, chemical composition, and diffusion coefficient values [9].

Thus, this research studied the diffuse element behavior in the solid-state dissimilar butt joint between Al/Zn-SSC 7075 with Al/Mg-SSC 6061 Al alloys to evaluate the diffusion and distribution of the elements after DW, and solve problems of welded joint of different materials. The results were evaluated to analyze the diffuse element by an optical microscope (OM), a scanning electron microscope (SEM), and an energy-dispersive X-ray spectroscope (EDS) on the effects and characteristics of globular structures in bonded joints. Then, the tensile strength and hardness properties were examined.

Materials and Methods

Experimental

In the experiments, the SSC 7075 and SSC 6061 Al alloy were taken as experimental materials, with the chemical compositions of both materials shown in Table 1. The base microstructure has a globular shape consisting of matrix phase in α-Al and $MgZn_2$ intermetallic compound of SSC 7075 Al alloy and the Mg_2Si intermetallic compound of SSC 6061 Al alloy shown in Fig 1. The sample was prepared to be a cylindrical shape with the dimensions of Ø10×40 mm. The sample surface was polished by P320 grit SiC paper and cleaned with acetone; then, used hot blow until the surface of the sample is dry.

Table 1 Chemical compositions by wt% of SSC 7075 and SSC 6061 Al alloy used in this work [10]

Materials	Zn	Mg	Cu	Fe	Cr	Si	Ti	Mn	Al
7075	6.08	2.50	1.93	0.46	0.19	-	-	-	Bal.
6061	0.25	0.80	0.18	0.70	-	0.40	0.15	0.15	Bal.

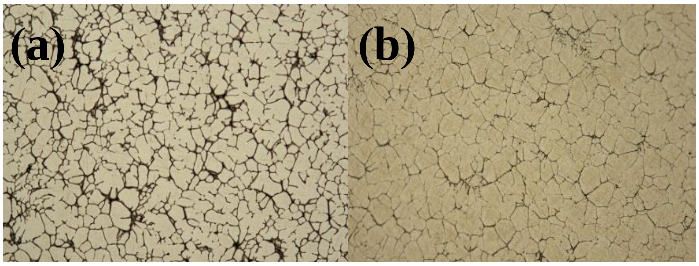

Figure 1. The base microstructures are (a) SSC 7075 and (b) SSC 6061 Al alloy.

The parameters used in the experiments consist of bonding temperature, bonding time, contact pressure under argon gas atmosphere. These parameters were preliminary experiments to evaluate the results after welding. They were then determined as a constant parameter in the experiment. The DW parameters are shown in Table 2. For bonding temperature, this was automatically controlled from room temperature to reach the bonding temperature at the rate of 13 Kelvin per min following by holding temperature, and then cool it down.

Table 2 Parameters of the DW conditions in this experiments

Parameter	Units	Values
Bonding temperature	Kelvin (K)	637, 723 and 773
Bonding time	min	60 and 120
Contact pressure	MPa	4
Argon gas flow rate	l/min	9

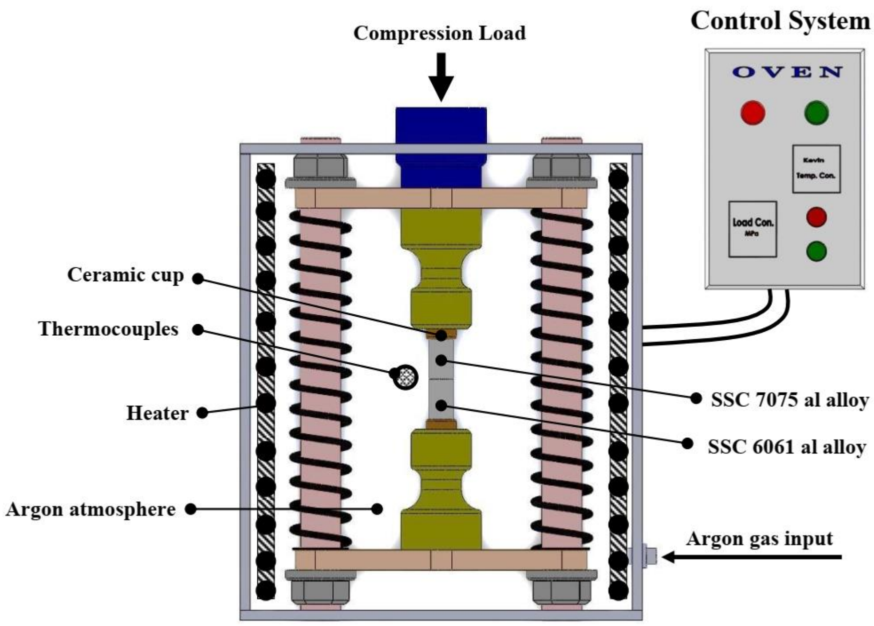

Figure 2. Schematic of DW of the dissimilar joint between SSC 7075 with SSC 6061 Al alloy.

Metallurgy

The samples for metallurgy analysis were cut in cross-section and polished their surfaces with P180, P320, P600, P800, P1000, and P1200 grit SiC paper respectively. Then, grinding with Al_2O_3 powder at 5, 1, and 0.3 µm and etched with Keller's reagent (when Keller's reagent was composed of 190 ml in H_2O, 2 ml in HF, 3 ml in HCl, and 5 ml in HNO_3). The scanning electron microscope brand FEI-Quanta model 450 was used to analyze the diffusion and distribution of the elements while the light optical microscope brand Reich, model: FMA037 was used to analyze defects and diffusion behavior.

Mechanical Testing

The sample preparation for tensile strength testing was done by following the ASTM E8-04 standard [11]. The tensile strength was tested by a machine brand LLOYD model EZ50 (MSI-Viking Gage, Duncan, SC, USA) and executed under room temperature. The hardness was tested by a Zwick/Roell Vicker's universal hardness tester model: ZHU (ZwickRoell GmbH&Co.KG, Germany) with a compressive load test at 100 gf, holding time for 10 sec. This was measured on the sample surface at every 0.2 mm distance away from the center.

Results and Discussion

Microstructure in Bonded line

The microstructure in bonded line of DW dissimilar joint between SSC 7075 and SSC 6061 Al alloy is shown in Fig 3. The bonding temperature and bonding time significantly change the microstructure, which α-Al phases in SSC 7075 Al alloy forms successful precipitation ability at high temperatures. For lower bonding temperature and less bonding time, asperities surface could be found and shown in Fig 3(a). On the contrary, pores can be eliminated through volume diffusion by increasing the bonding time and bonding temperature shown in Fig 3(f). However, if both parameters in the experiment were too high, it would have the potential to the grain to expand and the microstructure to grow (Fig 3(a-f)). This also resulted in the samples to become plastic deformation - deflected, distorted and enlarged [12].

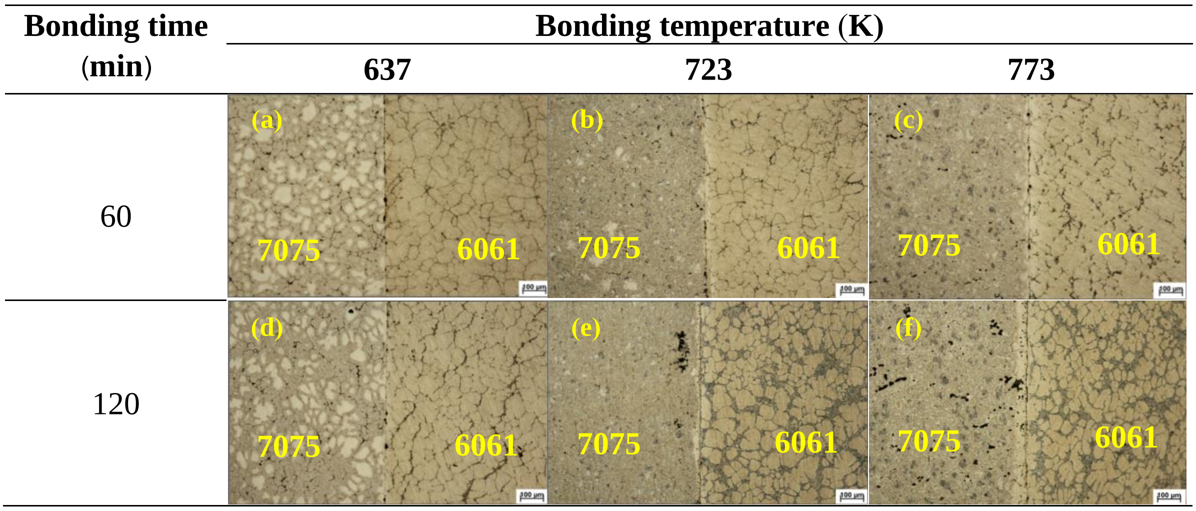

Figure 3. The OM photography of microstructure at 200X magnification was obtained from the bonded line in all experiments.

Characteristics in Diffuse Element

The evaluation of $MgZn_2$ and Mg_2Si intermetallic compounds indicates the distribution transformation phase. At 637 K in bonding temperature and 60 min bonding time, Mg_2Si and $MgZn_2$ intermetallic compound formed as the plate-like shape shown in Fig 4(a and b). The element of 0.40%Si, 0.80%Mg, and 0.70%Fe with high concentrations from SSC 6061 Al alloy can diffuse to SSC 7075 Al alloy. On the contrary, 6.08%Zn, 2.50%Mg, and 1.93%Cu with a high concentration of elements in SSC 7075 Al alloy which are good for the diffusion of the elements shown in Fig 4(c-m). However, the addition of bonding temperature and bonding time results in more complete precipitation shown in Fig 5(a and b). It also shows that the Mg_2Si and $MgZn_2$ intermetallic compound forms as a flake shape. The thermal energy activates atoms of the material to move on as shown in Fig 5(c-m) [13]. Also, it can be noticed that the Zn element has a low melting point and good diffusion coefficient. As a result, it can diffuse well into the bonded line. This can be explained by the high Zn concentration in the bonded line. Another reason for diffuse element relating to atomic size is that the smaller atomic size of the element makes the diffusion better than the larger atomic size [14].

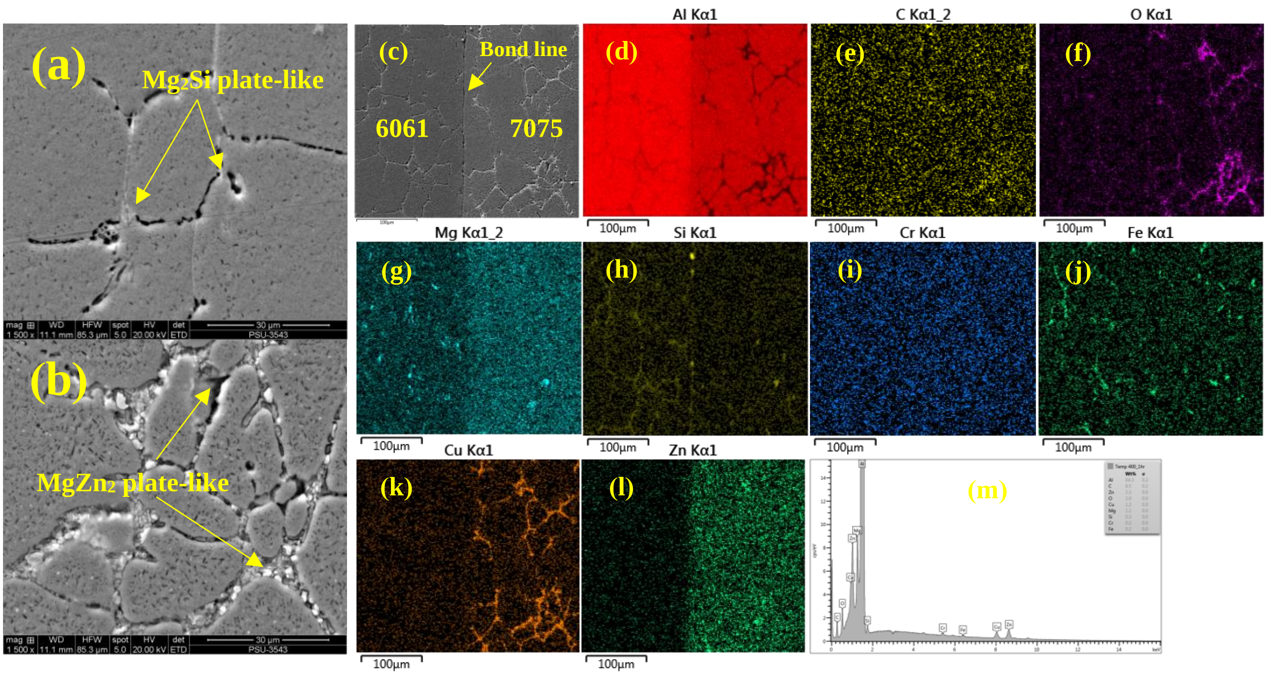

Figure 4. The energy-dispersive x-ray spectroscopy analysis at 637 K in bonding temperature and 60 min in bonding time of DW dissimilar joint between SSC 7075 with SSC 6061 Al alloy.

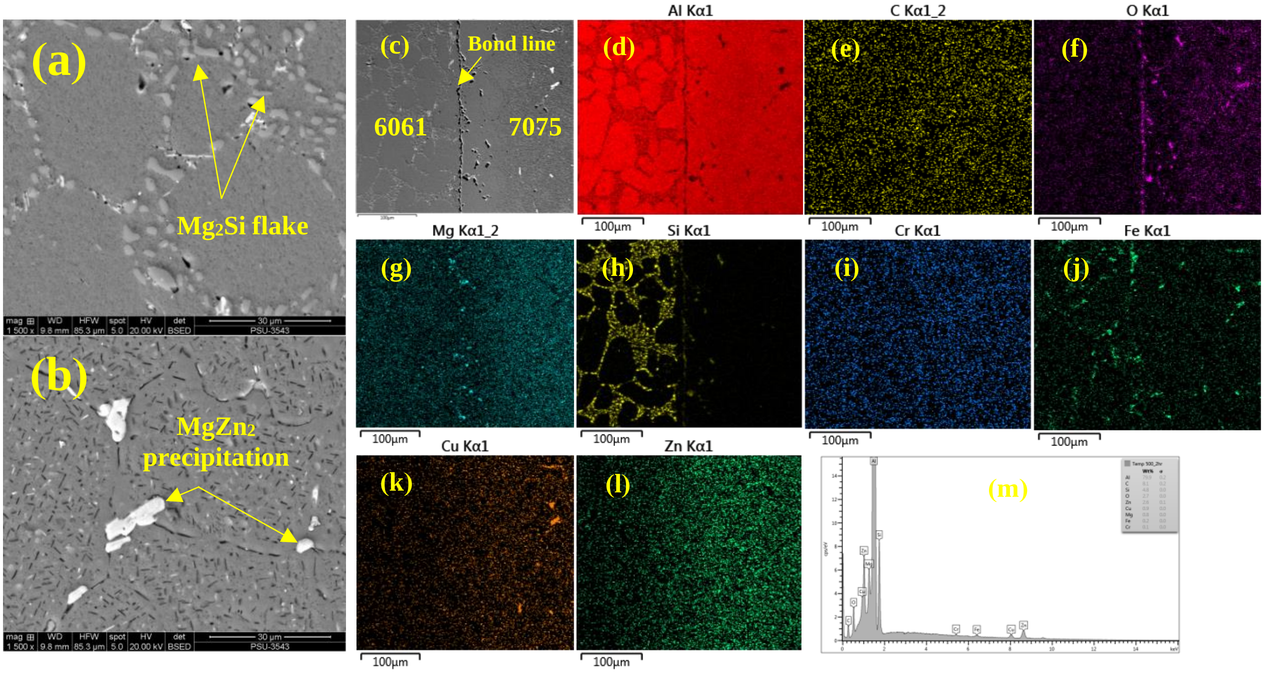

Figure 5. The energy-dispersive x-ray spectroscopy analysis at 773 K in bonding temperature and 120 min in bonding time of DW dissimilar joint between SSC 7075 with SSC 6061 Al alloy.

Mechanical Property Analysis

Fig. 6 shows the result of the tensile strength test on DW of the dissimilar joint of SSC 7075 with SSC 6061 Al alloy. The average maximum tensile strength was 76.80 MPa from 723 K in bonding temperature and 120 min in bonding time. In contrast, from 637 K in bonding temperature and 60 min in bonding time, the average maximum tensile strength was 23.12 MPa. However, bonding temperature at 773 K and bonding time for 120 min tends to cause lower tensile strength due to the sample deformation. The step for pore elimination through volume diffusion was succeeded leading to good tensile properties. The pore that remained after DW causes the initial of tear from the tensile strength test. This causes the tensile strength to be lower. However, the joint efficiency of DW is in the range of 10 to 40 percent of the tensile strength of the base metal [15]. The tensile strength of SSC 6061 and SSC 7075 Al alloy base metal were at 126.94 MPa and 144.17 MPa respectively.

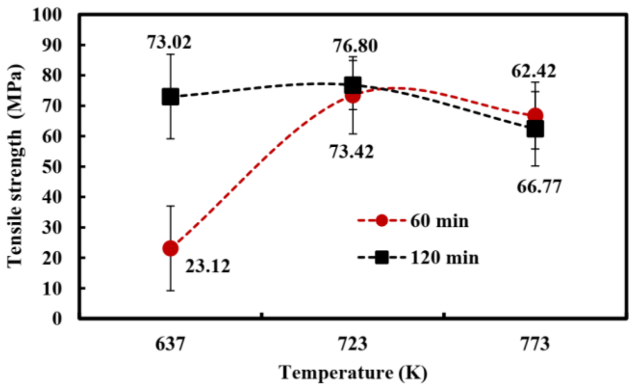

Figure 6. The tensile strength on DW of the dissimilar joint of SSC 7075 with SSC 6061 Al alloy.

The hardness profiles obtained from DW different material between SSC 7075 with SSC 6061 Al alloy are shown in Fig. 7. The result shows that the bonding temperature at 773 K tends to have higher hardness than what other temperatures did. In the same way, the bonding time for 120 min shows a higher hardness more than the bonding time for 60 min. This is because Mg_2Si and $MgZn_2$ intermetallic compounds precipitated in grain, intergranular, and distributed throughout into α-Al phases [16].

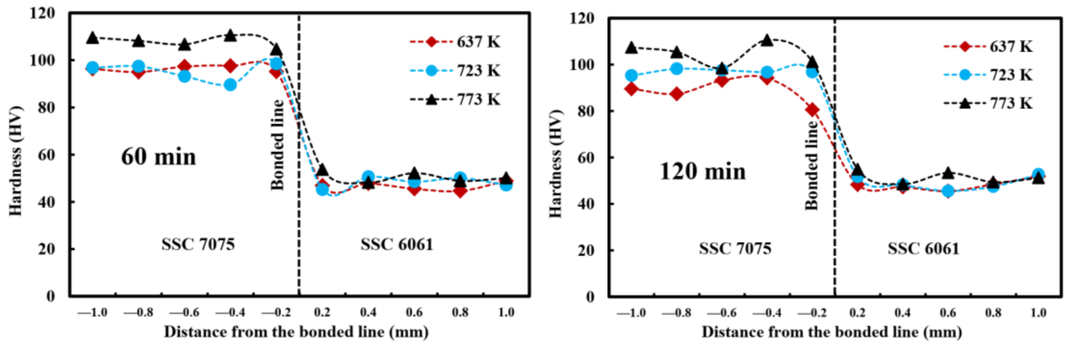

Figure 7. The hardness profiles on DW different material between SSC 7075 and SSC 6061 Al alloy.

Conclusions

The elements in SSC 7075 and SSC 6061 Al alloy were precipitated in a good solid-state form with the DW technique. Especially, the Zn element was formed in good agreement with diffusion ability. The Mg_2Si and $MgZn_2$ intermetallics distributed in the bonded line increasing in the hardness property. The successful diffusion mechanism causes the pore at the surface of the bonded line to be eliminated. From the experiment, it was found that bonding temperature at 723 K and 120 min in bonding time could provide the maximium average tensile strength at 76.80 MPa.

Acknowledgments

This work was supported by the Faculty of Industrial Technology, Songkhla Rajabhat University and GISCO Company Limited., Songkhla in Thailand.

References

[1] S. Wisutmethangoon, S. Janudom, R. Burapa, P. Dulyapraphant, J. Wannasin, T. Nonferr. Metal. Soc. 20(3) (2010) p. s1016-s1021.

[2] R. Canyook, S. Petsut, S. Wisutmethangoon, M.C. Flemings, J. Wannasin, T. Nonferr. Metal. Soc. 20(9) (2010) p. 1649-1655.

[3] J. Wannasin, R. Canyook, S. Wisutmethangoon, M.C. Flemings, Acta Mater. 61 (2013) p. 3897–3903.

[4] Kh. A. Ragab, A. Boualcha, M. Bouazara, T. Nonferr. Metal. Soc. 28(6) (2018) p. 1226-1232.

[5] C. Meengam, P. Muangjunburee, S. Chainarong, AMR. 881-883 (2014) p. 1301-1306.

[6] B. Zhou, S. Lu, K.L Xu, C. Xu, Z.Y Wang, T. Nonferr. Metal. Soc. 30(2) (2020) p. 318-332.

[7] F. Zhu, H. Peng, X. Li, J. Mater. Des. 159 (2018) p. 68-78.

[8] Z. Wang, C. Li, J. Qi, J. Feng, J.Cao, Int. J. Hydrog. Energy. 44(13) (2019) p. 6929-6937.

[9] C. Meengam, Y. Dunyakul, D. Maunkhaw, S. Chainarong, Metals. 8, 0637 (2018) p. 1-13.

[10] D. Min, Mater. Ultrason Sonochem. 52 (2019) p. 150-156.

[11] ASTM E8/E8M-09, ASTM International., April 3, 2020.

[12] S. Zeng, G. You, F. Yao, J. Luo, X. Tong, Mater. Sci. Eng. A. 804 (2021) 140782.

[13] S. Sebastian, V. Suyamburajan, Mater. Today. Proc. 37(2) (2021) p. 1706-1712.

[14] G. Sharma, D. K. Dwivedi, Mater. Today. Proc. 44(1) (2021) p. 2135-2141.

[15] A. Xydou, S. Parviainen, F.G. Djurabekova, Results Phys. 16 (2020) 102890.

[16] S. Kundu, M. Ghosh, S. Chatterjee, Mater. Mater. Sci. Eng. A. 428 (2006) p. 18-23.