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A simulation on the effect of ultrasonic vibration on ultrasonic assisted soldering of Cu/SAC305/Cu joint

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ABSTRACT

In the modern electronic packaging industry, the trend of miniaturization and the demand for advanced features of electronic devices have greatly reduced the size and weight of the electronic packages but increased the density of the packaging system. Higher input/output current density has to flow through these miniature interconnects or solder joints within the packaging system and thus, causing heat generated by the system to increase tremendously. This has driven the packaging design to include a built-in thermal enhancement feature, such as a large area bottom metal or heat sink to provide a direct thermal path out from the package to ease heat dissipation. So the main objectives of this study are to valid experimental work for solder joint failure due to the ultrasonic vibration and to investigate better mechanical properties for solder joint by FE analysis. ANSYS software has been used to analysis boundary conditions with the assistance of design modular (DM) to produce the model then export the model to ANSYS. After that input boundary conditions, the output of the simulation is shear stress then compare shear stress of experimental work with the output of the simulation. From the finding of 87% comparison between simulation to experimental work so will continue to try new parameters with same boundary conditions. It is showed that the maximum shear strength is 55 MPa for Cu/SAC305/Cu when it treated with 50 kHz for 4.5 sec and minimum shear strength is 35 MPa when it treated with 70 kHz at control time (0 sec). finally, this study discovered that the best method to improve mechanical properties for Cu/SAC305/Cu solder alloy treat this solder joint with frequency 50 kHz for 4.5 sec to get maximum shear strength.

1. Introduction

In the modern electronic packaging industry, the trend of miniaturization and the demand for advanced features of electronic devices have greatly reduced the size and weight of the electronic packages, but increased the density of the packaging system. Higher input/output current density has to flow through these miniature interconnects or solder joints within the packaging system and thus, causing heat generated by the system to increase tremendously [1].

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The investigation for the interfacial reaction on Cu pad, the smaller the solder ball is, the larger the interfacial Cu6Sn5 grains are, the thicker the intermetallic compound (IMC) layer is, and the less the Cu pad consumption is. The Cu concentration approached the solution saturation more rapidly in the smaller solder joint through grain boundary diffusion, resulting in smaller Cu outflux at the interface and consequently coarser interfacial Cu6Sn5 grains [2,14].

SnAgCu solder alloys simulations as one of the most popular lead-free solders because of its high reliability. However, there are also many problems not solved yet related to SnAgCu solder alloys [3, 13]. When reviewing the previous kinds of literature, there are many problems related to solder joint due to ultrasonic vibration [4, 15]. Finite element (FE) numerical simulation is a very effective tool for the analysis and optimization of integrated circuit (IC) package design. In particular, numerical simulation in terms of the vibration reliability of PCB assemblies has been much used to simulate the dynamic behavior. In this study will choose Sn-3.0Ag-0.5Cu (SAC305) because it is one of the most conventionally used solders in the current electronic packaging industry [1].

Other researchers focus on the effects on joint microstructural evolution. Ultra sonic vibration (USV) had positive effects on the formation of fluxes solder joints, grain size refinement, the distribution of various interfacial IMC phases within the joints, and restraining interfacial IMC growth [5, 11]. In this research, we will focus on effective of finite element analysis which it will help us to improve mechanical properties of the solder joint and investigate better properties for solder joints. The main objectives of this research are to valid experimental work for solder joint failure due to the ultrasonic vibration and to investigate better mechanical properties for solder joint by FE analysis.

Some researchers used ultrasonic soldering [6,10]. The effect of the ultrasonic vibration and several joining parameters on the soldered joints were investigated. Their finding was that aluminum could not be soldered well without ultrasonic vibration, and more than approximately vibration amplitude made the soldering possible. When the temperature was over the eutectic phase, the stable and sound joining has been achieved, the eutectic phase was between Al- and Zn- solid solution. The joints performed at the appropriate joining temperature, such as 673K, were sound when the application time of the ultrasonic vibration was less than approximately 10 seconds. Also, some researchers use ultrasonic wave propagation in metals to improve mechanical properties of solder alloys. A three-dimensional (3D) polycrystalline structure has been used [7,12] They were generated by multiphase-field modeling. It was introduced to ultrasonic simulation for nondestructive testing. Their results showed good agreement with respect to the velocity and the front shape of the pressure wave, as well as with respect to multiple scattering due to grains. Their research discussed the applicability of a transversely isotropic approach to ultrasonic wave propagation in a polycrystalline metal with columnar structures. According to a recent study, solder joint reliability greatly depends on the microstructure of the solder matrix and the morphology of intermetallic compounds (IMCs) in the joints.

In another research [8], the experimental results of ultrasonic processing liquid al uminium with the a 5-kW magnetostrictive transducer and a 20-mm niobium sonotrode producing 17-kHz ultrasonic waves are re- ported in this study. A cavito meter sensor for high-temperature was placed at different locations when the liquid was about to melt. Cavitation activity was measured at various acoustic power levels and in different temperature ranges. Below the surface of the liquid bulk, the cavitation intensity of the sonotrode was the highest, at the lowest temperature, and when the applied power was 3.5kW.

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2. Work Procedures

The brief process of the dissertation methodology is shown in Figure 1. A specific software will be chosen according to the field of work. In this study, ANSYS software will be used for collecting data through the process of simulation.

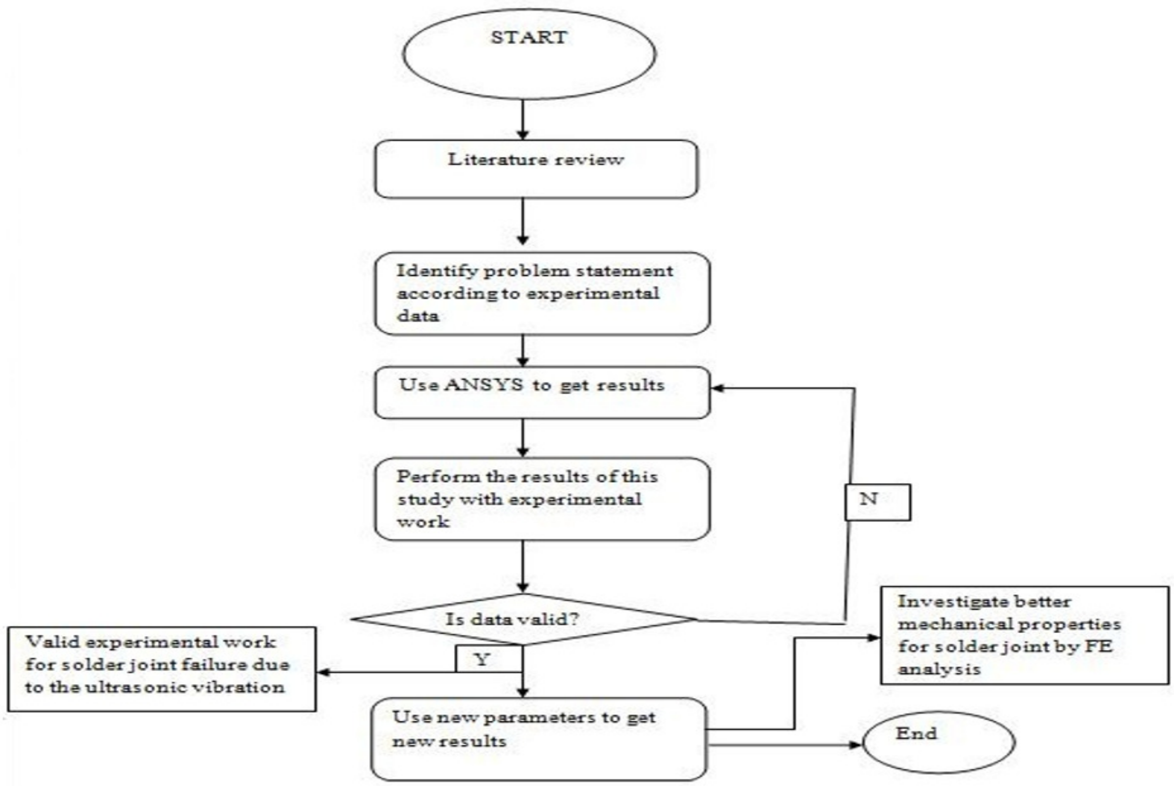

Fig. 1. Methodology Flow Chart

2.1 Solder Joint and Vibration Properties

The present study will focus on a specific range of ultrasonic vibration from 40 kHz to 70 kHz of ultrasonic vibration (USV) because this frequency can provide better temperature distribution across the soldering samples. In this study applied this USV to investigate the effect of USV time on the microstructure of Cu/SAC305/Cu lead-free solder joints. Cu substrates were selected to simulate the bottom heat sink of the electronic package and a thermal land of PCB. Also, we will choose Sn-3.0Ag-0.5Cu (SAC305) because it is one of the most conventionally used solders in the current electronic packaging industry[1]. For SAC305 alloy there are mechanical properties as based on another researchers [9] as shows in table 1

Table 1
Material Properties

Material	E (GPa)	(υ) Poisson's ratio	Density (g/cm^3)
SAC305	50	0.4	7.37

2.2 Meshing and Modeling

The case of this study can be studied through utilizing commercial software. ANSYS is a well-known software used to model and simulate ULTRASONIC VIBRATION and thermal transference aspects for solving the equations and producing the needed solutions. ANSYS is pre-processor is another software known as Design modular (DM), which builds and applies the mesh on the geometrical depiction of the problem under investigation. Both processing and post-processing phases are performed by ANSYS MECHANICAL.

The meshed model uses the elements of Tri type pave in complicated areas and Quad type paves in the rest areas. ANSYS provides a complete mesh flexibility with amorphous meshes the solution and it may be polished or roughened the grid depending on the solution. Once the grid had been read into ANSYS.

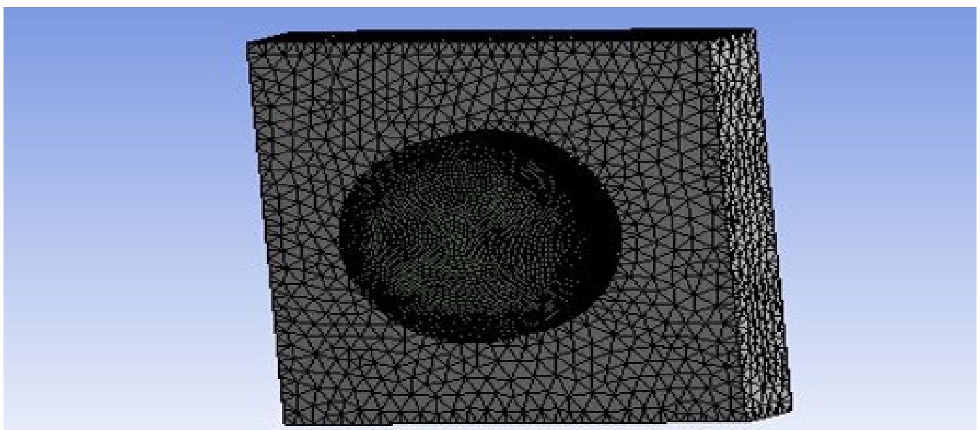

Fig. 2. The meshed model

2.3 Grid Independent Test

Based on the outcomes, it is seen that the FREQUENCY Nu is proportionate to the number of ELEMENTS, and the FREQUENCY was 70KHZ when number of ELEMENTS was261794. Moreover, there is no change in FREQUENCY when the number of ELEMENTS increasing to 282893 and 271895

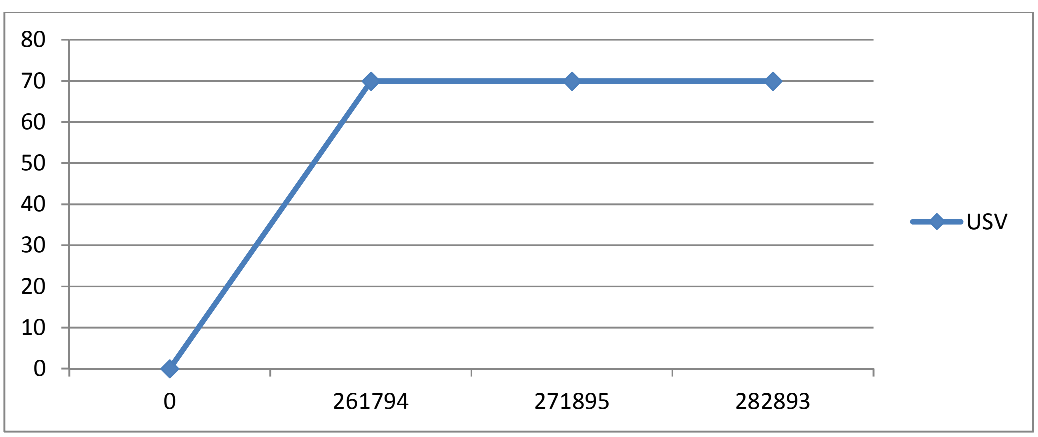

Fig. 3. Grid Independence Test

2.3 FEA Procedure

FEA model is built using ANSYS. Then modal analysis is performed to correlate the model by correlating the natural frequencies and mode shapes obtained from simulation with experimental results. After the transfer function and modal analysis results are validated. Figure 4 shows all procedure of simulation work. Output shear strength can be extracted from the simulation for a given input boundary conditions.

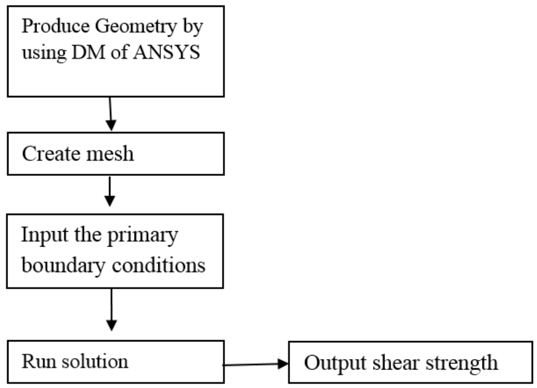

Fig. 4. FEA Methodology

3. Results and Discussion

This section will discuss the mechanical properties of Cu/SAC305/Cu solder joint and analyse the affection of vibration on it with the different period of time also the formation change the mechanical properties with the different value of ultrasonic vibration and give a suitable reason for why choose the specific range of USV for treating Cu/SAC305/Cu alloy

3.1 Geometry Calculations

Volume of SAC305 solder can be calculated by applying equation 1 to find original volume of SAC305 alloy as shown in figure 5.

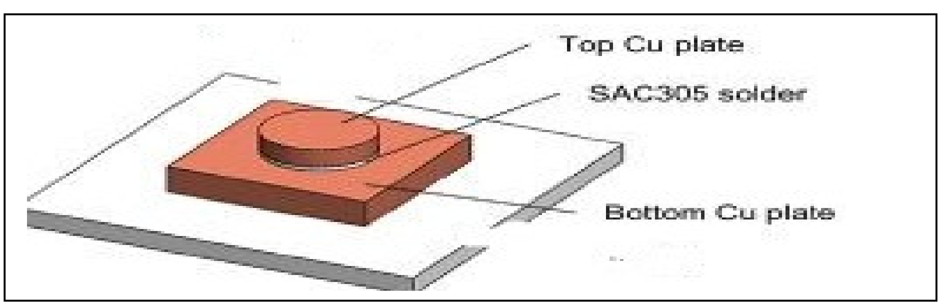

Fig. 5. The original SAC305 solder volume before soldering [1]

(Volume) $V = \frac{\pi}{4} D^2 * \text{h}$ (1)

where v, the volume of sac alloy, d is the diameter of it and h is the thickness of SAC305 alloy.

The original volume of SAC305 alloy before solder and after solder is constant, an only surface area will change. Therefore the original volume will be 11.3 mm^3.

Volume after soldering will be similar to volume before soldering, so according to the experimental work [1] to find the thickness of SAC305alloy after soldering depending on scale for cross section of microstructure of Cu/SAC305/Cu, therefore, the thickness of solder joint will be 0.22 mm which shown in Figure 6.

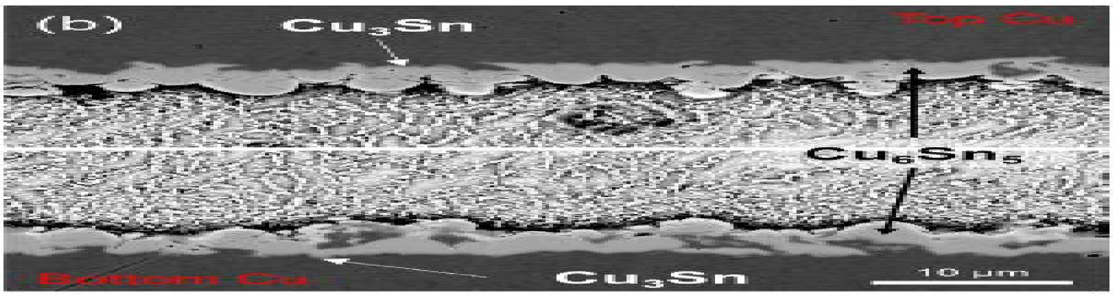

Fig. 6. Cross section of microstructure of Cu/SAC305/Cu solder [1]

The thickness of sac305 alloy is 0.22 mm. By using equation (1) to find the new diameter for SAC305 alloy after soldering and give 8.08mm.

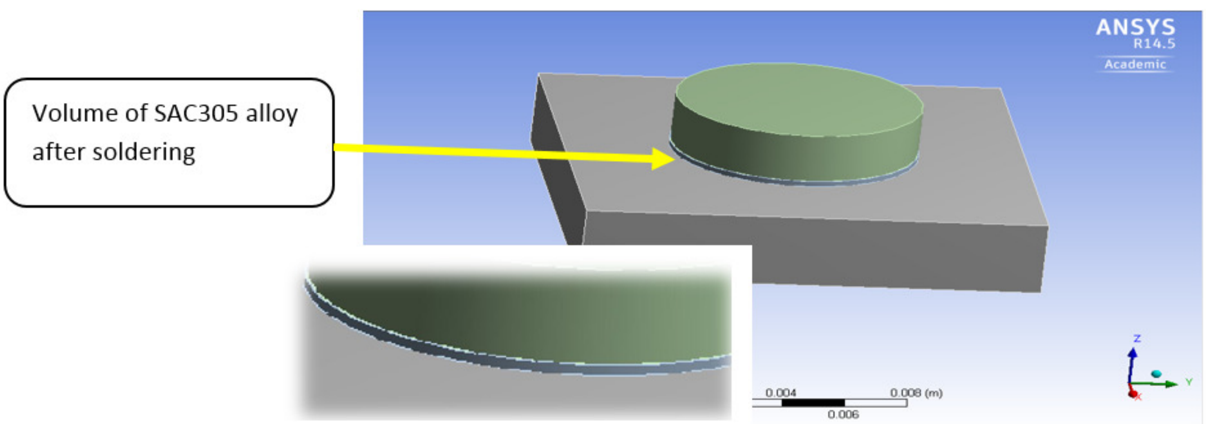

Fig. 7. Volume of SAC305 alloy after soldering

3.2 Validation

Validation of computer simulation models kHz during the development of a simulation model with the ultimate goal of producing an accurate and credible model. Simulation models are increasingly being used to solve problems and to aid in decision-making. In experimental data the output was shear strength of Cu/SAC305/Cu with periods (0,1.5,3, 4.5, 6) time of vibration reflow which shown in figure 8. The results approved that when compare the experimental results with simulation results the error between two studies was 13% so this study confidence 87%, therefore, will try new parameter to enhance mechanical properties for sac305 alloy.

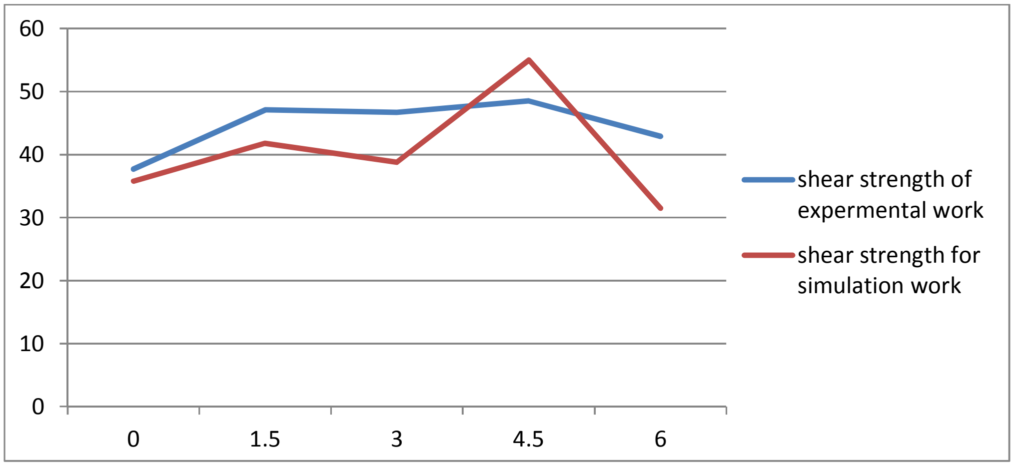

Fig. 8. Validation the experimental work and simulation work

3.3 New Parameters for Simulation Work

In this study will chose (40khz,50,kHz,60khz,70,khz) with periods (0, 1.5,3,4.5,6 sec) of time to investigate better mechanical properties for solder joint. Figures 9-10 show the max value of shear strength with these frequencies

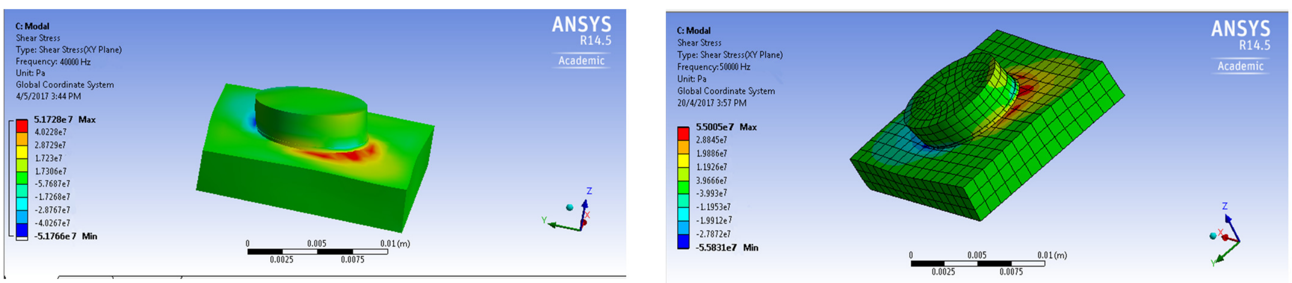

Fig. 9. Maximum shear strength for 40 kHz and 50 kHz

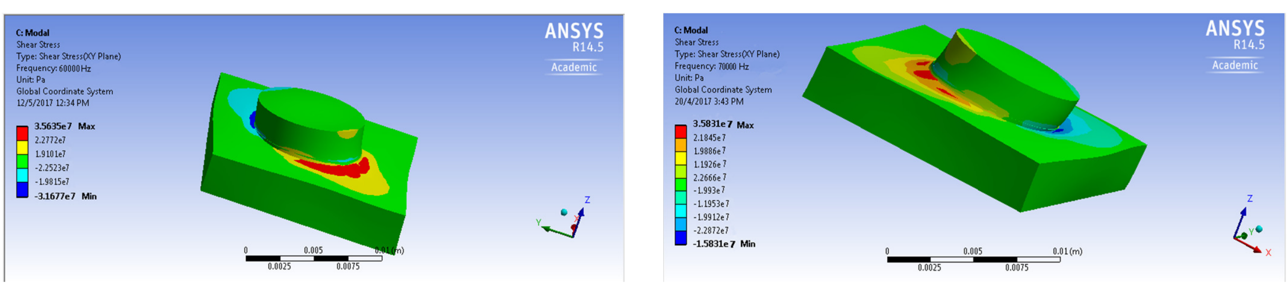

Fig. 10. Maximum shear strength for 60 kHz and 70 kHz

Graph in Figure11 shows that four curves for different values of ultrasonic vibration with periods (0, 1.5,3,4.5,6 sec) of time, the graph showed the max value of shear strength is for these trails is 55 MPa when the vibration was 50 kHz at 4.5 sec

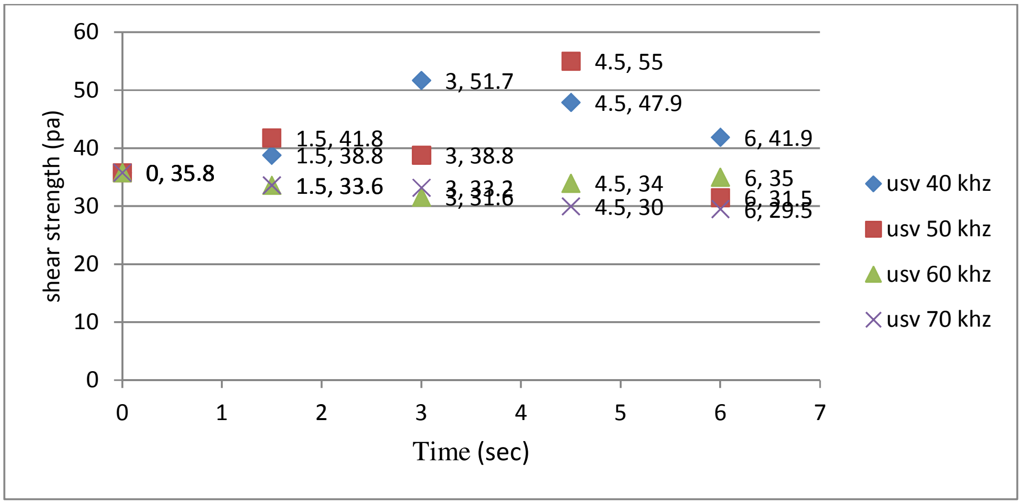

Fig. 11. Relationship between the USV respects to time with different frequencies

4. Conclusions

For Cu/SAC305/Cu solder alloy when it treated with different values of ultrasonic vibration to find the higher shear strength than the control sample. The samples treated according to periods of time (0, 1.5, 3, 4.5, 6sec) of time of ultrasonic vibration USV to investigate that the result showed the shear strength for Cu/SAC305/Cu when the frequency was 40 kHz is 51.7MPa at 3 sec and showed for50 kHz with same boundary condition the shear strength was 55 MPa when we are treated it for 4.5 sec and for attempt with 60 kHz frequency was with same boundary condition and results showed the shear strength was 35.8 MPa when treated for 0 sec, the maximum value of frequency of this study well be 70 kHz with same boundary condition and results showed that the shear strength was 35MPa at 0 sec .

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