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Reliability of Dissimilar Metal Soldered Joint in Fabrication of Electromagnetic Interference Shielded Door Frame

RehanWaheed, Hasan AftabSaeed, Wasim Tarar, Khalid Mahmood, Sajid Ullah Butt

Abstract**—**Electromagnetic Interference (EMI) shielded doors made from brass extruded channels need to be welded with shielded enclosures to attain optimum shielding performance. Control of welding induced distortion is a problem in welding dissimilar metals like steel and brass. In this research, soldering of the steel-brass joint has been proposed to avoid weld distortion. The material used for brass channel is UNS C36000. The thickness of brass is defined by the manufacturing process, i.e. extrusion. The thickness of shielded enclosure material (ASTM A36) can be varied to produce joint between the dissimilar metals. Steel sections of different gauges are soldered using (91% tin, 9% zinc) solder to the brass, and strength of joint is measured by standard test procedures. It is observed that thin steel sheets produce a stronger bond with brass. The steel sections further require to be welded with shielded enclosure steel sheets through TIG welding process. Stresses and deformation in the vicinity of soldered portion is calculated through FE simulation. Crack formation in soldered area is also studied through experimental work. It has been found that in thin sheets deformation produced due to applied force is localized and has no effect on soldered joint area whereas in thick sheets profound cracks have been observed in soldered joint. The shielding effectiveness of EMI shielded door is compromised due to these cracks. The shielding effectiveness of the specimens is tested and results are compared.

Keywords**—**Dissimilar metals, soldering, joint strength, EMI shielding.

I. Introduction

THE fabrication of EMI shielded doors requires a lot of welding to be done on door and frame sections. A key parameter in fabrication of these doors is dimensional accuracy. During seam welding of steel with brass out of plane buckling is produced due to accumulation of residual stresses. In this research, prospects have been studied to use soldering as joining process for the steel-brass joint. The soldering of metal sheets by soft leaded and lead free solders has been studied by many researchers. Weis et al. [1] studied the soldering of high strength aluminum alloy. Weis et al. suggested that in situation where thermal influence on base metal is critical, soldering is more suitable than welding process. Daly [2] also mentioned the advantage of brazing over welding process in situation where dissimilar metals have to be welded and welding induced distortion is critical. The strength of the joint is compromised in case of soldering. In situations where soldered joint is under fatigue loading, strength of joint becomes more important. Nourani and Spelt [3] studied the fracture toughness of soldered joint by using a DCB and ARCAN specimens. Brozek [4] studied the strength of soldered joints on galvanized steel sheets and copper sheets of 1mm thickness. Brozer tested the soldered specimens in universal testing machine and compared the strength of leaded solder and lead- less solder. Shangari [5] studied the failure of a soldered joint in nuclear power plant copper tubing. Shingari proposed that non-destructive testing techniques must be used to check the quality of joint as surface inspection only cannot predict the failure of joint under loading. Milosavljević et al. [6] proposed a special solder for joining steel with brass. Darveaux et al. [7] defined a constitutive relation for tin based solder alloys under thermal cyclic load. The strength of solder joint is weak as compared to the base metal strength. In this case joint, strength is 3 to 4 times less than the base metal, therefore reliability of the whole assembly needs to be investigated. Test criteria laid down in the US unified facilities guide specifications [8] are used. Door static load test and door sag test are used as test points for checking the integrity of soldered joint. A CAD model of door is prepared and analyzed through FE simulations to select appropriate sheet thickness of door frame at design stage. Some samples of door frame section are prepared for experimental study. The tightening torque of door hinge bolts is measured, and their effect on soldered joint is studied. The physical and mechanical properties of solder alloy Sn-9Zn are taken from the research work of El-Daly and Hammad [9].

RehanWahhed, Hasan Aftab Saeed, Wasim Tarar, Khalid Mahmood, and Sajidullah Butt are with Department of Mechanical Engineering, College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Islamabad, 44000, Pakistan (e-mail: rehan.waheed@ceme.nust.edu.pk, hasan.saeed@ceme.nust.edu.pk, wasimakram@ceme.nust.edu.pk, khalid.mahmood@ceme.nust.edu.pk, sajidullahbutt@yahoo.com).

II. FE Simulation

A CAD model of door section is prepared with door brass section profiles, the strength members of steel, and the soldered fillet joint with its proper width. The assembly of door and frame section is shown in Fig. 1. The main emphasis of this research is the door frame section. Door frame is made up of UNSC 36000 brass extruded channel. The profile of the channel makes it a female section with its counterpart male brass section attached to the door. The female brass section is soldered with a box section made up of ASTM A36 steel. The thickness of steel section can be varied keeping in consideration commercially available sizes and material. The steel box section takes all the structural load of door assembly during operation, i.e. opening and closing of door.

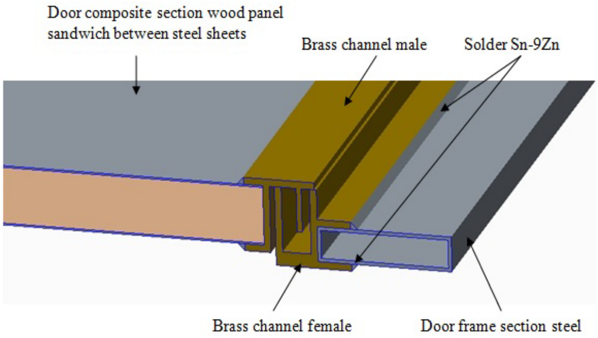

Fig. 1 Sectional view of EMI shielded door assembly

The opening and closing of door requires a lot of force due to EMI shielding gaskets placed in the female brass channel of door frame. A three-point locking mechanism is installed on door for smooth operation. The three point locking mechanism is not modeled here for simplicity of FE analysis. As per standard criteria defined in static load test mentioned in US unified facilities guide specifications [8], the door assembly should sustain a pressure of 2 kPa applied on door surface area with door placed horizontally such that it rests on door frame section and it can be open in downward direction. The weight of whole door is also sustained by the door frame sections. The FE model of door is shown in Fig. 2.

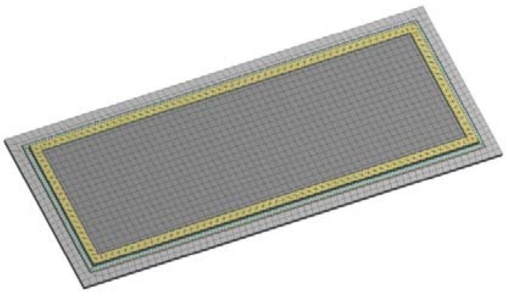

Fig. 2 FE model of EMI shielded door assembly

The requirement of sag test is that the door is opened 90^o and two weights of 23 kg are hanged with the extreme end of door within a distance of 5 inches. In addition, this weight should be kept hanging for 10 minutes. To simulate the sag test, a transient structural analysis is performed with total step timing of 600 seconds. When the door is opened with test weights hanging, all the load is transferred to door frame section through hinges. To simplify the FE model of sag test, only door frame section is considered. The appropriate loads are calculated and applied to door frame section at the point of hinge bolts. The passing criteria as mentioned in unified facilities guide specifications for both the static load test and door sag test are that deformation, if produced in any section of door assembly, should be less than 2 mm. In this research work, the main emphasis is on the integrity of soldered joint, therefore stress has been calculated in the vicinity of solder joint to check if this stress is within the rage of yield stress for Sn-9Zn solder alloy. In FE simulation, three test cases are considered:

Case 1: Door frame section with 2 mm thick steel box section
Case 2: Door frame section with 1 mm thick steel box section
Case 3: Door frame section with 0.8 mm thick steel box section

All of the above mentioned cases are simulated, and the results are compared to find the optimum sheet thickness for dissimilar brass-steel soldered joint.

III. Results of FE Simulation

The equivalent von-Misses stress for static load test on 2 mm steel section is shown in Fig. 3. On the door panel, maximum stress is in the center and at corners of the door. The male brass sections are cut at 45^0 and joined at the corner making a sharp edge. These sharp edges act as stress riser, hence more stress is observed on these points. Care must be taken to solder the corners carefully. On door frame side, maximum stress is in the center along the length of door. However, these stresses are below the yield point of Sn-9Zn solder.

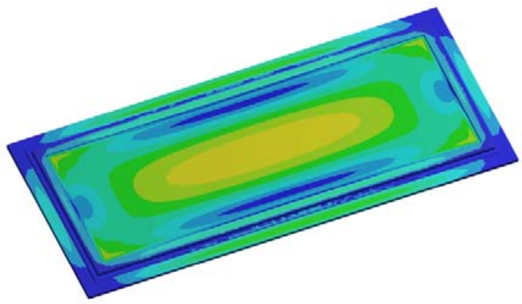

Fig. 3 Static load test simulation of 2 mm thick steel section

The maximum and minimum stress levels for the three cases are summarizedin Table I. The maximum total deformation in all cases is given in Table II for static load test.

TABLE I
Static Load Test Stress Result

	Max stress (MPa)	Min stress (MPa)
Case 1	2.203	325 x10^{-6}
Case 2	3.153	637 x10^{-6}
Case 3	5.960	289 x10^{-6}

TABLE II
Static Load Test Total Deformation

	Max total deformation (m)	Min total deformation (m)
Case 1	3.156x10^{-5}	3.507x10^{-6}
Case 2	2.682x10^{-5}	2.981x10^{-6}
Case 3	9.496x10^{-6}	1.055x10^{-6}

The deformation found out in transient structural analysis for sag test in 1 mm steel section is shown in Fig. 4. As the load is applied on the hinge area, it is transferred to the adjoining solder joint and the brass female channel.

The maximum and minimum stress level in transient structural analysis is given in Table III. The maximum total deformation of sag test is given in Table IV.

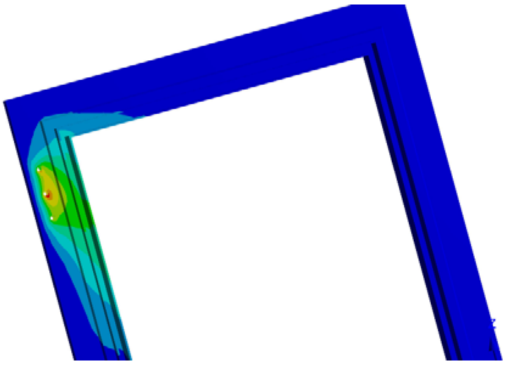

Fig. 4 Deformation in 1 mm steel section during sag test

TABLE III
DOOR SAG TEST STRESS RESULT

	Max stress (MPa)	Min stress (MPa)
Case 1	4.522	0.502
Case 2	16.654	1.850
Case 3	18.524	2.058

TABLE IV
DOOR SAG TEST TOTAL DEFORMATION

	Max total deformation (m)	Min total deformation (m)
Case 1	7.602×10^{-7}	8.447×10^{-8}
Case 2	1.265×10^{-6}	1.406×10^{-7}
Case 3	1.585×10^{-6}	1.762×10^{-7}

The total deformation found in both tests, i.e. static load test and sag test for all cases, is less than 2 mm. The stress level found for all cases mentioned in Tables I and III is also less than the yield criteria of Sn-9Zn solder alloy. The stress is in elastic range and hence cannot produce any permanent deformation or cause initiation of crack in solder joint.

IV. EXPERIMENTAL WORK

In fabrication of EMI shielded door the hinges, door lock assembly and door handle need to be bolted. The holes drilled for bolting purpose became suspect sites for electromagnetic radiation penetration. The attenuation level of whole shielded enclosure drops due to a tiny hole or penetration point left in shielding process. To cover the hinge bolts, EMI shielding gaskets are placed under the nut and washer of hinge bolt. The bolt is then tightened to produce perfect electrical bonding between bolt washer and outer skin steel sheet. The hinge and bolt with EMI gasket is shown in Fig. 5. A total number of three hinges are used for 7ft standard height of door. EMI gasket is placed on inner side of door frame to stop electromagnetic radiation from entering the shielded enclosure. Bolts of size M10 length 35 mm are used for this purpose. Bolt holes are drilled 80 mm away from the solder joint as per requirement of hinge. A total number of three bolts per hinge at 50 mm distance from center to center are required. For test purpose only single bolt is installed in test sample.

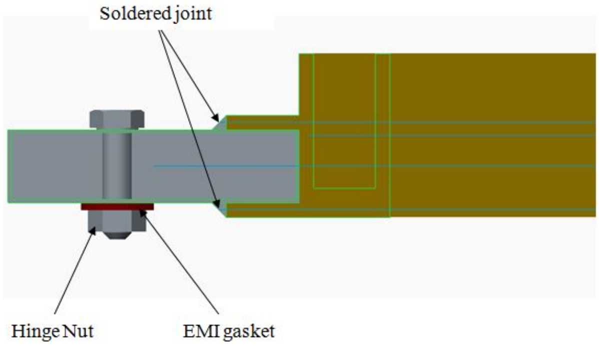

Fig. 5 Door frame section with hinge bolt installed

In this research, the bolt tightening torque is measured by tightening the bolt with a calibrated torque wrench and measuring the EMI shielding effectiveness through shielding effectiveness leak detector (SELD) equipment. The bolt tightening torque is found out to be in the range of 40 to 55 N.m for perfect electrical bonding. As the hinge bolts are very close to the soldered joint an experiment is performed to check the three different steel frame sections, i.e. 2 mm, 1 mm, and 0.8 mm under the load of tightened torque. For this experiment, small scale door frame sections are prepared. These sections have all the original dimensions accept length. The length of these sections is kept 100 mm. The samples are soldered properly with Sn-9Zn solder alloy. After soldering, holes for hinge bolts are drilled at appropriate location. The samples are then fastened in a test jig. Bolts are tightened on these samples with torque wrench. As starting point, torque of 30 N.m is set on the torque wrench. The bolts are further tightened with increasing torque of 5 N.m, and cracks in the soldered joint are observed. In 2-mm thick steel sample, the solder joint fails at a torque of 35 N.m. However, in 1 mm and 0.8 mm steel sections, no crack is observed up-to a torque of 70 N.m. At 70 N.m, both the thin steel sections deform plastically under the bolt washer. This permanent deformation was measured and found to be more than 2 mm in both samples. To counter the deformation in thin plates, honey comb steel sections are placed inside the door frame box section. The honey comb came under compressive load during the bolt tightening process and did not allow any deformation to take place at the maximum torque of 70 N.m.

A complete EMI shielded door assembly is prepared with door frame section of 1 mm thickness and soldered with Sn-9Zn alloy at steel –brass joint area. The door is then tested with shielding effectiveness test equipment in the frequency range of 10 kHz to 1 GHz as per US military standard 188-125 [10]. The shielding effectiveness of door was found satisfactory at all frequencies. A crack of size 30 mm length is deliberately produced on the hinge side of door. The door is again tested for EMI shielding effectiveness. This time the door does not meet the standard criteria. The graph of shielding effectiveness test is given in Fig. 6 along with the standard test criteria. At lower frequencies i.e. from 10 kHz to 1 MHz, the attenuation values are above the standard curve, but at higher frequency attenuation level drops drastically to small opening in the crack area. Small cracks and pit holes in solder joint have a huge impact on shielding effectiveness of EMI shielded enclosure.

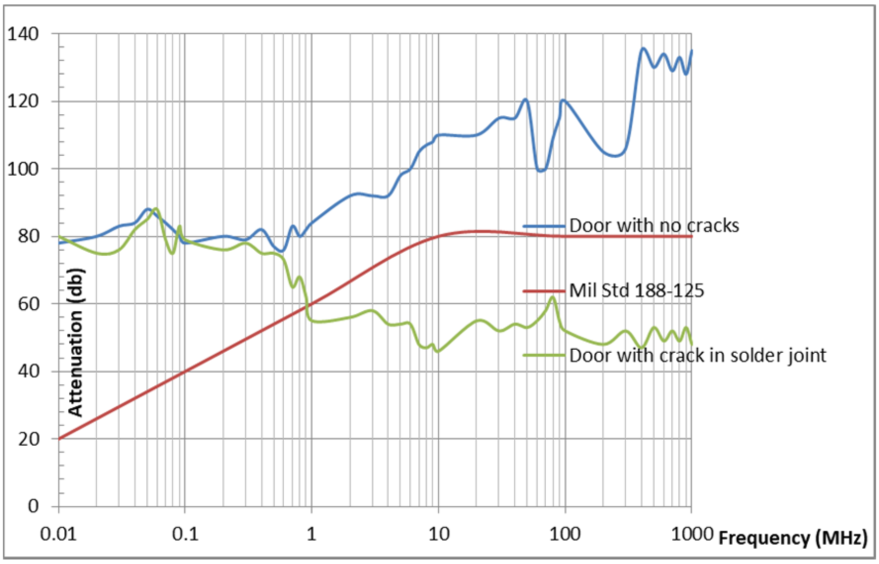

Fig. 6 Shielding effectiveness test result

V. Conclusion

The integrity of soldered joint on dissimilar metals steel with brass is tested in context with its application on EMI shielded door. Sheet thickness variation is studied on frame side of door to check bonding of the joint. It is revealed in this study that thick sheet, i.e. steel, of 2 mm is acceptable for this application under tensile or shear loading but if bending load is applied on the frame section as shown in the experimental study of hinge bolt tightening torque, cracks will appear in the steel to solder alloy interface of the bond. The brass to solder alloy interface remains intact, but electromagnetic radiations find passage through these cracks and the shielding effectiveness of the whole enclosure is compromised. The thin steel plates remain intact in tensile, shear and bending loads. In the torque tightening test, the thin sheets deform locally in the area of load application. The stress produced due to this local plastic deformation is not transferred to the solder joint. The joint remains intact even when the tightening torque is increased much higher than the required level.

VI. Recommendations for Future Work

In this study, EMI shielded door having solder joint along the periphery is tested under static load test and swing test. A further investigation of swinging door closure test may be performed to authenticate the integrity of solder joint and overall reliability of door. In addition, these tests are for EMI shielded doors installed in static enclosures that are placed on ground during service life. For mobile shielded enclosures that are to be installed on vehicles for transportation, fatigue test must be performed to check reliability of solder joint.

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