EvaluationofVibrationAmplitudeStepping andWelding Performance of 20 kHz and 40 kHzUltrasonicPowerofMetalWelding

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Abstract:Todayultrasonicpowertechniqueisconsideramandatorytechniquewhichisalwaysenteredinmanyprocessessuchas in metal and plastic welding to overcomes many issues, with aidedof applying force (pressure) and supplied high frequency vibration, asolid-stateweldcanbegeneratedbyultrasonicmetalweldingtechnique. That give a technique the ability to join not only a smallcomponents, whereas also to join thicker specimens, depend on aproper control of matching welding conditions. Therefore a weldingperformance can be study and compared after designed welding horntoresonanceatfrequenciesof20kHzand40kHz.Theanalysesofthedesigned horn are completed through use a vibration mathematicalexpressions, modal and harmonic analyses to ensure the weldabilitydue to applying ultrasonic power to the working area and also tocompare the performance of joint at using two resonance frequenciesof 20 kHz and 40 kHz. The dimensions of the horns were determinedto match the selected resonance frequencies, which the lengths werecalculated as 132 mm and 66 mm respectively. The analysis of theexciting modal indicates that the axial vibration modes of 19,584Hzand 39,794Hz are obtained in 10^th^ mode, while the two frequencyvalues are recorded 19,600 Hz and 39,800 Hz from the frequencyresponse of the two horns. The weld strength between Al and Cuspecimens with a thickness 0.5 mm were evaluated using tensile test,whichtheanalyseswereobtainedunderusingdifferentweldingpressure and varied amplitudes. The results were recorded withinexciting a horn with two different resonance frequencies, show theenhancementofweldstrengthandqualitythroughcontrolofsteppingamplitude, the enhancement means obtain good strength of the weld,reducestickinghorn tospecimen,andlower specimenmarking

***Keywords:** Ultrasonic welding, horn design, vibration amplitude,steppingamplitude,weldingperformance.*

I. INTRODUCTION

Ultrasonic welding is a technique normally depends on asolid-statebondingprocessinwhichthematerialsarecompletely joint through applying high frequency in form ofshearvibrationtocreatescrubbingbetweenintimatesurfaces, and the bonding subjected to force or pressure toconfirmbond. Thehigh vibrationgeneratedwillhelpto reform the intimate surfaces by vibration deforms and flattensurfaces, removing asperities, oxides and contaminants, andallow for increasing contact area of the weldment specimens[1],[2], this allow the technique to be applicable on variousthinnerandthickermaterials[3].Ultrasonicweldingtechnique strongly entered in industrial and manufacturingfields to join materials with good strong and high precision[2]. Furthermore, this technique does not require any addingoffillerorsolder,whichputthistypeofweldingtechniquetobemoresuitableforenvironmentspeciallyinreducingcarbonemissionandcontrollingofenergyconservationenvironmentally andeconomically[4].Themaincomponents of ultrasonic welding system are power supplytogeneratepower,transducerorconvertertoprovidevibrationwithspecificamplitude,boostertoraisedisplacement amplitude and horn to maximize the amplitudeand to work. Also, other components such as the anvil forclampspecimensduringweldingandfixtures,showninFig. 1. The horn vibrate with different vibration modes, but thetuningisfocusedonlongitudinalmodetoensurethatthehornexcited at required dynamic characteristics and subsequentlyeffectonstrengthandqualityofweld.Themechanismofthetechnique is to convert 50 or 60 Hz alternating current intodynamical energy of 20 kHz or 40 kHz. An optional boosteris used to raise the limited amplitude of transducer and alsoenclosed the welding system at nodal zone and the horntransmitsthehighvibrationalmotionthroughcarryingultrasonic energy to the weld materials. Sufficient amount ofreceiving ultrasonic energy by welded parts depend on highdiffusionofmaterialmolecularatintimatesurfaces[1].Although many studies have been conducted on ultrasonicwelding,usingdifferentweldingfrequencies,various experiments and weldability, but most of these studies payless attention on examining welding performance betweentwo different horns. In addition, the lack of using controlsamplitude stepping for most of previous studies were issued.Therefore, it is required to examine the operating frequencyof the horn to improve the performance of the weld and toenhancestrengthofthevariousbondingmetals.Thepresented work shows a study of welding performance forjoinmaterialsbyultrasonicweldingtechniquethroughimprovebothweldstrength andquality.

AnumericaldesignbyfiniteelementanalysiswithANSYS code and subsequent completing experiments of anintegrated welding system with exciting horn at 20 kHz and40kHzhelptoinvestigatetheperformanceofweldatcontactsurfaces,andthentoallow forstudytheeffectofmainweldingparametersonwelds.Theweldstrengthischaracterisedexperimentallyintermsoftheresultsofrepeatedtensilesheartests.Theabilitytouseamplitudesteppingprofileistoobtaingoodweldstrengthwithreasonablequality.Also, tosolveseveralissuessuchassticking horn/specimenandpartmarking.

II. NUMERICALDESIGNOFTHEEXCITINGULTRASONICHORNS

A finite element method with code ANSYS is efficientlyperformedhelpfordesignthemaincomponentsofultrasonicdevice(i.e.Horn),whichhorndesignmusthascompatibilitytotherequirementofhighamplificationandmoderateclamping forceinordertoachievegoodweldingconditionofspecimens [5]. Vibrational characteristics such as, resonantfrequencyofexcitation,separationoffrequency,amplificationofvibrationdisplacement,uniformityofamplitude at horn tip surface, and the distribution of stressesconcentration, should be carefully examined during designhorn.

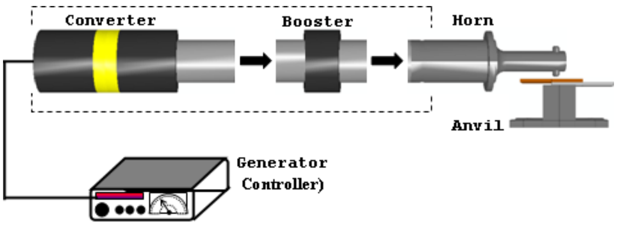
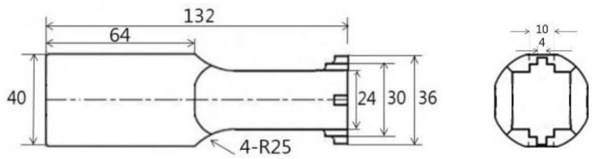


Fig.1.Maincomponentsofultrasonicweldingsystem

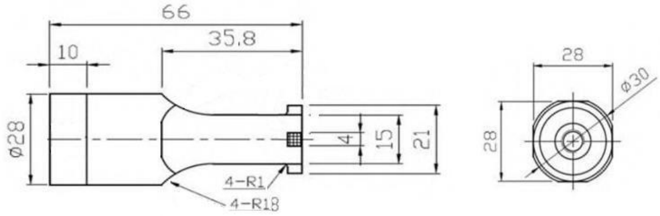
Thesteelischosenasaselectedmaterialforthedesigninghorns, because it has good acoustic properties and suitable toresist against wear. Further with low cost, the steel has goodmachiningmaterialandeasyformationtore-shapeindifferentforms.Theselectionofmaterialdependsonthetypeofweld,propertiesofweldmentsuchasstrengthandhardness. Itis mentionedhere,thatthewelding membershould have material harder than the material of the horn, asthis recommended in welding process. Different horn profilecanbedesignforultrasonicapplicationssuchasexponential,step, conical, catenoidal … etc, which the type of profileindicatestheamountofamplificationratioforthehorndesign.Highamplitudeamplificationisgenerallyrecommendedwithstepprofileofthehorn;howeverunfavourable stresses should be avoided at working area asthese stresses increases due to increase in amplification ratiorelative to the radial change in horn diameter [8], but thestresses can be shifted back due to make some modificationin the horn profile. In design a horn, the first step is todetermine alengthofthehornbyusingmathematicalexpression. Then, the horn length was identified based onrelationship between wave length and resonant length. Thehornlengthwasroughlydetermined,andsequentiallydeterminedtheshape,crosssectionanddimensionsaccordingtothenumericalvaluesofmodeshapeand analysesofnaturalfrequency.Itwasnotedhere,thatsome errorswererecordedbytheoreticalanalysisofthehorn.Aftercheck all requirements of the horn design, the information ofthe sketch horn with its specification are entered as an inputdata to the CNC program to get the final shape of fabricatedhorn.Thefinalshapesofthetwodimensionalsketches oftwofrequencies (20 kHz and 40 kHz) is shown as in Fig. 2.Table-I shows the mechanical properties of the horn material(steelalloy)forthefiniteelementanalysisofbothfrequencies.

Table-I: Propertiesofthehornsmaterial

Hornfrequency (kHz)	Poisson's effect (-)	Physicaldensity (kg/m3)	Young's modulus(GPa)
20	0.33	7810	210
40	0.33	7850	207



(a) 20kHztwodimensionalsketchhorn



(b) 40kHztwodimensionalsketchhorn

Fig.2.Twodimensionalsketchesofultrasonichorns

III. DATAEXTRACTIONFROMTHEVIBRATIONANALYSISOFTHEHORNS

Finiteelementanalysisisautomaticallyperformedthroughsettingtheshapeandanumberofmeshesformodellingandanalyzing horns.Themodelswerebuiltthrough sketch the horn and define material properties thenassignmentthepartandapplypropermeshbeforesetboundaryconditions,afterthatthehornrestraintthroughconnecting it with bolt, and specified the exciting movementto allow for vibrating horn axially. A high precision CNCmachine is performed to design and manufacturing horns, themachine program are set based on the characteristics of thevibrationalanalysisofselectedhorn.The analysesofthevibrationresponsesforthedesignedhornsareshowninFig.3,which the value of the natural frequency of 20 kHz horn isrecorded to 19.895 Hz very close to 20 kHz. The frequencyresponseofthehornwascalculatedatthe9thmodewhich pickup at the tip of the horn to ensure getting high amplitude.Whereas the vibrational response of 40 kHz horn is recorded39.654Hzalsocloseto40kHz,whichthefrequencyresponseisobtainedatthe9thmodeandthroughgettinghighamplitudeat horntip.

The analyses of the vibration response for the excitinghornarecarriedoutwithinfrequencyrangevariedfrom(10-30) kHz and the excitation is collected at the horn surface(horn tip). The results of analysis show an acceptable close tothe numerical result of 19.980 Hz. In addition, the harmonicresponse was also determined at the 40 kHz horn tip, whichthe data were determined within the range of (30-50) kHz.Similar with the 20 kHz horn, the frequency response of 40kHzisdeterminedattheoutputofthehorn,whichhasavalue39.654 that is close to the result of predicted value. Fig. 4 (A)and(B)plotstheresultsofvibrationresponseofthehornat20kHzand40kHz respectively.Theanalysisofsimulationmodels shows highest value of amplitude pointed at horn tip,which the horn have good gain in providing displacementamplitude,andthe longitudinal mode of vibrationfor theexciting horn seems to be very close to the result obtainedfromsimulationmodels.Thehorngainwasalsocalculatedbydividing the output amplitude / input amplitude of the horn,which the vibration amplitude recorded (17.2 micron), withhorngain5.5forthe20kHzhorn,and(26.0micron),withthehorngain4.0forthe40kHzrespectively.However,gainmaydropdownduetoincreasecouplingbetweenvibrationmodes,motiondistortionandlossinenergywhichaffectonoperationalprocessesquantityandquality [8].

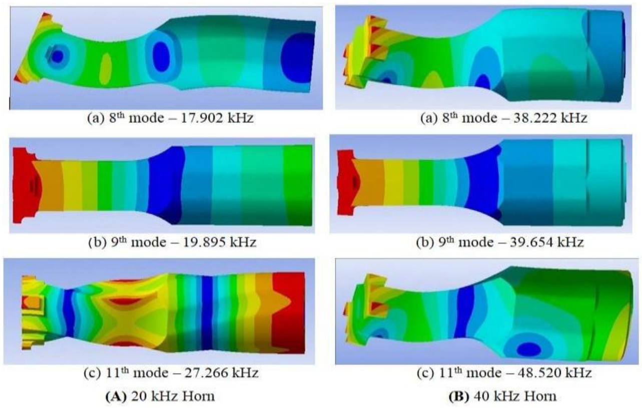


Fig.3.Predictiontheseparation frequencymodesat(A)

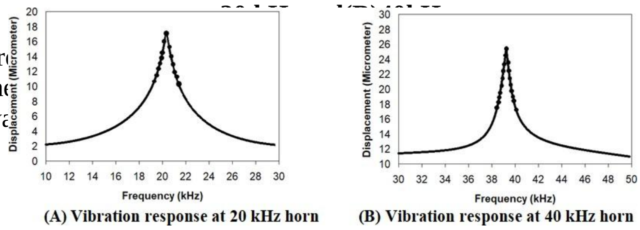


Fig.4.Vibrationresponseanalysisofthedesignedhorns: (A) 20kHzand(B) 40kHz

IV. WELDINGSYSTEMANDTHEIRPARAMETERS

A. Setupofweldingprocess

In order to joint specimens, welding system should bebuild, assembled and to work. The horn which is consideredthemaincomponentoftheweldingsystemwasdesigned

B. Steppedamplitude

addingbooster between horn and transducer), which form weldingstack. The transducer linked to the power supply (generator,type Sonic) to receive an alternative current from the electricmainpoint.With1kW maximumcapacityof ultrasonicgeneratorthedesignedhornswereexcitedatoperatingfrequenciestoprovidesufficientmechanicalvibrationneeded for weld. A tensile machine is preformed to holdwelding stack and to support welding specimens being sit onstationary anvil. Also, tensile machine has ability to controlandmeasuretheforceapplyingoverweldmentduringprocess, and torecordthe value of force bythe 2.0kNmachine load cell. A computer program that equipped bytensile machine is saved the amount forces applied againstthe time. Horn tip is designed in the form of flatten withknurled surface to help for contact with upper specimen andavoiditfromslippageduringvibration,whilethelowerspecimen is strongly held by anvil (shown in Fig. 1). Thealuminiumandcopperspecimenswerecutandpreparedaccording to the ASTM and BSI Standard codes [6], [7].Specimens dimension were set to be 50 x 10 mm for all sheetsthat having thickness 0.5 mm. 10 mm was set for overlapspecimenstomatchwiththedimensionofhorntip,asshownin Fig. 5. During test the strength of welded specimens, thebending effect on specimens was observed and that resultederrorinmeasuringstrength.Therefore,toavoidbendadummy plates were added. Several trials were carried out ondifferent welding conditions, each trial was repeated five orsix times prior to get results, then the results were averagedand the standard deviation was extracted for each trial. Thetrials were arranged in order of welding (Al-Al) specimensand(Cu-Cu)specimens.Anumberoffailedtrialswereexcludedfromresults,becausethosespecimensthataresticking with horn or either those trials that required morepower or applied force to confirm joints. In experimentaltrials,inputweldingparameterswheresettoensuregoodjointand to evaluate the weldability of the weld specimens, theseparameters are process time, applying force and vibrationamplitude.

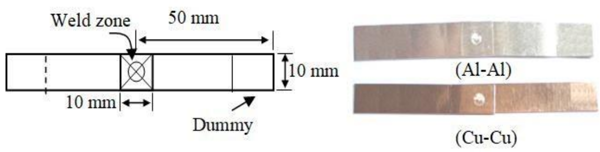


Fig.5.Specimenlayout andweldedcoupons withwelding area

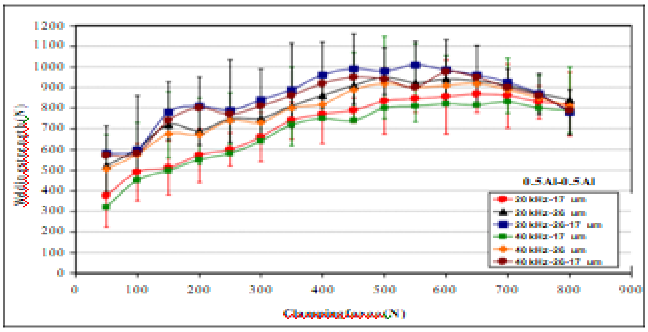
Inultrasonicprocesses,generallyultrasonicamplitudeapply totheprocesshasaconstantvalue,whichitsvaluecanbepresettohigherorlowervaluedependsonthespecification ofthe weldingsystem. However,analternativetechniquewhichispresentedinthiswork istoapplyamplitudestepping.Thesteppinghereallowstheweldtobedonebycontrollingamplitudebetweentwodifferentvalues. Thedigitalscreenof ultrasonicgenerator withcontrollingknobsallowtotriggerforthetransitionsofthesettingamplitude values, which pre settingcanbemadebyeithertime period of weld process or change the energy level or power[10].

Theprocedureforapplyingsteppingamplitudebeginwith pre set high amplitude value as this value is required toprovide sufficient joints for overlapping specimens and tocreate a solid-state form of weld. Then, the amplitude issuddenly lowered to minimize the frictional heat betweenintimatesurfacesandallowforhighinterlockatomsofmaterials diffusion. It was noted here, that stepping processmade the samples soft, less damage and lower sticking to thehorn tip. A series of experiments have been conducted on 20kHz and 40 kHz design horns using stepped amplitude toinvestigateweldingperformanceandtoensureobtainedgoodenhancement for the both strength and quality of joiningparts.

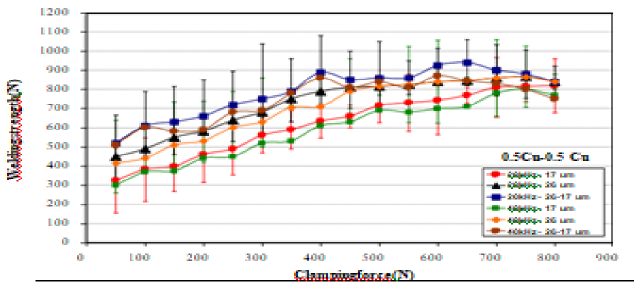
C. Theinfluence ofjoiningmetalsbyusingconstantandsteppedamplitude

Theweldabilityofthe20kHzand40kHzdesignedhornswassuccessfullydonetoevaluatetheweldprocessesthroughwhich the strength between specimens were compared andanalysed. Fig. 6 (A) and (B) plots a relationship between thestrength of the de-bonded specimens against the values ofapplyingforce,whichtherelationswascarriedoutonusing mmspecimensthicknessthatweldedultrasonicallyby20kHz and 40 kHz respectively. The welding processes werecarried out through applying different constant and steppedvibrational amplitudes. For each input parameters, five testswere done, then the average values were determined witherrorbars,sothestandarddeviationindicatesthevariationofstrengthagainstapplyingforce.Itwasnotedthattheweldingstrength is increased due to increases in clamping force andfortheprocesstimeuptoonesecond,butitwasobservedthatexcessive force may produce high friction, more heat andthen suppress the relative motion between surfaces, which inturn lower weld strength [9]. Overall, the strength of weld isproportionaltothetimeundertheinfluenceofapplyingclampingforce,whichlowervaluesofstrengthwererecorded with 40 kHz than 20 kHz under the common valueofselectingamplitude.The reasonforthateither due tofrictionheatgeneratedbetweenjoiningspecimensisconcentrated at tip of the horn, also the diffusion at intimatesurfaces of selected materials which is facilitated at 20 kHzcompared with 40 kHz. For the welding of Al-Al specimens,the maximum strength recorded is 880 N at 20 kHz underclamping force of 680 N and vibration amplitude 17 µm,while at 40 kHz, the maximum strength was recorded 820 Nunder clamping force of 700 N and vibration amplitude 17µm. Fig. 6 confirms that the weld strength increased withincreasingofamplitudeto26µm.Theweldingstrength versus clamping force tests were determined with welding ofCu-Cu specimens, which the maximum strength of 20 kHzhornwasrecorded790Natclampingforce700Nandamplitude 17 µm, and the maximum strength of 40 kHz hornwas recorded 770 N at clamping force 750 N and amplitude17 µm. Similar to the weld Al specimens, the weld strength ofjoiningCu-Cuspecimensincreasedwithincreasingamplitude to 26 µm, but the overall that the strength of Custay below of Al specimens. No evidence indicates that thestrengthofweldincreasesduetoincreasethevalueofclamping force for welding material specimens. In case ofsetting amplitude 26 µm, despite resulting high strength, it isalso leads to increase in standard deviation beside leave anoticeablemarkon jointspecimens.Duringexperiment,part of trials was failed due to sticking of horn tip/upper specimen.However,stickingpartsbecomesmoreprevalentonspecimens when the welded specimens subjected to a valueof clamping force above 600 N, but this result to lower inweld strength despite using constant and stepped amplitudes.Further,itwasshownthatthestrengthissignificantly affectedbythematerialpropertiessuchashardnessandroughness,ashigherstrengthvalueswererecordedwithaluminium specimensthancopperspecimens.

InFig.6,theinfluenceofapplysteppingamplitudetechnique is shown through indicate the weld strength valuestakenatdifferentclampingforces.Theadvantagesofchanging the amplitude from higher value (26 µm) to lowervalue (17 µm) were clearly seen in Fig. 6, through reducingthesizeoferrorbarsandlowerinstandarddeviations,andincontrast increase in weld strength, but during examine theweld strength, aluminium specimens show slightly highervalues of strength compared with copper specimens underusingidenticalparameters.Finally,itwasobservedthatapplyingthesteppedamplitudewillimproveweldconsistency and reduce other issues such as sticking, partmarking, tool fracture and glowering. Further, the use ofstepping amplitude may enhance the quality of weld andprovideproperstrength forjoiningmaterials.



(a) Ultrasonicweldingspecimens(Al-Al)



(b) Ultrasonicweldingspecimens(Cu-Cu)

Fig. 6.Variations of weld strength vs. clamping force forjoinedspecimens:(a)Al-Aland(b)Cu-Cu,forrocess conditionsandfrequencyofdesignedhornsat20kHzand40kHz

0.6

V. CONCLUSIONS

Thisworkpresentsadesign,simulationandfabricationofan ultrasonic welding system in order to study and evaluatetheweldabilityofjoinedspecimensthroughusingtwodifferent horns that are excited by 20 kHz and 40 kHz. Finiteelementanalysisisperformedsuccessfullytoexaminefrequencyresponsethroughanalysesofbothmodalandharmonic response. The welding input parameters such asforce,amplitudeandspecimensarrangementhavesignificanteffectonthestrengthofweld,whichhigherstrengthobservedforthosespecimensofweldaluminiumtoaluminium compared with slightly lower strength measuredfor weld copper to copper specimens. For all trials the weldstrength exhibits high values due to increase in clampingforce,butexcessinapplyingforceabove600Nwillresulttodeteriorate and drop in weld strength. An evaluation of weldstrength is carried out through using three amplitude values,starting from 17 micron to 26 micron for normal constantamplitude,thena comparisonis done for applysteppingamplitude process of previous two amplitude values (26-17),toimproveweldstrength,reduceerrorbarsandlowerstandard deviation. In addition, the stepping process allowsforreducingspecimenadhesiontothehornandlowerspecimenmarks.Accordingtothechangeinweldingcondition, the overall tendency of weld strength increaseswiththeincreaseinclampingforceduringprocesstimeuptoone second. The overall tendency of evaluating weldabilityshowsthattheweldstrengthsignificantlyaffectedby welding parameters such as time and amplitude, and it havedirectproportionalwiththesetwoparameters,butthestrength does increased due to increase in clamping force.Thestudyconfirmedthatlowerweldstrengthofjointspecimenswasdeterminedby40kHzcomparedwith20kHz,even when using the same vibration amplitude or applyingstepping amplitude. The reason is related to the amount offriction heat concentration at joint, and another reason is thefacility of diffusion at weld interface for the both selectingmaterials,meansthataluminiumexhibitmoretodiffuse thancopperfor thetwodesignoperating frequencies.

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