Finiteelementbasedmodellingofthestructuralresponseofweldedmaterialsincomplex

loadingconﬁgurations.PartII:Constitutivemodellingconsiderations

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Abstract

Thistwo-partarticlepresentstheresultsofnumericalpredictionandexperimentalstudieswhichaimtodeterminethestructural

responseoffrictionstirweldedaluminium2139-T8subjectedtocomplexloadingconﬁgurations,andinparticular,airblastloading.

Theaimofthisworkistodevelopanumericalmodellingmethodologytoallowdetailedpredictionofthelocalstrainevolution

acrosstheweldzoneasthishassigniﬁcantinﬂuenceinrelationtostructuralresponseandfailure.Inparticular,themethodallows

local material property gradients, which are due to variation in strengthening mechanism arising from microstructural damage

caused by thermal loading during the welding process, to be incorporated into a macro scale structural model. Part I details

themethodologyusedtoimplementlocalmaterialpropertygradientstogetherwithexperimentalevidencetoverifythepredicted

structural response in a range of loading conﬁgurations. Part II provides an insight into the assumptions made in Part I with

respecttohighstrainratematerialsmodellingacrosstheweldzoneandtheassociatedevidenceforthevariationinstrengthening

mechanismsinthealloy. Thecombinedworkpresentedhighlightstheimportanceofaccuratedescriptionofthevariationinlocal

materialproperties,particularlytheworkhardeningrate,indeterminingtheresponseofstructuresunderblastloading.

Keywords: Blastloading,Digitalimagecorrelation,Materialsmodelling,Finiteelementsimulation,Materialscharacterisation

1. Introduction

inducesigniﬁcanttransienttemperatureriseandplasticdefor-

mationthroughinteractionoftheweldingtoolwiththework-

piece[6,7]. WhilsttemperaturerisesinFSWremainsbelow

the melting point of aluminium, the combination of thermal

andmechanicalloadingcaninducediﬀusionalandrecrystalli-

sationprocessesinthework-piece[8,9,10].FSWisknownto

causephenomenasuchasprecipitatecoarsening;localdissolu-

tionofprecipitates;recoveryandrecrystallisation.Thisleadsto

theformationofmeso-scaleregionsacrosstheweldknownas

thenugget,theThermo-MechanicallyAﬀectedZone(TMAZ),

andtheHeatAﬀectedZone(HAZ).Thecombinedthermaland

plasticdeformationeﬀectsonthematerialmicrostructurealter

thelocalmaterialpropertiesinweldedstructures[8,9,10,6].

Asaresult,therearelargegradientsinmaterialandmechanical

propertiesacrossaweldzone[11].

InFiniteElementbasedmodelling,theuseofJohnson-Cook

constitutivemodelsiscommonplacewhensimulatingthenon-

linearresponsestructures[12,13]. However, sinceobtaining

parameters locally within a weld is diﬃcult [14], the typical

methodfordeﬁningtheconstitutivemodelparametersacross

theweldzoneistoassumethatthereisonlyvariationinyield

stressacrossaweld[12,13].Itisgenerallyacceptedthatthere

may be signiﬁcant variation in properties, such as the work

hardening rate, across a weld [15, 13, 16]. Thus, determin-

ingthenon-linearresponseofweldscanbediﬃcultandrequire

carefulcalibrationandinterpretation. InPartIofthisstudy,a

methodforimplementingmaterialpropertygradientsinmacro

scaleFEmodelstosimulatestructuralresponseofFSW2139-

T8wasdeveloped.Themethodwasshowntoprovideaccurate

Itiswidelyacceptedthatthemechanicalpropertiesofmet-

alsarelinkedtothematerialmicrostructureandthestrength-

eningmechanismsofthealloy. Foragehardenablealuminium

alloys,themechanismswhichcontributetothestrengthofthe

alloyinclude: precipitatehardening,solidsolutionstrengthen-

ing,workhardening,andgrainsizereﬁnement[1]. Uponage

hardening,ternaryAl-Cu-MgalloyswithlowCu:Mgratiosare

knowntoleadtotheformationoftheAl2CuMgbasedS’orS

phases[2]. Incomparison,Al-Cu-MgalloyswithhighCu:Mg

ratiosleadtotheformationofCuGPzonesandsubsequently

the Al2Cu θ0 phase; the addition of Ag promotes formation

of the Al2Cu based Ω phase [2, 3, 4]. The addition of trace

amounts of Ag in ternary alloys with Cu:Mg ratios of above

5.6,suchas2139-T8,enhancestheagehardeningresponseand

promotestheformationofAl2Cubasedprecipitatesaheadof

S’andSphases[2]. θformshabituallyonthe{100}α andΩ

formshabituallyonthe{111} [5]. Undertheappropriateheat

α

treatment,thehexagonalplate-likeΩphaseformsaheadofGP

zonesleadingtohighdensitiesofthestrengtheningphase[2].

IntheT8condition,thesizeanddistributionofΩphaseisop-

timisedtoreducedislocationmotion,hence2139isconsidered

tooﬀerpeakstrength.

Joining processes, such as Friction Stir Welding (FSW),

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