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Optimization of Thickness Variation of Cone Formed by Superplastic Forming of Ti-6Al-4VAlloy

Soumendra Pattanayak, Swatisnigdha Singh,
Jagannath Institute of Engineering and Technology, Cuttack, Odisha, India
Gurukula Institute of Technology, Bhubaneswar, Odisha, India

ABSTRACT: Superplastic formingis avaluabletool for thefabricationof complex partsusedin aircraft and automobileindustries. A number of techniques are applied toform componentsin these industries.Incommon method called blowforming,asheetofsuperplastic materialisclampedin rigid die and formed into the desired shape through pressureappliedbyaninertgas.Thisprocessusuallyleadstorathernon-uniformthicknessdistributionwithgreatest thinningoccurring in regions where stresses are higher such as centre of the sheet. In order to obtain uniform thickness distribution,thesuggestedmethodistopre-formthesheet in such a way that the thickness of the initial sheet before the blowformingat thecenter is high so that after the blow forming the component will have uniform thickness throughout. Forthis in a 3mm thick Ti-6Al-4V sheet superplasticity was induced by "quench- roll-recrystallise" method was used to formaconeby blowing argon gas over the sheet in a die. A second blank was pre-formed so that the thickness at the centre ofthe blankwas 3mmand that at the ends (periphery) was 1.5 mm. After blowing the cone, the variation in the thicknessfromtheapextobaseoftheconewasreduced to 0.3mm. In order to obtain further uniformity in the cone formed,anotherblank was pre-formed,tomake that central thickness as 2.5mm, which tapers down over periphery to 1.5mm.This timevariationof thickness from the apex to base of the cone is 0.2 mm, which is nearly 10%, which is acceptable inmostofthecases.
Keywords: Super Plastic Forming, Quench-roll-recrystallise, Thickness Variation

I. INTRODUCTION

The superplasticforming isan emergingtechnologyinvolving the elevated temperature forming of sheetmaterials capable of achieving forming higher strains of200-1000%. The exceptional formability afforded by theprocesspermitsthemanufactureofcomplex-shapedpartsin fewer stages with minimum waste. In this process thedeformation is carried out under low pressure and largeelongationisreached withoutfailure.Materialssuchastitanium, aluminum alloys, when subjected to the properconditionsofpressure,temperatureandstrainratecanexhibit the phenomena of superplasticity [1, 2]. Theseconditionsaresummarizedas,for a grainsizelessthan10µm,lowstrainrateoflessthan$10^{-3}$$sec^{-1}$andtemperatures of □ 0.5 T_m where T_m is the melting point ofthematerial[3].Themainapplicationfieldsofthisprocessareaircraftandautomobileindustries.Infact,itsapplication for aircraft structures have been expandingrecently because of its superior characteristics, such aslow-cost,lightweightandshortfabricationtime[4-8].

TheTi-6Al-4Valloy(□ + □)iswidelyusedasastructural material in the aerospace industry due to itslowdensityhighspecificstrength,goodcorrosion resistance, excellent high temperature properties, highformability associated with super plasticity[9]. A numberoftechniquesareappliedtoformcomponentsindustrially.Inacommonmethodcalledblow/vacuumforming,asheetof superplastic material is clamped in a rigid die andformed into the desired shape by a pressure differentialapplied by an inert gas. This process usually leads torathernon-uniformthicknessdistributionwiththegreatest thinning occurring in regions where strain ratesare higher such as the center of the sheet. While thethinning characteristics can be strongly influenced by theformingmethodemployedandassociateddieinteractions. The material properties, such as m, can alsohave a pronounced effect on the thinning profiles. Theinfluence of these parameters on thickness variation inspherical domes has been illustrated both experimentally[10,11]andanalytically [12-14] byanumberofinvestigators. Thomsen, Holt and Backofen [15]evaluatedsuch thinning characteristics as a

function of m, with thefinding that the lower the m the greater is the thinning.The aspects of optimization of thickness variation areseldom available in literature. Especially in the case ofcone forming the thickness optimization is not readilyavailableinliterature.
Thecommonmethodsusedtoobtainuniformthickness distribution are female drape forming, reversebulging plug assisted forming etc. [4]. But these methodsrequire additional process / tooling. Hence the proposedmethod is to pre-form the sheet in such a way that thethickness of the initial sheet at the center is higher so thatafter the blow forming the component will have uniformthicknessthroughout.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

Mill processed 15 mm thick Ti-6Al - 4V plate with (□ + □)microstructure was waterquenched aftersoaking atatemperature of 1000^0C for 30 min. This quenched platewasrolledat 700^0Cuptoathicknessof3mminoneheat.

Superplastic Cone Forming, with UniformThicknessBlank

InthefirstexperimenttheTi-6Al-4Vblankof80mmdiameter and 3mm thickness was blow formed to a coneof40mmbasediameter(approximately)at atemperatureof850^0C,underastrainrateof10^{-4}sec^{-1}.Thecorrespondingflow stress (□) at 850°C, under a strain rate of 10^{-4}sec^{-1}wasobtainedas □=17.9MPa.Therequiredconstantpressure for forming of the first stage i.e.,up to the stagewherethemembranemakesthefirstdie-contactwascalculatedas500psi(3.74.MPa)fromthefollowingequationswhichwasdevelopedbyDutta[18]

4S 1

⁄

⁄

Thefinishrollingtemperatewasrecordedas400^0C.
Samplefromtherolledplatewereannealedat850^0Cto

P= i □1□e □□˙ et □ 2 e □3 2□˙ et□

0

i a

(4.1)

obtainfinegrainsinturninducesuperplasticity,whichisoneofthepre-requisiteforsuperplasticforming.Threeblanksof80mmdiameterwerecutfromthesheetprocessedby“quench-roll-recrystallise”method.Fromthefirst blank cone was formed by blowing the inert gas at apeakpressureof500psi(3.47MPa)andatatemperature
TheequationofDutta&Mukerjeewasfurthermodified by Mihai Vulcan et.al,[18] for second stage offorming, for first stage the Dutta&Mukerjee equation isadequateascommentedbyMihaiVulcan

P□ 2Si □a²e □□edt □2□²□2□(□²□a²)^{1}2□ ^{1}2 ⁄ ⁄

ρ

of850^0andastrainrateof10^{-4}s^{-1}inhydraulicpressof40

□i i ii i □

i

(4.2) ⁄ ⁄

Tcapacityasshowninfigure.1,inaconicaldieofdiameter

□2□²□a²□2□(□²□a²)^{1}2□

e^{1}2□˙ edt□

40mm and apex angle 58^0. Thickness at various positionsfromthecentreoftheformedconeweremeasuredbyintertestingmachineasshowninfigure.2,andwasobserved

□

Where,

i i i i i □ 0

non-uniformthicknessdistributionwithgreatestthinningat the centre (apex). The thickness of the cone formed attheapexwas1.1mmandat the base as 3mm.Henceinorder to obtain same thickness at the apex and the base,second blank was pre-formed so that the thickness at thecentre of the blank was 3 mm and at the ends(periphery)was 1.5 mm. This was done by machining the blank onlathe by taperturning attachment.Now the blankwasblowntoformaconeinthesamedieatthesamepressureand was observed almost uniform thickness at the apexand at the base. In order, to obtain further uniformity inthe thickness of cone formed the third blankwas pre-formed,sothatthethicknessattheend(periphery)was 1.5 and at the centre were 2.5. Now the blank was blowntoformaconeinthesamedieatthesame pressureandwas observed uniformity in thickness from apex to thebaseofformedcone.

III. RESULTS AND DISCUSSIONS

3.1.SuperplasticConeFormingfrom"Quench-roll-recrystallise"Sheets

It is widely known that superplastic blow forming of acone with apex angle 58°, under constant strain rate canbe achieved by applying a constant gas pressure [16]. Inother words constant gas pressure (P) induces a constantstress(□)intheformingmembranewhichinturnproducesconstantstrainrate.

$a_i$isthedieradius□$_i$istheradiusofcurvatureatany instant;

□$_e$ is the equivalent strainrate which isequal tothicknessstrainrate;

dtistheinfinitesimalsmallchangeintime;

$S_i$isthethicknessofthemembraneatany instant;

□$_0$istheinitialflowstress.

After forming, the cone thicknesses at various regionsweremeasuredbyintertestingmachine.Thicknessesweremeasuredfromthecentreofthecone(apex)attheintervalsof 4mm and were tabulated as shown in table 1. It wasfoundthatthatthereismorethinningatthecentre(apex)thanattheends(baseofthecone)asshowninfigure3.The measured values of thicknesses at the apex and at thebasewere1.1mmand3mmrespectively,whichisobviously un-acceptable for any application. The absolutevariationinthethicknessfromapextothebasewas1.9mm.This is due to the prevailing stresses at theapex and base. The stresses at the apex are balancedbi-axial stresses □$_1$ = □$_2$ due to the symmetry. At the baseplain strain conditionsprevails(□$_3$ = 0) due tothedieresistanceandhenceeffectivestrainrate□ isslowerattheequator. As a result, the equator was thicker than at thepole.Thecone formedwasshowninfigure4.

ControlofThicknessVariationofConebyPre-formingtheInitialBlank

As mention earlier section 3.1.1 that while forming thecone from a uniformity thick blank, a wide thicknessvariation between the apex and base of the formed conedeveloped, therefore another blank was pre-formed tocreate a thickness profile i.e., 3mm at the centre wastapering down to 1.5 at the periphery. This was done bytaperturningonalathemachine.By observingthedifference in thickness of the cone formed from uniformthick blank, the later blank was given this particularprofile.Afterformingthesecondconethicknessatvariousregionswasmeasuredby,intertestingmachineas mentionedearlier.Thethicknessesatvariouspointsweretabulatedintable2,whichshowsnearlyuniformthickness throughout the entire cone. Figure 5.shows thethickness profile of the cone. The measured values ofthicknesses at the apex and at the base were 1.6mm and1.9mmrespectively,thereforetheabsolutevariationinthe thickness from the apex to base was 0.3m. In order toobtain further uniformity in the thickness of the coneformed, third blank was pre-formed to make that centralthickness as 2.5mm, which tapers down to the peripheryto 1.5mm. Taper turning on lathe machine as mentionedearlier was employed to make this variation on the blank.After forming, the cone shows less variation in thicknessbetween apex to the base as shown in figure 6. Themeasured values of thicknesses at the apex and at thebase were 1.5mm and 1.7mm respectively as shown intable3theabsolutevariationinthethicknesswas0.2mm.The variation of thickness is nearly 10%, whichcouldbeacceptableformostoftheapplications.Numericalmethodscanbeattemptedinfuturetoobtainafurther refined thickness profile of initial blank, so thatthe final thickness of the component becomes still moreuniform.

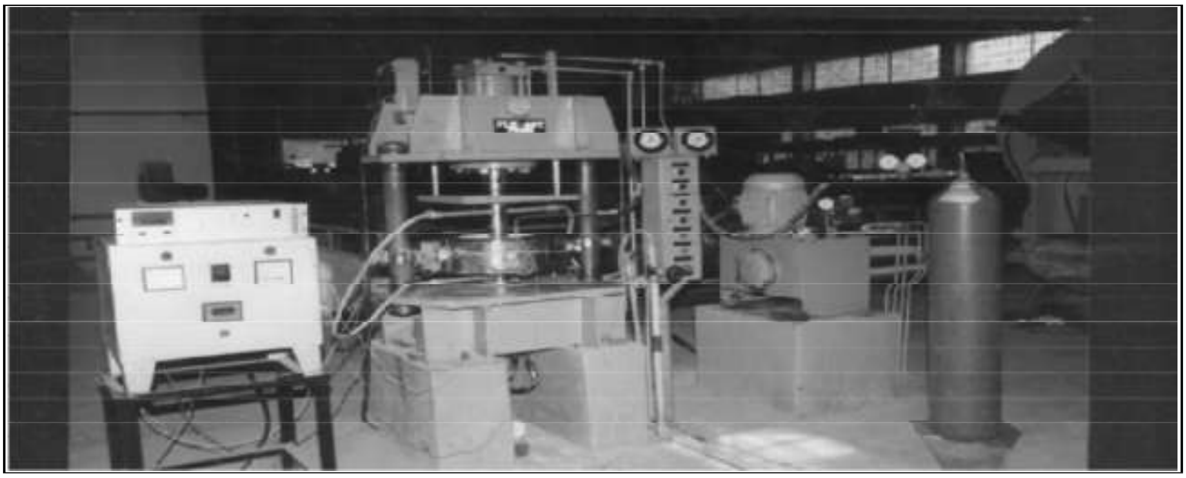

Figure1:40THydraulicPress

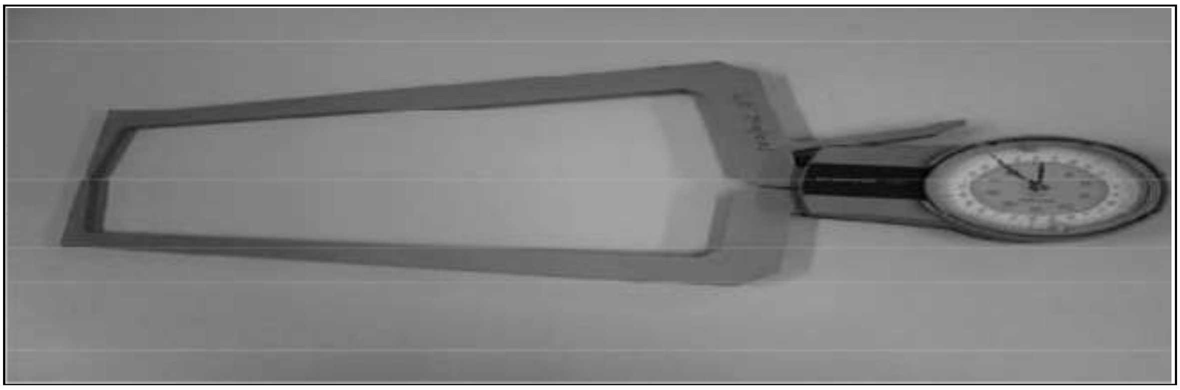

Figure2:InterTestingMachineforMeasuringThickness

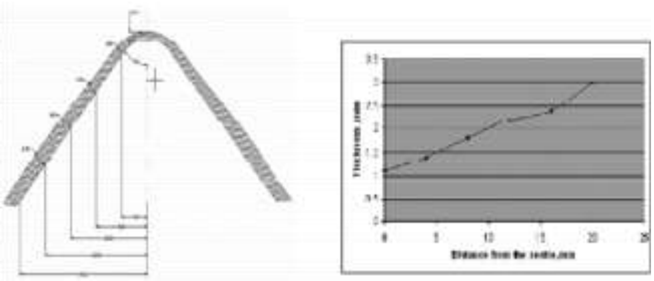

Figure3:ThicknessVariationoftheConeFormedfromCentre(Apex)totheBaseforBlank1

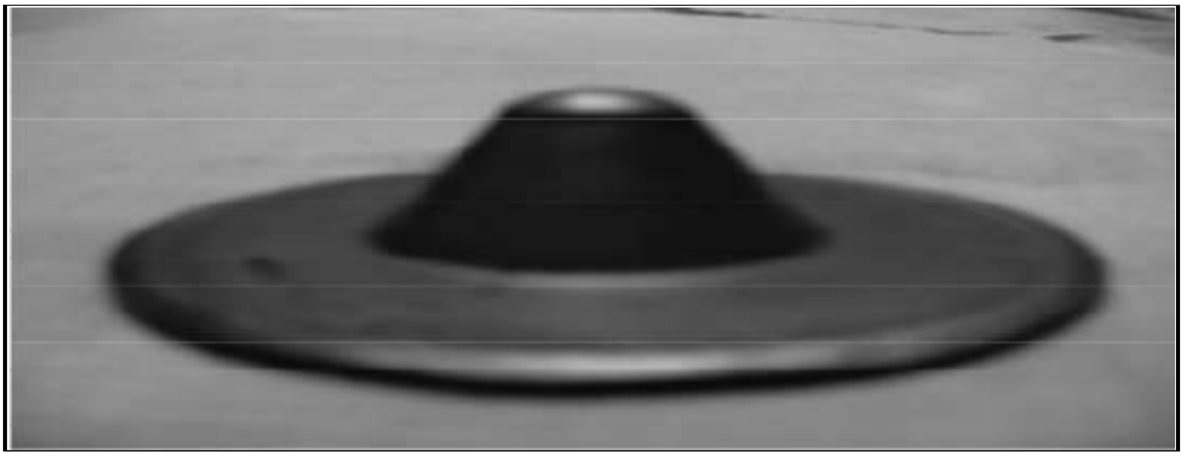

Figure4:ConeFormedbySuperplasticForming

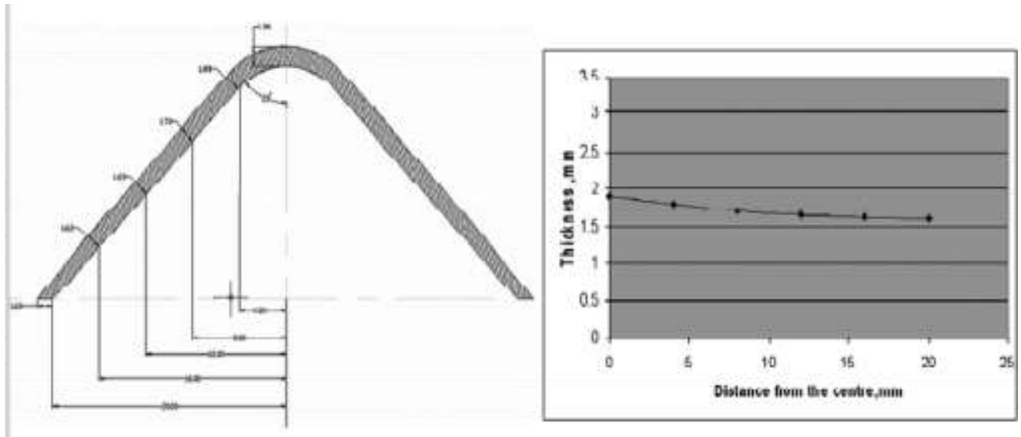

Figure5:ThicknessVariationoftheConeFormedfromCentre(Apex)totheBase,forBlank2

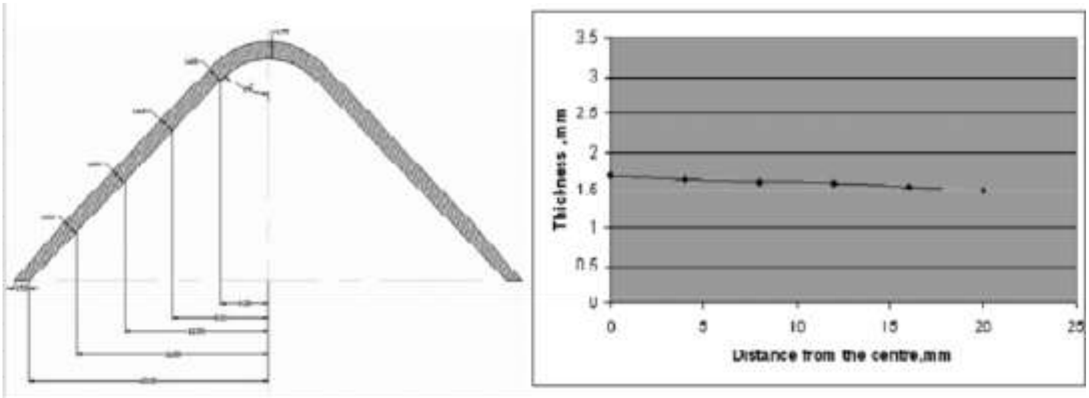

Figure6:ThicknessVariationoftheConeFormedfromCentre(Apex)totheBaseforBlank3

Table1
ThicknessoftheConeatVariousPointsasMeasuredfromtheCentre(Apex)oftheConeFormedfromtheBlank1

Sl.No	Distancefromthe centreinmm	Thickness inmm
1	0	1.1
2	4	1.4
3	8	1.8
4	12	2.2
5	16	2.4
6	20	3.0

Table2
ThicknessoftheConeatVariousPointsasMeasuredfromtheCentre(Apex)oftheConeFormedfromtheBlank2

Sl.No	**Distancefrom thecentreinmm**	**Thicknessinmm**
1	0	1.9
2	4	1.8
3	8	1.7
4	12	1.65

5	16	1.62
6	20	1.6

Table3
ThicknessoftheConeatVariousPointsasMeasuredfromtheCentre(Apex)oftheConeFormedfromtheBlank3

Sl.No	Distancefrom thecentreinmm	Thicknessinmm
1	0	1.7
2	4	1.65
3	8	1.62
4	12	1.6
5	16	1.55
6	20	1.5

IV. CONCLUSIONS

Pre-forming the initial blank in such a way that thethickness at the center is higher gradually decreasing atthe periphery, will lead to the development of a cone withnearlyuniformthickness.NumericalMethodscanbeusedto obtain the thickness profile of the pre-forming blanksheet,sothat thefinalthicknessof thecomponentformedwillhavemoreuniformity

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