2020 NUMISHEET BENCHMARK 1
─ Springback Prediction of Twist Die Panel
(Version 2. Jan 28, 2020)

The objective of this study is to benchmark springback prediction capability of various software and skills of users using AHSS and Aluminum for form a product feature typical of automotive components, such as found in B-pillars. The tooling for this study is provided by the A/SP (Auto/Steel Partnership) and is referred to as the Twist Die due to the tendency of the panel to twist during springback. In addition to twisting, the panels are also prone to exhibit side wall curl, which together are the two most difficult types of springback to control and compensate in die engineering. Consequently, the Twist Die is an excellent tool for springback analysis and has been used by the A/SP for this purpose for several years. The objective of the benchmark is to predict the springback of the formed panel stamped under two processing conditions, one with binder load to constrain metal flow and the other with a draw bead-like feature known as a stake bead. Unlike a draw bead that is machined on the binder and die surfaces to constrain metal flow throughout the stamping process, the stake bead is machined on an expansion of the punch that encroaches on the area of the conventional binder. Consequently, the stake bead acts as a miniature punch, and contacts the metal in the last several mm of punch stroke, with the intention to stop any further flow of metal from the binder into the die cavity. If the flow is stopped, the last moments of the forming process is changed from draw forming to stretch forming. To add to the challenge of predicting the springback under two very different processing conditions, the benchmark challenge includes panels stamped from a DP 980 and a 6000 series aluminum alloy.

Twist Die GEOMETRY

The assembled Twist Die tool geometry is shown in Figure 1a. The upper die components, shown as green surfaces in Figure 1a and 1b, are defined in the IGES File named

01_Twist_Die_UPR_Die.igs.

The lower punch and locator pins, shown respectively as brown and pink surfaces in Figures 1a and 1c, are defined in the IGES file named

02_Twist_Die_LWR_Punch_And_Pins.igs.

The lower binder, shown as light blue surfaces in Figures 1a/1c is defined in the IGES file named

03_Twist_Die_Binder.igs.

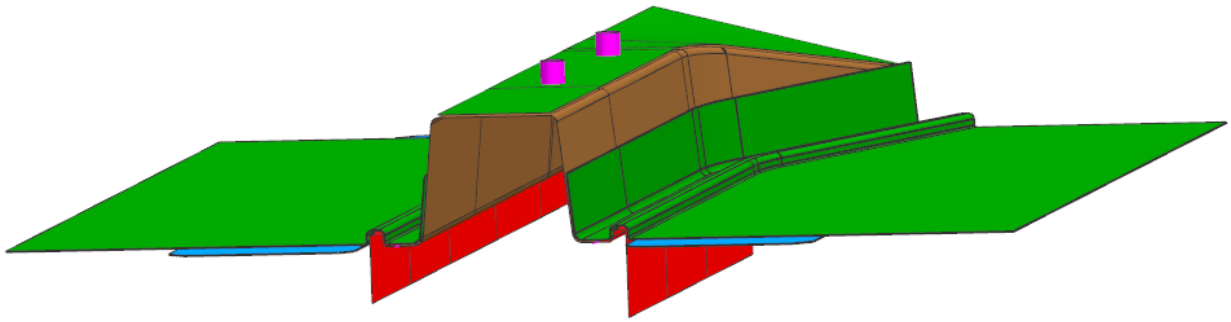

Figure 1a. Twist Die Assembly

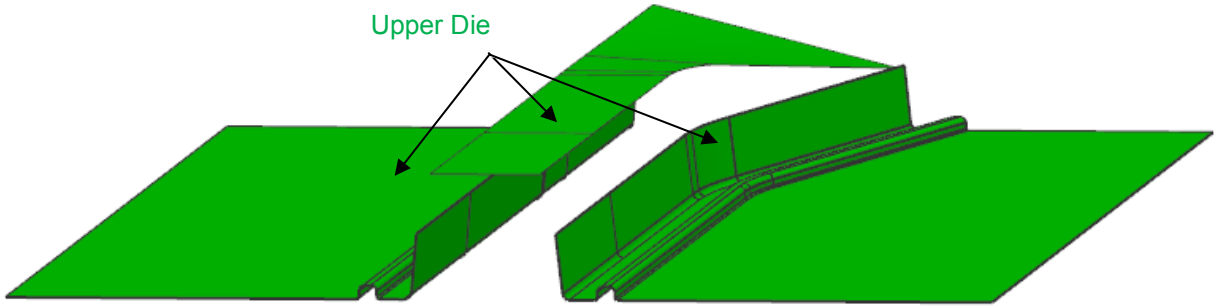

Figure 1b. Twist Die Upper Die

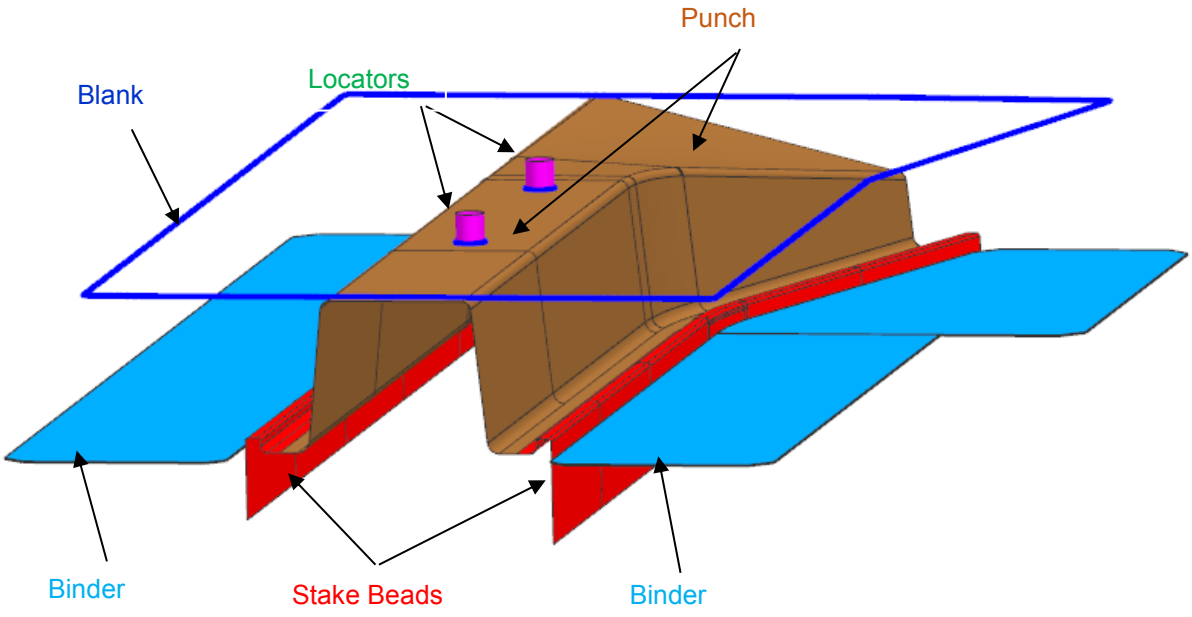

Figure 1c. Twist Die Lower Assembly

The stake bead geometry, which is used only in the process involving stake beads, is shown as red surfaces in Figures 1a and 1c, and is defined in the IGES file named

04a_Twist_Die_8mm_Beads.igs.

The Twist Die Tooling has the feature to enable the stake bead height to be adjusted to any value between 0 and 10 mm, where the stake bead is illustrated in position relative to the punch in Figure 2a at its full depth of 10 mm. The benchmark challenge involves only two cases, one with the stake bead height set to 8 mm and the other with the stake bead tooling removed. Since surface patches of the stake bead geometry defined in the above IGES file are already offset relative to the punch surface geometry to produce a bead height of 8 mm, the simulation with stake beads is most conveniently done by treating the surface patches defined in the punch and stake bead IGES files as one solid tool. The case without stake beads can be conveniently simulated by excluding the surfaces patches of the stake beads and using only the surfaces defined in the IGES file for the punch to define that component of the tool.

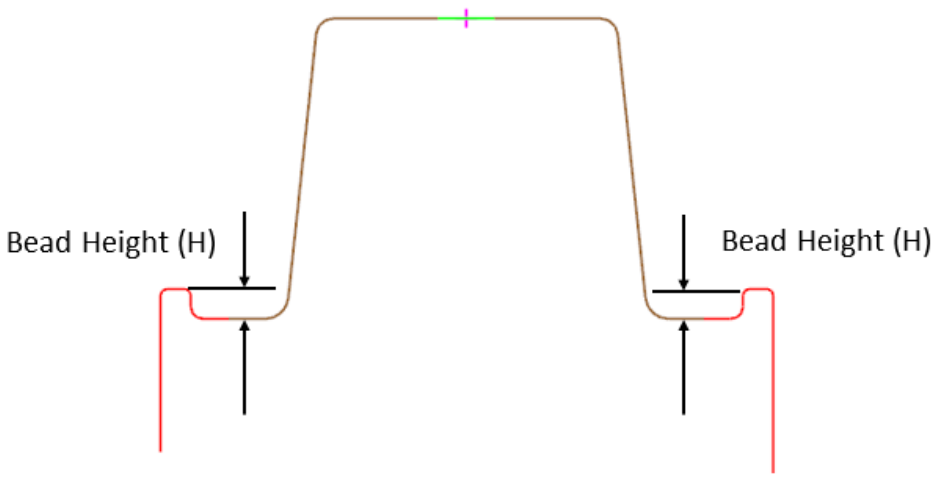

Figure 2a. Twist Die Stake Beads (Red). The surface patches for the stake bead are shown in this figure represent the maximum bead height of 10 mm, but are displaced down by 2 mm in the 04a_Twist_Die_8mm_Beads.igs file relative to the punch surface patches so that the effective bead height match the benchmark test conditions of 8 mm.

The blank boundary, including location of holes for positioning the blank, shown as dark blue lines in Figure 1c, is defined in the IGES file named

05_Twist_Die_Blank.igs.

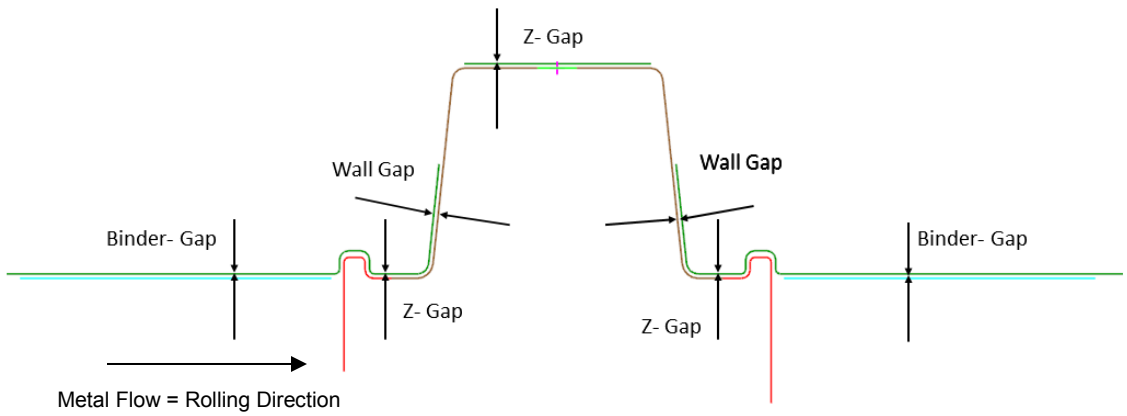

Figure 2b. Twist Die dimensions

Twist Die Specifications

The Twist Die is an A/SP stamping test die. To allow testing a larger range of materials with different thickness, the wall gap between punch and die was designed to a higher value than typically used in die engineering for stamping automotive products. Identification of material and process dependent parameters are illustrated in Figure 2a and 2b. The values of these parameters used in stamping the two metals for the two conditions are listed in Table 1. As explained in the previous section, the height of the stake bead is already reflected in the definitions of the surface patches for the punch and stake bead in their respective IGES files. Therefore, for the case of forming with stake beads, these two sets of surface patches should be treated as one solid tool during the forming process. In other words, it is not necessary to make any adjustment in the tooling or process controls for the case of forming with beads, to explicitly account for the Bead Height parameter other than to combine the two sets of surface patches to create one tool.

Process	**No Stake Bead**		**With Stake Bead**	
Parameter\Material	**DP 980**	**AA 6xxx-T4**	**DP 980**	**AA 6xxx-T4**
Z-Gap	1.60	1.60	3.2	2.5
Binder Gap	1.60	1.60	1.60	1.60
Bead Height	N/A	8 mm	N/A	8 mm

Table 1. This table reports *actual values* of the important process control parameters.

The Binder Gap was set to 1.6 mm, which is larger than the sheet thickness for both metals used in this study but smaller than the 2.13 mm gap between the die and binder surfaces defined in their IGES files. The 1.6 mm gap is maintained using pads (called kiss blocks) attached to the upper die and lower binder surface located outside of the sheet metal blank. Since the upper die and binder never pinch the sheet metal, the binder load (reported to be 40 US tons) does not play a role in forming other than to ensure that the Binder Gap remains at the fixed value throughout the stamping, including for the forming conditions with stake bead.

After closing the die on the binder to a fix Binder Gap of 1.6 mm the combined die and binder should then stretch the metal over the punch (or the punch and stake bead) surfaces until the Z-Gap, as illustrated in Figure 2b, is reduced to the values listed in Table 1 for each of the four cases involved in BM1.

Forming

The Twist Die operates as a single action draw. At the beginning of forming, the flat surface of the binder is raised 100 mm so that the blank does not initially contact the punch when the blank is set on the flat binder surface. However, the initial binder height is low enough that the two 19.0 mm diameter locator pins on the punch shown in Figure 1c pass through the two 19.2 mm precut holes in the blank. The blank perimeter and holes are laser cut. The rolling direction of the sheet coil is aligned with the draw-in direction as illustrated in the horizontal axis of Figure 2b (the Y axis of the tool and blank geometry files).

The upper draw die consists of three pieces. Some of the non-contacting areas of the die are omitted from the IGES File data file, as shown in Figure 1c. However, the three pieces of the die geometry defined in the data file move down together as a solid piece. The upper die first closes to a position equal to Binder Gap above the binder, which includes allowance for the metal thickness. This gap is maintained constant by a reported 40 US Tons, which is enough to keep the Binder Gap fixed during subsequent forming, but because the Binder Gap is larger than the sheet thickness, does not provide additional restraint by frictional forces. The upper die and binder continue in downward motion together until the upper die closes to a position equal to Z-Gap above the punch. The upper and lower tool surfaces also include allowances for the metal thickness.

The lower punch is stationary throughout the entire forming process. In the case of the process *without stake beads*, the stake beads surfaces illustrated in Figure 1c should not be included in the simulation file so that the subsequent deformation is controlled only by the punch surface. In the case with stake beads, since the stake bead geometry defined in the IGES file is already defined to result in a stake bead depth of 8 mm if the punch/bead surface are drawn to full depth, no offset is required for the stake bead geometry, as was suggested in the original posted instructions document. This Bead Height remains stationary throughout the forming process at its current setting of 8 mm.

Springback Simulation Set Up

According to the characteristics of the Twist Die geometry and springback, the method of three points (A, B and C) with six constraints is used in Twist Die springback analysis (Figure 3). Table 2 lists the three constraint point coordinates and constraint directions to remove rigid body translations during the springback simulation and to enable unambiguous comparison of the springback predictions and measurements. The coordinate system for these constraints are relative to the punch surface coordinates defined in the IGES file for the punch surfaces, which are fixed

in position throughout the forming process.

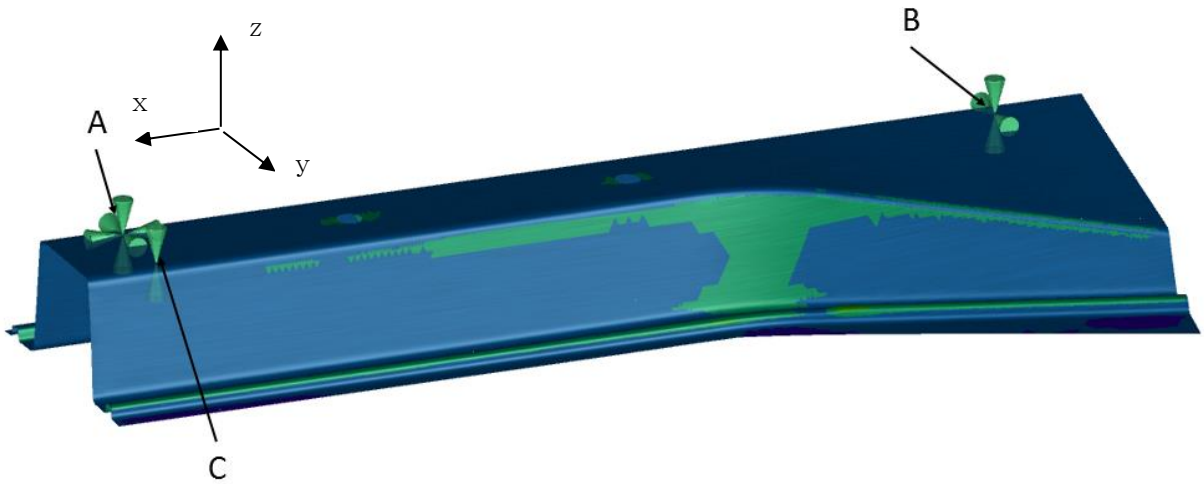

Figure 3. Springback constraint points. Note that the direction of the x-axis has been corrected from what was erroneously illustrated in Version 1 of this document.

Point	Coordinate			Constraint Direction		
	X	Y	Z	X	Y	Z
A	360.6	-25.0	1381.0	Yes	Yes	Yes
B	-389.4	-25.0	1379.2	No	Yes	Yes
C	360.6	45.0	1381.0	No	No	Yes

Table 2. Constraints to remove rigid body translation prior to springback simulation and analysis.

Springback Measurement Specifications

To ensure consistent location of measurement and prediction of springback, participants are requested to cut 5 sections through the panel after springback and application of the constraints defined in Table 2. These sections are requested at specific planes perpendicular to the x axis, selected to represent the main features of the springback that occurs in this asymmetric panel. The 5 sections are to be cut in the planes defined at the X coordinates listed in Table 3 and labeled SEC-N, as illustrated in Figure 4. Other sections, as well as STL file scans of the panels will be made available for further studies after the Numisheet Conference.

Section	**SEC-1 (X)**	**SEC-6 (X)**	**SEC-7 (X)**	**SEC-8 (X)**	**SEC-9 (X)**
Cut Plane	+360	-149.4	-219.4	-319.4	-419.4

Table 3. Definition of the X coordinate of the cutting planes for the description of sections to characterize springback.

Participants are requested to report the (X,Y,Z) coordinates of the *upper*[1] surface of the mesh at 19 reference points labeled P_0 to P_{18} on each section at the locations defined in Table 4, with the 17 interior points, P_1 to P_{17} positioned roughly as illustrated by the cross marks in Figure 4 and the points in sequence from the end point with negative Y coordinate to the end point with positive Y coordinate. Each section is expected to have the same value of the X coordinate, as defined in Table 3 but these values are requested to be included in the submitted Excel Report file to confirm that the sections cutting specifications are correctly followed by participants. The end points should be located at the edges of the formed panel for that section. The coordinates located in the "walls" of the panel (P_5, P_6, and P_7) and (P_{11}, P_{12}, and P_{13}) should span between the material point at the last contact with the die radius and the material point at the first contact with the die radius (at the "die impact line).

Point or Points	**Location on part geometry**
P_0	End point of the section (blank edge) at -Y coordinate
P_1 and P_2	Outside the TPC with the bead cavity outer radius
P_3 and P_4	Between the TPC of the bead cavity and die opening radii
P_5, P_6, and P_7	In the die wall between the TPC of the die radius and die impact line
P_8, P_9, and P_{10}	Between the TPC of the punch radii
P_{11}, P_{12}, and P_{13}	In the die wall between the TPC of the die impact line and die radius
P_{14} and P_{15}	Between the TPC of the die opening and the bead cavity radii
P_{16} and P_{17}	Outside the TPC with the bead cavity outer radius
P_{18}	End point of the section (blank edge) at +Y coordinate

Table 4. Description of the location of consecutive points P_0 to P_{18} on each section as illustrated in Figure 4 relative to the tangent points of contact (TPC) with tool surface radii at the end of forming. Consecutive points should be reasonably spaced apart, preferably as far apart as possible within the TPC's described in this table.

It is acknowledged that the locations of the 17 interior points are only roughly defined to be sequentially located in the key areas of the formed panel. It is therefore expected that participants will be reporting physically different material points on these 17 points than are reported by other participants. Different values are expected to be reported even in the fantasy in which two participants predict the same shape of the panel. While this may seem to create a challenge for analysis of the benchmark results, the predicted coordinate data will be compared to the experimental scan data represented by sufficient points to capture all features of the surfaces, or used to calculate features of the springback, such as radius of curvature, that are not sensitive to the precise location of the specified points.

Prediction accuracy will be in part be based on the average root mean square errors of these calculations over the entire part, as well as sections of the part. To the degree that analysis can make sense of the results, analysis of areas of the panel where sidewall curl or twist dominate the springback will also be reported. In addition to absolute errors in surface positions, additional standard metrics based on springback angles and radii of curvatures will also be used for

[1] In this context *upper* refers to the side of the sheet that does not come in contact with the punch.

evaluation. Further details of the analytical procedures will be described at the Numisheet Conference.

If participants are unable to report the upper surface of the mesh and can only report the location of the middle surface (node location of shell elements for example), they should indicate this in the Report File in the General Information worksheet in Cell B25. In this case that Cell B25 in the submitted report contains the word 'Yes', the location of the upper surface will be estimated from the reported membrane values and an estimate of the local sheet thickness and surface normal will be applied. If participants can determine and report the outer surface coordinates, or they simply do not want their submitted surface data to be projected to the outer surface, they should enter the word 'No' in Cell B25.

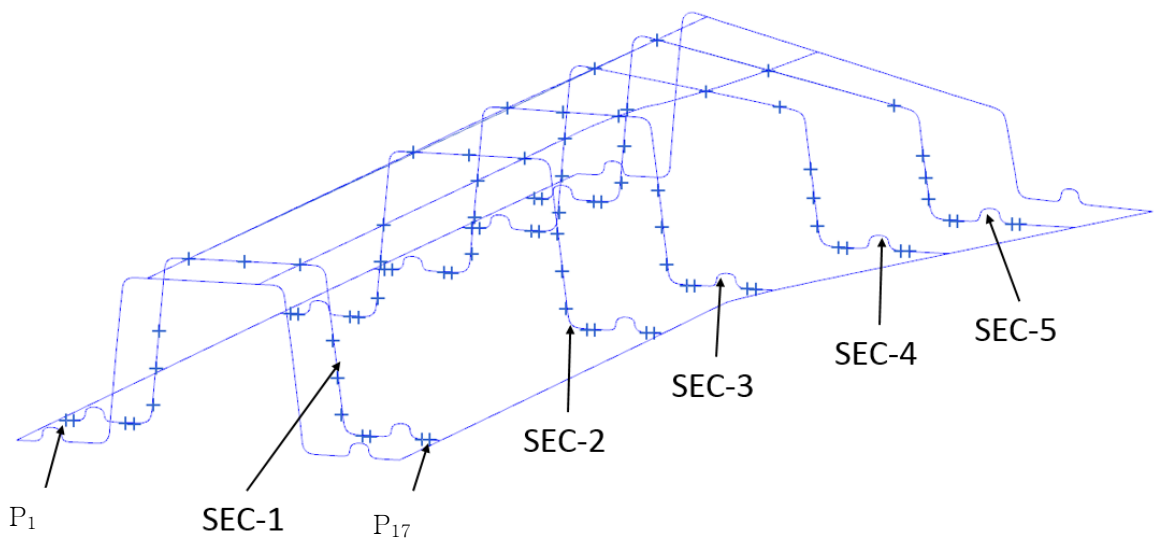

Figure 4. Springback measurement sections and points.

MATERIAL PROPERTY DATA

Uniaxial tension tests at 0, 15, 30, 45, 60, 75, and 90 degrees to the RD of the sheet coil and bulge test data are provided for calibration of constitutive models. In addition, tension-compression tests along the RD are also provided for calibration of kinematic models. Data from 3 specimens are provided for each test condition. The test data has been processed by the CalSysSmart™ software developed by Prof. Jeong-Whan Yoon to 1) extract material properties from each test, 2) identify and exclude outliers, and 3) calculate average properties for each test condition. These average properties are then used by CalSysSmart™ to calibrate a set of commonly used constitutive models. In addition, Prof. Fusahito Yoshida provided calibrations of the Yoshida-Uemori kinematic hardening model using the MATPARA™ software he developed using the tension-compression,

uniaxial, and bulge test data. Details of these analyses and options available to participants are described in the file:

ConstitutiveModelCalibrationData.pdf

which is included in the downloaded files along with *all* the material test data reported in various Excel™ files. Participants are not constrained to use one of the calibrated models provided in the data files but may use either the raw test data or the summary data (average of non-outlier properties) provided in the data files to calibrate their own preferred state of the art constitutive model or to calibrate one of the provided models with their own state of the art calibration methodology.

BENCHMARK REPORT

Benchmark submissions are requested to be uploaded through the 2020 Numisheet website up until the cutoff date of June 15, 2020. This cutoff date is necessary for the benchmark committee to analyze the submissions and prepare reports and presentations for the Benchmark Review at the 2020 Numisheet Conference from July 19-July 24. Every effort will be made to include late submissions, but it cannot be guarantees. Earlier submissions will be greatly appreciated as these will help expedite the analysis and reporting preparations for the Benchmark Review at the Numisheet Conference.

When individuals register their interest in participating in the benchmark, they will be assigned an identification number NN. (Any participant who believes they have registered and have not been notified of their assigned identification number by March 15, should notify thomas.b.stoughton@gm.com).

When participants are ready to submit their results, they are requested to change the name of the BM1_Report File to **BM1_Report_NN.xlsx**, where NN is the assigned identification to the participant when they register.

Although participants may submit more than one report, participants are discouraged from submitting more than one. Participants should keep in mind that the purpose of the benchmark study is to assess the state of the art in simulation and analysis and understand that multiple submissions can undermine this assessment. So, it is expected that participants will only submit their best assessment. On the other hand, there is value for participants to try a range of models or numerical methods to explore what works best. To address this need, it is recommended that the results of a participant's study of multiple approaches, particularly to compare results using different fracture models, to be instead submitted as a paper for publication, and submit only their best guess among these multiple approaches to the Benchmark Study. However, in the case that participants decide to

submit multiple entries despite this recommendation, the submissions should append a single letter in alphabetical order to the name of the file using their assigned 2 digit identifier. So, their first submission should be a file named **BM1_Report_NNa.xlsx**, the second submission, **BM1_Report_NNb.xlsx**, etc. For the assessment of the state of the art in simulation, the Benchmark Committee may decide to accept only the first submission from an individual, but all submissions will be processed and included in the analysis that will be reported at the conference.

Participants are requested to carefully follow the instructions listed in report template and fill in data in the cells shaded in light green on all five worksheets. It is particularly important not to modify the document in a way that changes the cell location of the requested data or for that matter, the content of any other cells in the worksheets. The reason for this requirement is that the analysis of the benchmark submissions will be handled by an automated program that will extract the information from the specific cells of the Report file. If any submission uses a different format or modifies the given format, it will be rejected by the analysis program the Benchmark Committee is developing. Participants who submit results that are rejected by the automated analysis will be informed for the cause of the rejection and given an opportunity to resubmit their results in the expected format by a specified deadline.

AUXILIARY INFORMATION

Although the data provided in the BM1 download includes all the required files with the material data and properties defined by traditional methods as described in the MATERIAL PROPERTY DATA Section of this and the supporting document *ConstitutiveModelCalibrationData.pdf*, an additional download package is available from the Numisheet Benchmark homepage in a link to the *MaterialDataSourceFiles.zip* package. This package contains material test data for all four metals used in BM1 and BM2, including source data and application of alternative data reduction analysis. The purpose of this additional download is to provide access to more details of DIC strain and surface measurements and to enable more aggressive application of DIC technology to determine onset of localized necking and possible extension of stress-strain behavior and R value measurement beyond the point of maximum load. The source data containing DIC measurements at up to 201 points down the centerline of the specimen are reported in a CSV file for each of the 21 monotonic uniaxial tests and 3 cyclic uniaxial tension-compression tests contained in separate folders for each metal in the *MaterialDataSourceFiles.zip* package. Details of this aggressive application of DIC technology and its results are provided in the following file

LocalDIC_StrainData.pdf.

included in the *MaterialDataSourceFiles.zip* package. This data is not necessary for use in application to complete BM1, whose data is adequately provided with the primary BM1 download

package and described in the file named ConstitutiveModelCalibrationData.pdf. The auxiliary data described in the file named LocalDIC_StrainData.pdf is provided primarily for application in follow-up studies after the Numisheet Benchmark Study is closed. However, participants may consider using the data files defined in the LocalDIC_StrainData.pdf file for their analysis of the BM1 applications.