INTEGRATED COMPUTATIONAL MATERIALS ENGINEERING APPROACH TO DEVELOPMENT OF LIGHTWEIGHT 3GAHSS VEHICLE ASSEMBLY (ICME 3GAHSS)

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ABSTRACT/EXECUTIVE SUMMARY

The goal of the program is to successfully demonstrate the applicability of Integrated Computational Materials Engineering (ICME) for the development and deployment of third generation advanced high strength steels (3GAHSS) for immediate weight reduction in passenger vehicles. The ICME approach will integrate results from well-established computational and experimental methodologies to develop a suite of material constitutive models (deformation and failure), manufacturing process and performance simulation modules, a properties database, as well as the computational environment linking them together for both performance prediction and material optimization. The project officially started on February 1, 2013.

The project has six technical co-dependent tasks (as listed in the "Approach"). The bulk of this period's work was focused on model development and validation, with five universities (Brown University (BU), Clemson University (CU), Colorado School of Mines (CSM), Michigan State University (MSU), and the University of Illinois at Urbanna Champaign (UIUC) and Pacific Northwest National Lab (PNNL). Initial efforts were to modify existing length scale material models for steel and to develop the constitutive material parameters to run these models and predict the steel chemistries and microstructures

that will enable 3GAHSS. This information will be used by participants from the steel industry to manufacture steel coupons for model validation and refinement.

During this period of performance, General Motors, LLC (GM) provided Baosteel Group Corporation (BAO) QP980 steel (a near third generation steel made from the quench and partitioning (QP) process developed by the Advanced Steel Products and Process Research Center (ASPPRC) at the CSM), for the purpose of adapting material models for steel, defining the needed constitutive material parameters, and gathering material properties data for the execution of these models. The BAO QP980 steel is a reasonable baseline material because the QP process is one of the potential process pathways to developing 3GAHSS. The BAO QP980 steel chemistry and its mixed microstructure, consisting of ferrite, martensite and retained austenite, provide sufficient information for early model adaptation.

On August 15, 2013 a steel experts meeting was held with representation from the steel industry, automotive original equipment manufacturers (OEMs) and CSM with the objective of defining the steel processing pathways that would enable a third generation steel. During the meeting, several possible steel processing pathways were discussed. The medium manganese transformation induced plasticity steel (TRIP) and enhancement of the QP process were preliminarily identified as those pathways that have the highest probability of achieving the mechanical properties specified in the Funding Opportunity Announcement (FOA) for the two Department of Energy (DOE) proposed 3GAHSS targets, i.e. exceptional strength, high ductility and high strength, exceptional ductility.

A significant amount of test data has been gathered on the BAO QP980 steel, which includes but is not limited to uniaxial, bulge, bilinear, micro-hardness, and micro-pillar compression testing. One significant development is the creation of three dimensional (3D) representative volume elements (RVEs) for the BAO QP980 steel. This marks the first known time that 3D RVEs have been used in ICME development and will improve model accuracy, especially forming simulation, by accounting for natural and processed induced anisotropy of sheet steels. This work is an excellent demonstration of how integration is occurring between the Task 2 sub-recipients.

The side structure of a 2008 Model Year (MY) sedan was selected to demonstrate the weight savings potential and associated costs with the proposed 3GAHSS. During this period, the Engineering + Design AG (EDAG) firm under the leadership of GM, generated finite element models (FEM) of the entire Body-in-White (BIW) and a bill of materials with alloy chemistries for each component, defined the overall body structure performance including the contribution of the body side structure load paths, and generated a preliminary technical cost model. Once fully characterized, the baseline assembly will be contrasted against design optimized assemblies using gauge optimization first to show the 3GAHSS material impact on weight savings and later to shape optimization and demonstrate how 3GAHSS will enable more efficient designs. The project assumed an optimized spot welding and adhesive bonding joining strategy.

The project team produced a flowchart of the model assembly and integration process, which will be used to assemble the length scale material models and integrate them with the forming, design optimization and technical cost model. Increased emphasis on assembly of the material models and forming simulations as 3GAHSS designs mature are planned for the 2014 Fiscal Year (FY). The project is on track to meet all deliverables for the first budget period and all subsequent years.

Accomplishments (2013 FY)

- General Motors, LLC transferred the design package for a 2008 model year sedan to EDAG. EDAG processed the design package to generate finite element analysis (FEA) models for the entire 2008 sedan BIW design.

- A bill of materials was generated for the 45 components that make up the side structure and alloy chemistries for each component were identified.
- On September 30, 2013 the project team met Milestone #1 'Selection of body structure components/subassembly and identification of baseline materials'. The project team identified the side structure from a 2008 model year sedan as the baseline subassembly from which the four or more targeted AHSS components will be selected to demonstrate that the 3GAHSS will reduce weight in structural automotive components and assemblies.
- The team produced a preliminary technical cost model for the baseline design and future 3GAHSS designs.
- The project team approved the use of spot welding with adhesive bonding for the baseline and 3GAHSS sub-assembly designs.
- EDAG established a computer aided engineering (CAE) method and load cases for analysis of the baseline and 3GAHSS assemblies and created LSDYNA format material cards.
- The UIUC computed the elastic constants, lattice parameters, and force constants of body centered cubic (bcc) and face centered cubic (fcc) iron, which serve as inputs into the lattice Green function method for dislocation core structures and, ultimately critical resolve shear strengths for each 3GAHSS phase to be used with the crystal plasticity modeling.
- The Combined Constraint Crystal Plasticity (CCCP) was modified to include a dislocation density-based hardening model and to account for the non-Schmid law.
- In close cooperation with BU, and under the leadership of Dr. Louis Hector, Jr., MSU has completed an initial 3D RVE for the BAO QP980 steel. This marks the first known implementation of 3D RVEs in ICME modeling and will be a fundamental component of the steel crystal plasticity model.
- The CSM completed a comprehensive literature review on metallurgical paths that can be further exploited leading to the property targets aimed in this project. The literature review and initial results of composite modeling were presented in the Steel Experts Meeting held at the Auto/Steel Partnership (A/SP) office in Southfield, Michigan on August 15, 2013. Quench and partitioning and medium manganese TRIP steel were proposed as two possible steel pathways that would enable 3GAHSS with the mechanical properties of the two DOE proposed 3GAHSS.
- BU generated electron backscatter diffraction (EBSD) patterns of the as-received BAO QP980 steel to determine the volume fraction of retained austenite and its distribution at interfaces. BU ran micro-pillar compression tests to generate flow properties of the ferrite, martensite and austenite in BAPQP980. BU also applied EBSD at various levels of plastic tensile strains until fracture to determine the change in the volume fraction of retained austenite with strain and especially beyond the ultimate tensile strength (UTS). BU provided the data to MSU to enable the generation of 3D RVEs.
- CU completed all uniaxial tensile testing on the starting material (BAO QP980) at room temperature and a selected quasi-static rate ($2x10^{-3}$ s^{-1}), covering seven orientations with respect to rolling direction (0, 15, 30, 45, 60, 75 and 90°). CU established a testing linkage with the National Institute of Standards and Technology (NIST), Gaithersburg, MD for testing over the low dynamic range for vehicle impact and completed a first set of high strain rate tensile testing using Kolsky Bar achieving a strain rate of ~850 s^{-1} as the lowest strain rate. Flow curves were generated for three orientations (0, 45 and 90°) with respect to the rolling direction.

- CU completed material deformation studies using digital image correlation (flow stress/strain curves, mechanical properties, plots of strain hardening exponent with strain, evolution of the R-value with strain.)
- CU completed temperature measurements of material samples deformed at room temperature and quasi-static rate; plots of temperature increase as a function of plastic strain have been generated.

Future Directions

- Complete the characterization of BAO QP980 steel and derive relevant constitutive parameters for input into the crystal plasticity model.
- Complete and assemble material length scale models and provide initial meso-scale computational predictions for 3GAHSS chemistries and microstructures (Project Milestone #2).
- Manufacture AHSS and 3GAHSS steel coupons for testing and model calibration and validation.
- Identify, adapt, and apply forming and fracture simulation to baseline and 3GAHSS designs in the third year of the program (Project Milestones #4 and #3 respectively).
- Complete characterization of the baseline assembly (Project Milestone #1). Evaluate the potential weight savings that can be achieved by substituting the two target 3GAHSS on the baseline assembly weight using gauge optimization. Once actual 3GAHSS materials are devised conduct full design optimization, including shape optimization, of the baseline assembly to determine the cost impact and weight savings of using 3GAHSS on automotive structural assemblies.
- Integrate material length scale models with the forming model, fracture model, technical cost model with design optimization. Provide a user manual for the ICME model and data repository for material property data.

Technology Assessment

- Target: Model elements must be within 15% of experimental results and the optimized 3GAHSS assembly must achieve 35% weight savings at no more than $3.18 cost per pound of weight savings.
- Gap: There is no existing ICME framework that ties together all length scale computer models with forming simulation, fracture modeling and design optimization, especially with low and high level optimization loops. Although a linear input/output connectivity can be achieved between the length scale material models, optimization loops will require significant coding that may be complicated by disparate codes used in the individual models.
- Gap: Boundary conditions have been applied to model elements to facilitate assembly and integration within the project four year duration. For example, the number of solutes to be evaluated has been limited, inclusions and precipitates are largely ignored, and dislocation dynamics are superficially treated. These are all opportunities for future work and model improvement but these boundary conditions may adversely affect model accuracy.
- Gap: The weight savings targets are aggressive and it is not known if these targets can be achieved with the selected sub-assembly using the two proposed 3GAHSS grades as defined in the FOA. An optimized joining strategy of spot welding with adhesive bonding was selected for the baseline and 3GAHSS design optimization studies. The project will first assess the potential weight savings through material substitution and gauge optimization using the two proposed 3GAHSS grades. Once 3GAHSS coupons are made available, full design optimization, including shape optimization, will be performed to determine if optimized 3GAHSS designs can achieve the desired weight savings while meeting strength requirements.

- Gap: This program will not assess the manufacturability of the shapes proposed during design optimization. Forming simulations may mitigate this risk but shape optimization may generate shapes that may not be easily manufacturable. Technical cost modeling may provide a qualitative assessment of manufacturability where the cost of the proposed components may exceed the $3.18 per pound weight-saved target.
- Target: Two different 3GAHSS are defined by the FOA, exceptional strength and high ductility (>1500 MPa UTS, >1200 MPa YS, >25% elongation) and high strength and exceptional ductility (>1200 MPa UTS, >800 MPa YS, >30% elongation).
- Gap: The ICME model will predict the necessary chemistry and steel microstructure needed to meet the target mechanical properties but process development (melting, rolling, intermediate heat treatments, finishing, etc.) may be needed to produce sheet steel with the predicted microstructure. The project will leverage the expertise of steel industry participants to guide process development using laboratory size heats to develop a process that can achieve the predicted microstructure.

Introduction

The goal of the program is to successfully demonstrate the applicability ICME for the development and deployment of 3GAHSS for immediate weight reduction in passenger vehicles. The ICME approach used in this project will accelerate the development and widespread deployment of 3GAHSS through modeling of multi-scale metallurgical, thermal and mechanical processes in coil sheet development to automotive part and assembly manufacturing and ultimate in-vehicle performance. By integrating a suite of comprehensive, science-based computational models at different length scales in the ICME environment, this project will demonstrate to end users in both the automotive and steel industries that immediate cost-effective weight savings can be achieved with 3GAHSS, and that the ICME framework will support a reduced development to deployment lead time in all lightweight materials systems. The product of this proposed effort will be a simulation toolset and computational infrastructure composed of material models and associated validation data at different length scales together with the software and application programming interfaces developed by the project team.

The project faces three distinct challenges, 1) to develop an ICME model, 2) to develop a viable 3GAHSS and 3) to optimize an automotive design concept for a material that does not yet exist. As shown in FIGURE 1, there are no commercial 3GAHSS and no U.S. steel company currently markets a 3GAHSS. FIGURE 1 also illustrates the relative values for BAO QP980 and the two DOE targets for 3GAHSS. Although the manufacturing of 3GAHSS is not a deliverable of this program, the DOE proposed two 3GAHSS grades with mechanical properties listed in TABLE 1 as targets for the program. The project began the task of adapting existing material models for steel by selecting an AHSS grade, BAO QP980, which has mechanical properties on the cusp of the 3GAHSS envelope. In the absence of the 3GAHSS, the BAO QP980with its mixed martensite and retained austenite microstructure will 1) facilitate the identification of relevant constitutive parameters for each length scale material model 2) provide a means to validate these models and 3) help define the microstructural elements that will be needed for a 3GAHSS.

The first year of the program will develop the framework to assemble the length scale material models. Starting in the second year of the program, the project team anticipates that the developed and assembled models will provide early 3GAHSS predictions of steel chemistries and microstructures that will enable a 3GAHSS. These early predictions will be used by the six steel industry participants to guide the manufacturing of steel coupons with mechanical properties that will evolve toward the DOE targets as the models mature and are validated.

FIGURE 1: Target 3GAHSS Properties

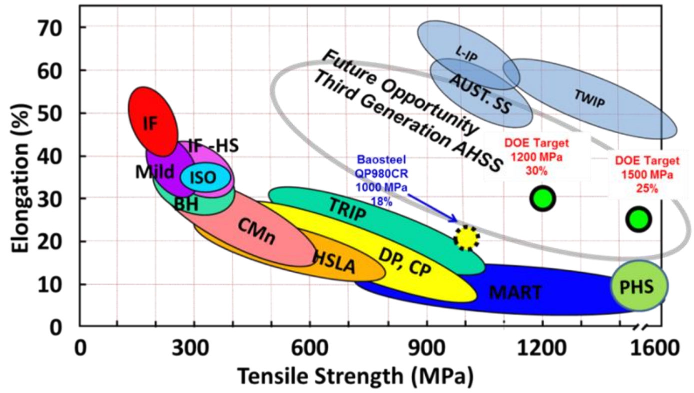

TABLE 1: 3GAHSS Types

Ferrous Sheet Metal Type	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (Uniaxial Strain to Failure)	Uniform Elongation
High Strength, Exceptional Ductility	≥800	≥1200	≥30%	≥20%
Exceptional Strength, High Ductility	≥1200	≥1500	≥25%	≥8%

As the models are being adapted and assembled, a baseline will be established to demonstrate the potential benefits of the 3GAHSS to reduce automotive assembly weight. An automotive assembly will be identified which must contain a minimum of four 3GAHSS components extracted from a 2008 MY or later production vehicle. Initially, the baseline assembly will be fully characterized in terms of the weight, cost and performance criterion. An iterative design optimization process of gauge and shape optimization will be applied to the baseline assembly substituting 3GAHSS for AHSS and developing a 3GAHSS design that can meet the proposed weight savings target listed in TABLE 2. Coupled with design optimization are forming modeling and simulation, fracture modeling and simulation and technical cost modeling to assess the manufacturability, performance and cost of the different design iterations with the goal of achieving the cost targets listed in TABLE 2 without compromising component and assembly performance.

TABLE 2: DOE FOA Weight and Cost Targets

Vehicle System	System Definition	Weight Reduction Target	Cost per Pound of Weight Saved ($/lb. saved)
Body	Body-In-White, Closures, Windows, Fenders, & Bumpers	≥35%	≤3.18/lb.

Work to integrate the material, forming, fracture, and cost models with design optimization will span the entire length of the program. The primary project deliverable includes an ICME model and user guide to enable users to run the model. The objective is to create an ICME model capable of predicting part and assembly properties from the sheet properties and the process history within 15% accuracy at all length scales that will enable the baseline structure to meet the specified weight and cost targets.

The challenges of this program require significant academic and cross-industry expertise, and regular communication and collaboration between these parties to make the integration component of the project successful. The project is highly leveraged with expertise from the participants shown in TABLE 3 supporting the entire life cycle of material, process and product development. Prior collaboration between these project participants through the United States Automotive Materials Partnership (USAMP) and the A/SP provides a unique and successful foundation for addressing the technical challenges of this program.

TABLE 3: Project Participants

Universities/National Labs	Industry
Brown University	Chrysler Group LLC
Clemson University	Ford Motor Company
Colorado School of Mines	General Motors Company
Michigan State University	AK Steel Corporation
Pacific Northwest National Lab	ArcelorMittal
University of Illinois	Nucor Steel Corporation
	Severstal NA
Consortiums	ThyssenKrupp USA
Auto/Steel Partnership	U. S. Steel
United States Automotive Materials Partnership	EDAG, Inc.
	Livermore Software Technology Corporation

Approach

The project has been structured with seven tasks as follows:

- Task 1: Project Management and Planning
- Task 2: Model Development and Model-Level Validation
- Task 3: Forming: Component-Scale Performance Prediction and Validation
- Task 4: Assembly
- Task 5: Design Optimization
- Task 6: Integration
- Task 7: Technical Cost Modeling

<u>Budget Period 1:</u>

During the first year, the program achieved the following:

- Completed numerous experiments to characterize the behavior of BAO QP980 steel as a baseline for adapting well-established computational material models for AHSS.
- Completed the first phase of the atomistic calculations which includes the development of a Density Functional Theory (DFT) based solid-solution strengthening model for iron crystal structures relevant for 3GAHSS: bcc Ferrite, fcc Austenite, and body-centered tetragonal (bct) Martensite.
- Developed 3D RVEs for input into the Crystal Plasticity Finite Element Model (CPFEM).
- Defined steel processing paths which will likely produce a 3GAHSS and will assist in developing a plan to produce steel coupons for the purpose of model validation (Project Milestone #1).
- Defined and flow charted a process in which the material constitutive models will be assembled and integrated with manufacturing process and performance simulation modules, performance prediction, and material optimization.

- Identified the side structure of a 2008 high volume production sedan as the target sub-assembly from which 3GAHSS will be substituted for a minimum of four AHSS parts to demonstrate the weight saving potential and cost of using 3GAHSS in structural automotive assemblies (Project Milestone #7).
- Identified the joining methodology to be used for the baseline assembly and 3GAHSS assemblies (Project Milestone #6).
- Defined a technical cost model which will be used to compare the baseline assembly costs against the two DOE proposed 3GAHSS targets.

Budget Period 2:
The second year of the program will begin the transition from model adaptation to model validation. At this time, AHSS coupons with microstructures different from BAO QP980 will be manufactured for testing and model validation. The model inputs and outputs will be defined to facilitate the process of assembling the constitutive material models. By the end of the second year, the material models should have some limited predictive capability and enable the first iteration of 3GAHSS simulation and prediction (limited to the ability to propose steel chemistries and microstructures that may generate steels with the DOE proposed mechanical properties for 3GAHSS (Project Milestone #2)).

The baseline sub-assembly identified in the prior period will be fully characterized, which will include a FEA model, defined load paths based upon established vehicle performance criteria, a bill of materials for the vehicle sub-assembly, and a preliminary cost model. Using the joining criteria defined in the prior period, the project will apply gauge optimization to determine the cost and weight savings potential of substituting the two proposed DOE 3GAHSS grades for the four or more AHSS components. This will enable a preliminarily determination of the weight and cost of the sub-assembly with the DOE 3GAHSS grades applied. An estimate can then be made as to whether the DOE mass reduction targets can be achieved from the optimal 3GAHSS materials.

Forming simulation will begin during this period coupled with design optimization as the project measures the manufacturing feasibility of the 3GAHSS components. This work is expected to reveal opportunities for part commonization as well as component designs that can best respond to applied load paths.

Budget Period 3:
The third year of the program will begin with the assembly of the constitutive materials models and refinement in their predictive capability. By this time, the 3GAHSS designs will be complete providing an assessment of the cost and weight savings potential of 3GAHSS. Fracture modeling will begin during this period utilizing the constitutive models fit to the mechanical properties of the 3GAHSS materials and the known forming requirements of the sub-assembly. This work is scheduled to be completed by the end of the budget period (Project Milestone #4).

Integration of the material models with the forming, fracture, performance and cost models will be accelerated during this period using the flow charts defined in Budget Period One. By the close of the budget period the project is expected to have a rudimentary ICME model (Project Milestone #3). Key to this work will be the framework that enables the ICME model to execute 3GAHSS simulations.

Based on Budget Period Two 3GAHSS model simulations, steel coupons will be produced, tested and characterized using tests applied to the baseline BAO QP980 steel. These samples are not expected to have the target mechanical properties of the two proposed 3GAHSS in the FOA, but rather these samples will be representative of microstructures with properties closer to the targets for the purpose of correcting and/or validating the length scale material models.

The project will continue to improve the individual models and the linkage between the models, and optimize the integration of the ICME model (Project Milestone #9) during this period. Upon completion of the program, a final forming model (Project Milestone #5), a completed technical cost model (Project Milestone #11), an ICME user guide and data repository (Project Milestone #10) will be developed as part of the final project deliverables.

Steel coupons will continue to be manufactured using more accurate predictions from improved material model simulations. The project has assumed that proposed material chemistries can be successfully processed to achieve the proposed microstructures. If the resulting coupons have the properties of or near the two proposed 3GAHSS targets, the project will utilize the mechanical properties derived from the 3GAHSS coupons for the final stage of design optimization. The final 'actual' 3GAHSS design (Project Milestone #8) will be contrasted against the baseline assembly weight and cost as well as results derived from the two theoretical DOE 3GAHSS targets. The final design will provide a better means to assess the potential of 3GAHSS to meet proposed cost and weight targets as well as the potential design flexibility from proposed and actual 3GAHSS.

Results and Discussion

The UIUC is applying existing first principal DFT methodologies and other atomistic-scale methodologies to compute relevant parameters of the crystal plasticity model of the 3GAHSS (e.g. various hardening parameters of the different phases in the steel microstructure, critical resolved shear strengths) and to compute accurate geometries of relevant defect structures (e.g. dislocation cores) in the various phases of the 3GAHSS. The atomistic-scale methodologies will serve as a computational means for calibration of the microstructural models following the ICME approach. This will enable the prediction of flow curves, yield criteria and stress / strain curves. The atomistic approach will also define relevant parameters that can be computed with discrete dislocation dynamics modeling which is not part of the present project.

BU is evaluating austenite stability as a function of strain to better predict the flow properties of third generation steels. Part of this work is the development of test procedures to evaluate the submicron properties (e.g. flow behavior) of austenite, which include microhardness and micro-pillar compression testing, which is significantly complicated by sheet steel's highly anisotropic properties due mostly to processing.

CU is conducting coupon-level mechanical tests on the BAO QP980 and eventually the 3GAHSSs to provide flow behavior, anisotropy, formability, adiabatic heating and failure/fracture data as inputs to the crystal plasticity and state variable models at MSU and PNNL. During this reporting period CU continued the characterization of the starting material BAO QP980, and received additional material from GM. Testing activities covered quasi-static tensile testing, bake hardening behavior, temperature increase due to tensile deformation, measurements of volume fraction of retained austenite, high strain rate testing (Kolsky Bar), preliminary high strain rate testing (servo-hydraulic), and preliminary bulge testing.

MSU is applying and integrating the atomistic and microstructural scale material models to generate material models that can be used in the crystal plasticity material models and state variables models to enable the prediction of flow curves, and stress / strain curves for 3GAHSS. This work will enable automotive forming process engineers as well as automotive CAE engineers to accurately model the material response of steel, advanced high strength steel, and 3GAHSS. The development of the first ever three dimensional representative volume elements (3D RVEs) is included in this work and will enable improved accuracy in predicting material properties over the two dimensional RVEs. FIGURE 2 is a pictorial of the 3D RVE generated for BAO QP980 steel.

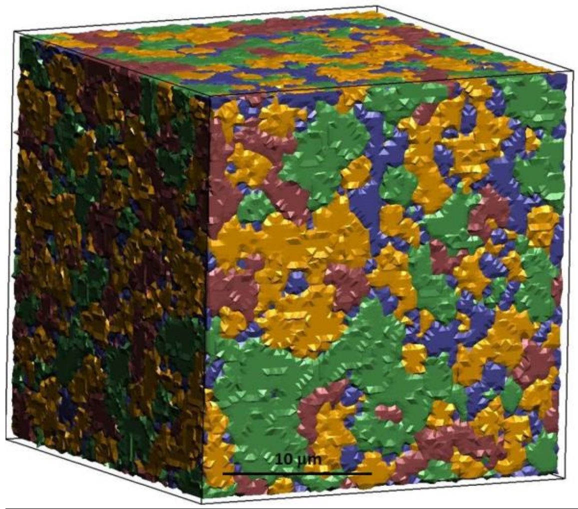

Figure 2: Three Dimensional Representative Volume Element of BAO QP980 Steel - (Green = Martensite, Blue = Austenite and Red + Yellow = Ferrite)

PNNL is adapting single phase state variable models to accommodate multiphase third generation steels. PNNL is supporting advanced experimentation involving synchrotron radiation measurements at the Argonne National Lab Advanced Photon Source and has offered the use of its atom probe tomography capability to measure solute concentration and partitioning in the various 3GAHSS phases (needed by the atomistic and crystal plasticity components of the project). PNNL has also transferred their implementation of a transformation kinetics model to enable GM to begin forming simulations of steels with TRIP chemistries. PNNL also established a Sharepoint site that is serving as a *de facto* data repository for the project.

General Motors (GM) provided a vehicle data package for a 2008 MY sedan from which the baseline assembly was extracted. The baseline assembly will be used to demonstrate the potential weight and cost impact of third generation steels on automotive structures and assemblies. EDAG processed this vehicle data to generate representative finite element models from which the side structure was chosen for the baseline assembly, see FIGURE 3. The joining criteria, load cases, and the framework for the technical cost model were defined. GM is also providing computational support to the atomistic, crystal plasticity, and forming components of the project

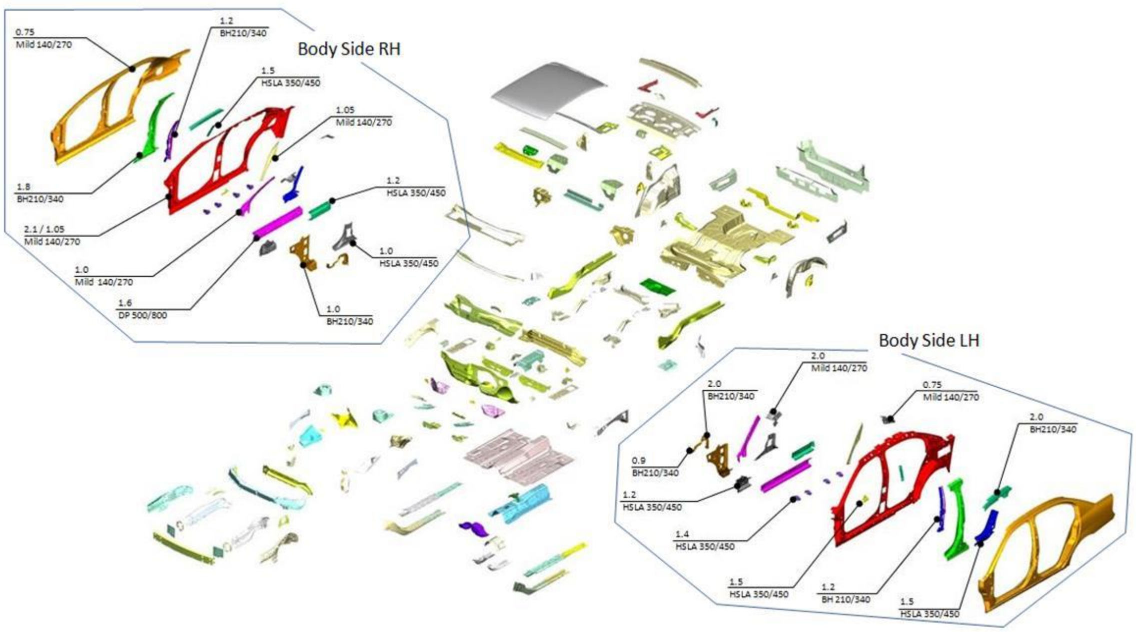

Figure 3: Baseline Assembly: Side Structure Part Details

During this budget period, the model assembly and integration process was flow-charted which will be used to assemble the length scale material models and integrate them with the forming, design optimization, and technical cost model.

Technology Transfer Path

The primary deliverable of this program is an integrated computer model with a user guide that will enable users to develop 3GAHSS. The software will include a high level description of the integrated models along with a description of input variables, output variables, state variables, and relational databases implemented within the final software deliverable. The user's manual will provide an overall description of the user implementation approach for the software.

During the development of the ICME model, the project will be developing test methodologies for evaluating and characterizing 3GAHSS such as nano-hardness testing, micro-pillar, bulge testing, sheet tension-compression, etc. If the results from these tests can be correlated to macroscopic bulk materials properties testing then these tests are expected to be adopted for future work and potentially industry standardization.

Additionally, if the individual length scale material models show a high degree of accuracy then these models will be adopted by industry and academia for expansion and refinement to cover additional steel processing paths. Primary users of the technology are the partners that are engaged in this project which is expected to speed the implementation of results and lessons learned.

Conclusion

Although still in the early stages (first eight months), the project is on track to meet the first period deliverables. The task teams were still able to better define the scope of work for the tasks such as flow charting the assembly and integration of the models, flow charting the co-dependent work of forming simulation with design optimization, and defining a technical approach to selecting a focal sub-assembly that can best utilize 3GAHSS with respect to applied load paths as determined from applied vehicle performance criterion. This work facilitated the development of supplier statements of work (SoWs) and improved the ability of the project to coordinate co-dependent tasks thereby increasing the likelihood that the project will successfully achieve the objectives and proposed deliverables.

Task 2 is fully launched and is focused on adapting length scale computer models for 3GAHSS and deriving representative constitutive parameters for the BAO QP980 steel. The project has identified several potential processing paths for making 3GAHSS, which include carbide free bainite, stainless steel, medium and high manganese TRIP steel and further enhancement of the quench and partitioning processing pathway. The project is working on developing a plan, due January 31, 2014 (Project Milestone #1), to make sample coupons for model validation.

The effect of solute upon elastic constants and dislocation dynamics has been completed for both ferrite and austenite with work continuing in the 2014 FY on martensite. Test results from uniaxial, bilinear, tension/compression, microhardness, bulge, and micro-pillar testing will shortly be passed to the crystal plasticity and forming component models to facilitate model validation. Work to evaluate the effect of strain and temperature on austenite stability will continue in the 2014 FY with emphasis on contrasting and validating test methodologies. Work in the 2014 FY will focus on correlation of test results with bulk material properties, and between crystal plasticity model predictions against state variable model predictions, and bulk materials properties test results.

Significant effort was needed to develop 3D RVEs for AHSS using BAO QP980 steel as a starting microstructure. The results should improve the predictive ability of the crystal plasticity model by being able to better assess the natural and processing induced material anisotropy of sheet steels. This appears to be the first time that 3D RVEs have been derived for ICME work, which is especially noteworthy considering the multiphase nature of steel versus more homogenous materials such as aluminum.

The side structure from a 2008 model year sedan was selected as the assembly from which four or more AHSS components will be selected to evaluate the potential of 3GAHSS to reduce weight in automotive structural assemblies. The performance criterion for the side structure was defined, a bill of materials generated for all side structure components and a preliminary technical cost model developed. Full characterization of the side structure is underway with a January 31, 2014 deliverable date.

Flow charts were developed to coordinate the co-dependent tasks of forming simulation, design optimization and technical cost modeling. During the 2014 FY, the project will continue to adapt existing material models and transition from development to testing and validation as steel coupons are made available. Also during this period, the materials contribution of substituting 3GAHSS for AHSS on the weight of the side structure using only gauge optimization will be assessed. This work will also initiate the identification and application of forming models.

Flow charts were developed during this period to coordinate both assembly and integration of the computer models. Work to assemble the material models will increase throughout the 2014 FY with emphasis on documenting the inputs and outputs of each model and establishing the necessary linkages and optimization loops to facilitate assembly and eventual integration into the ICME model.

PRESENTATIONS/PUBLICATIONS/PATENTS

Hector Jr., L.G. The Next Generation of Advanced High Strength Steels – Computation, Product Design and Performance. Presentation given at the Great Designs in Steel Symposium, Livonia, Michigan, U.S.A., May 1, 2013; AISI/SMDI, Southfield, Michigan

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APPENDIX A: ACRONYMS

2D/3D	Two Dimensional / Three Dimensional
3GAHSS	Third Generation Advanced High Strength Steel
A/SP	Auto / Steel Partnership
AHSS	Advanced High Strength Steel
AISI	American Iron and Steel Institute
AIST	Association for American Iron and Steel Technology
ASPPRC	Advanced Steel Processing and Products Research Center
BCC	Body-centered cubic
BCT	Body-centered tetragonal
BIW	Body-in-White
BU	Brown University
CAE	Computer Aided Engineering
CCCP	Combined Constraint Crystal Plasticity
CPFEM	Crystal Plasticity Finite Element Model
CSM	Colorado School of Mines
CU	Clemson University
DOE	Department of Energy
DFT	Density Functional Theory
EBSD	Electron Backscatter Diffraction
FCC	Face-centered cubic
FEA	Finite Element Analysis
FEM	Finite Element Model
FOA	Funding Opportunity Announcement
GM	General Motors
ICME	Integrated Computational Materials Engineering
MPa	Mega Pascals
MSU	Michigan State University
MY	Model Year
NETL	National Energy Testing Laboratory
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
PNNL	Pacific Northwest National Laboratories
QP	Quench and Partitioning
RD	Rolling Direction
RVE	Representative Volume Element
SAE	Society of Automotive Engineers
SMDI	Steel Market Development Institute
SoW / SSOW	Statement of Work / Supplier Statement of Work
TRIP	Transformation Induced Plasticity
TWIP	Twinning Induced Plasticity
UIUC	University of Illinois at Urbana-Champaign
USAMP	United States Automotive Materials Partnership
UTS	Ultimate Tensile Strength
YS	Yield Strength