Title: DYNAMIC MATERIALS TESTING AND CONSTITUTIVE MODELING OF
STRUCTURAL SHEET STEEL FOR AUTOMOTIVE APPLICATIONS

RECEIVED

OCT 11 1996

OSTI

Author(s): C. M. Cady, S. R. Chen, G. T. Gray III, M. F. Lopez
R. W. Carpenter II, and D. Korzekwa

Submitted to: Final Progress Report

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

**DYNAMIC MATERIALS TESTING AND
CONSTITUTIVE MODELING OF STRUCTURAL SHEET STEEL
FOR AUTOMOTIVE APPLICATIONS**

Final Progress Report

August 23, 1996

**C. M. Cady, S. R. Chen, G. T. Gray III, M. F. Lopez,
R. W. Carpenter II, and D. Korzekwa**

**Los Alamos National Laboratory
MST-5, MS-G755
Los Alamos NM, 87545**

Work Statement

The objective of this study was to characterize the dynamic mechanical properties of four different structural sheet steels used in automobile manufacture. The analysis of a drawing quality, special killed (DQSK) mild steel, high strength, low alloy (HSLA) steel, interstitial free (IF), and a high strength steel (M-190) have been completed. In addition to the true stress-true strain data, coefficients for the Johnson-Cook (JC), Zerilli-Armstrong (ZA), and Mechanical Threshold Stress (MTS) constitutive models have been determined from the mechanical test results at various strain rates and temperatures. The experimental data and the material coefficients of the four sheet steels have been reported in previous progress reports. The mechanical properties and material coefficients for the constitutive models have also been presented at the monthly group meetings of the Auto/Steel Partnership (A/SP). A summary of the constitutive data is presented in Tables 1 and 2.

Compression, tensile, and biaxial bulge tests and low strain rate tests, strain rates below 0.1/s, have been completed on all four structural steels. Compression and tensile specimens were cut from the as-received steel plates supplied by the A/SP by wire EDM. The biaxial bulge tests were conducted on the 12" x 12" steel plates as a check of the compression test results. The data from the through-thickness compression and from the biaxial stretching where the applied stress states are similar were found to be nearly identical for the mild steel DQSK material. The confirmation that the balanced biaxial tension and through-thickness compression results were similar increased our confidence in using the through thickness data to optimize the material coefficients for the constitutive models. From these test results it was determined to proceed with the material modeling optimization using the through thickness compression results because: 1) the biaxial tests could not be conducted at high rates nor at elevated temperatures, and 2) the biaxial tests would most accurately represent damage to the steel sheet under "crash" punching-type loading. Compression tests at higher strain rates and temperatures were also conducted and analyzed for all the steels provided. Constitutive model fits were generated from the experimental data. Reproducibility of the constitutive data was determined using multiple experiments for all the sample configurations and materials. Duplication of some experiments was also conducted on different load frames to demonstrate experimental reproducibility, and the measuring devices (load cells, strain gages) were calibrated periodically by the manufacturers.

In the previous progress reports we have shown a lower work hardening rate, "softening" behavior, at high strains for the intermediate strain rate tests. Concern was raised about these results, and since then we have conducted experiments on materials that were well characterized in the past at Los Alamos National Laboratory (LANL) (Cu, Ta, 1018 mild steel, and annealed 304 stainless steel) in order to determine and quantify the source of this drop in work hardening. We have also conducted intermediate rate tests using a second MTS-machine to determine if the unusual stress/strain behavior is material or machine dependent.

Testing

The constitutive stress-strain responses of the four steels under tensile, compressive, and biaxial stretching were successfully completed on all four materials. Compression and tensile specimens were cut from the steel plates by EDM. Compression specimens were cut in the through thickness, in plane-transverse to the rolling direction, and in plane-parallel to the rolling directions. Tensile specimens were also cut in plane-transversely and parallel to the rolling direction. The biaxial bulge tests were conducted on the "as-received" steel plates with no special specimen preparation. The low strain rate tests, between 0.001/s and 1/s, were conducted using a screw driven load frame (Instron model 1125) and also duplicated on a servo-hydraulic load frame (MTS model 880) in displacement control. Intermediate strain rate

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

tests, between 10/s and 200/s, were conducted on a specially built high-rate MTS frame (model 810) and on an MTS model 880 which was adapted to reach strain rates of ~ 50 /s. This adaptation was only used to investigate the intermediate strain rate "softening" in the work hardening behavior and not performed on all the materials. Additionally, high rate tests, between 1000/s and 7000/s, were conducted on a split hopkinson pressure bar (SPHB). The temperature response of the steels was also investigated for temperatures ranging from -196°C to 600°C at low and high strain rates. Tensile tests were conducted on a screw-driven Instron at room temperature and strain rates of 0.001/s and 0.1/s and the biaxial bulge tests were conducted at a strain rate of ~ 0.001 /s.

Results

The constitutive data for the four sheet steels at low, intermediate and high strain rates has been presented previously in our monthly progress reports. A comprehensive summary of this test data is shown as true-stress/true-strain plots in Figs. 1 through 13. Figures 1 to 4 show direct comparisons of the room temperatures tests for all four steels at strain rates of 0.001/s (Fig. 1), 0.1/s (Fig. 2), ~ 50 /s (Fig. 3), and 2000/s to 6500/s (Fig. 4). The yield strength of the M-190 steel is seen to be substantially higher than the other three steels tested under all strain rates. The flow stresses at low and high strain rates (Figs. 1, 2, and 4) are all approximately parallel for all the materials. Biaxial bulge tests conducted at strain rates of ~ 0.001 /s were also conducted on each of the four materials. The results of the biaxial tests were very similar to the results of the through thickness compression tests, as expected from classical stress-state analysis (Fig. 5).

Additional tensile tests have been conducted on the DQSK steel because the reported yield stress on the National Steel Data Sheet was significantly higher than the value measured by the Los Alamos group. Tests were repeated on different machines as well as repeated at facilities in Detroit. The results show (Fig. 6) that the thinned sections tested in November of 1995 at LANL, August of 1996 at LANL and in Detroit at National Steel are repeatable. Also on this plot are the "as received" curves from Detroit and Los Alamos. These curves are essentially the same to 2% strain at which point the strain rate of the Detroit test was jumped up by an order of magnitude. These results indicate that the inhomogeneity in the mechanical properties in the through-thickness direction developed due to the temper rolling. The yield strength of the quasi-static through-thickness compression test matches the value for the thinned tensile test. This can be understood if one thinks of the DQSK as a layered composite with a hard surface and a softer center layer. This composite layered structure is thought to be the direct result of the temper rolling that the DQSK steel receives. Further investigation of this composite effect using the Vickers hardness test with a 100 N load shows that the hardness varies from a value of ~ 110 near the surface to a value of ~ 75 in the center of the DQSK sheet steel. This hard surface layer measures ~ 0.01 inches in thickness on both the top and bottom surface with one of the surfaces being slightly harder than the other. In the past, tensile samples were machined to have a thickness of ~ 0.05 inches with equal amounts of material removed from each side. The compression samples received only a skim cut to make sure the loading surfaces remained parallel. [Based on this information and suggestions from Jim Fekete, *et. al.* we will only remove the galvanizing material from any future steel plates tested at LANL].

Low-magnification micrographs of the under sides of the biaxial bulge test samples show an interesting "ribbed" or "striped" characteristic on one of the DQSK bulge tested steel plates (11/21/95 progress report). We are still probing the exact microstructural cause of this observation but based on preliminary metallographic examination believe it may be linked to local textural effects.

Our initial studies on the M-190 steel revealed that we had a small problem. The initial M-190 plate-stock received was sufficiently thick that it exceeded the capacity of the hydraulic bulge tester after only 5% strain. Accordingly, a thinner gage M-190 plate was requested from the A/S-P and was successfully tested to high strains. The difference between the two thickness plates of M-190 appears to be attributed to a small yield differences of the two plates tested. The room temperature, strain rate summary for each individual material is presented in Fig. 7a-d. The mechanical property tests are seen to be reproducible for similar test conditions and specimens. The data indicates that the yield strength increases as the strain rate increases for all the steels examined.

Further investigation of the yield strength and hardening behavior as a function of temperature and strain rate is presented in the next four figures. Evaluation of the DQSK material shows that increasing temperature correlates with decreasing flow stress levels for a given strain (Fig. 8). There appears to be a drastic change in the behavior of the DQSK materials at higher temperatures, between 400°C and 600°C, where the data suggests that either the dominant deformation mechanism controlling plastic flow changes or the microstructure of the DQSK steel is no longer stable. Our guess based on prior experience would be the latter. At $\approx 500^{\circ}\text{C}$, the stress-strain behavior is nearly identical to that of the 400°C test (Fig. 8). When the temperature was raised above 500°C the stress/strain behavior is dramatically different and depends heavily on the soak time prior to testing. Accordingly, stress/strain data only up to 500°C was utilized for the constitutive modeling of the DQSK steel.

A summary of the test conditions and strain-rate/temperature results for the HSLA steel are shown in Fig. 9. Again, an increasing temperature correlates with decreasing flow stress levels for a given strain and the yield stress decreases with increasing temperature and decreasing strain rate. The IF steel sheet also shows a decreasing flow stress for a given strain as the temperature is increased or as the strain rate is decreased (Fig. 10) and the yield behavior is the same as for the HSLA steel. The yield stress at intermediate strain rates in the M-190 steel (Fig. 11) is the only anomaly in the generalization that as the reduction in strain rate or an increase in temperature will lead to a decrease in yield strength accompanied with a decreasing flow stress for a given strain.

Additional experiments were conducted on the DQSK and M-190 steels to evaluate the potential influence of cold-work or low-temperature unstable microstructures on the constitutive response of these steels (Fig. 12a,b). The results indicate that the DQSK steel was not significantly cold worked and the annealing process only served to recover a small amount of the plastic strain in this material. There was little evidence of grain growth or any other diffusion processes. The M-190 steel on the other hand showed a significant drop in its flow stress and yield stress over the whole range of strain rates following annealing. Possible recrystallization and grain growth were both thought to be occurring. Another aspect of this problem that was investigated was the influence of sample size on the constitutive response measured. Figures 13a,b illustrate the importance of maintaining a minimum sample aspect ratio to attain accurate mechanical property data for sheet steel materials. For the DQSK steel an initial aspect ratio greater than 1 seems to offer the best results. This result is confirmed by experiments conducted on the IF steel. At high strain rates it appears that the minimum acceptable aspect ratio is again ~ 1 . We know that the stress/strain behavior is influenced by the aspect ratio if it is smaller than ~ 0.75 . This problem may be avoided, given careful attention to lubrication, by stacking thin-section sheet through-thickness compression samples on top of one another and then testing this stacked configuration.

Two conclusions can be drawn from the mechanical property experiments conducted on the A/SP sheet steels: 1) the mechanical property tests are reproducible for similar test conditions and specimens regardless of the machine used or sample location within a 12"x12"

blank for the sheet steels, and 2) the stress/strain response of all the sheet steels are strongly influenced by strain rate and temperature consistent with the known response of body-centered-cubic metals due to a strong intrinsic lattice resistance (Peierls Barrier).

Constitutive Models

Selected stress/strain data from the through thickness compression tests that represented the temperature and strain-rate sensitivities of the four different sheet steels were used in the analysis of the constitutive models for each material. The selected curves and the results from the fits to the models are depicted in Figs. 14 to 19. A brief description of all the constitutive models and the equations used in the constitutive models was presented in the November '95 progress report. In general a minimum deviation from a series of selected stress-strain points according to Eqn. (5) (Appendix A, progress report 11/21/95) was used for the constitutive data for each steel as the criterion to converge the optimum or "best overall fit" set of parameters for the constitutive models. The Johnson-Cook (JC) model fits for the entire range of strain rates and temperatures is shown for all the steels are shown in Fig. 14(a-d). As discussed previously for the J-C model, the yield stress is frequently missed in these model fits is one wishes to capture the work-hardening response of the steel of interest. The large strain-rate and temperature sensitivities in BCC materials can not be reproduced by the JC model as evidenced from the model fits for strains lower than 0.05.

The JC model represents the strain-rate sensitivity of the flow stress in a linear relation with respect to logarithmic strain rate. This imposes a strong limitation to capturing the high strain-rate sensitivity typical of BCC metals observed at high strain rates. This limitation forces the user to set "reasonable" parameters to the material coefficients, in the case of the HSLA steel an upper bound on m has been set to a value less than two. The value predicted using the model could be substantially larger. However, it does not represent a real material coefficient. The inaccuracies and lack of robustness of the JC model, which was developed for FCC metal applications, discouraged us from suggesting that the predictions of the material coefficients for these steels are optimum. Further discussion of the limitations and drawbacks of the JC model have been presented in the 11/21/95 progress report as well as a number of our journal publications on constitutive models.

The Zerilli-Armstrong (ZA) model fits are presented in a similar fashion in Fig. 15(a-d). The fits were optimized for the strain hardening behavior exhibited at medium and low strain rates. The fits to the high strain-rate conditions are seen to substantially deviate from the experimental data at strains higher than 0.2. This high strain hardening behavior at high strain rates is probably due to deformation twinning. The temperature and strain-rate sensitivities of the sheet steels examined are well described using the ZA model for BCC structures (12/21/95 progress report). The ZA model was found to be able to represent the strain hardening behavior although it does not totally capture the yield stress level (Fig. 15b). The stress-strain curves for the tests at high ($>1000/s$), medium ($1-100/s$) and low ($<1/s$) strain rates at room temperature along with the optimized ZA model fits for DQSK and HSLA steels are shown in Fig. 16a,b.

For some applications such as predicting the buckling of the material under deformation, the yield stress plays an important role. Satisfactory fitting of this condition is obtained between the experiments and calculations using the ZA model. Enforcing the model to accurately fit the yield stresses was used to generate another set of parameters for the ZA model and is shown in Fig. 17a,b. By setting the yield stress parameter the strain hardening behavior for strains smaller than 0.1 is less accurately represented by these sets of parameters. Distinct strain hardening differences between the low and the high strain rate data were however also observed; therefore, an additional set of parameters was generated for the ZA model mainly to fit the high strain-rate data (Fig. 18a,b). The yield stress and the strain hardening behavior for the dynamic

tests is shown to be accurately reproduced in this fit. Although the simple ZA constitutive model cannot accurately model directly complicated material behavior, i.e., multiple strengthening mechanism contributions it is acceptable to "fine tune" the parameters to match the application as closely as possible. It is recommended that a rough estimate of the exact deformation conditions should be studied in order to select a suitable "fine-tuned" set of parameters for a specific application. Further discussion of the limitations and drawbacks of the JC and ZA model have been presented in the 11/21/95 progress report.

A summary of the optimized fitting parameters for the JC and ZA models are presented in Table 1. This table includes all the results derived for the DQSK, HSLA, IF, and M-190 steels. Although the JC and ZA models have certain limitations, the simple mathematical forms used in these models makes the implementation in many finite element simulation packages straight forward, and many finite element packages used in industry and the defense complex already include the simple, curve-fit derived, mathematical forms used in these models

The Mechanical Threshold Stress (MTS) model fit for the four steel is shown in Fig. 19a-d. The MTS model fits accurately predict the yield strengths of each steel tested, and are also shown to accurately capture the hardening coefficients. The parameters used in the MTS model fit are presented in Table 2. We have high hopes that further development of this model will produce even more accurate and robust predictions for both FCC and BCC materials. Ever-increasingly more inclusive metal-kinetics theory will be needed in the MTS model to attain this goal.

Discussion

The difference between the in-plane tensile and compressive results are believed to reflect the tensile/compressive strength difference that is typical in many heavily rolled sheet steels and are fully consistent with the "R" value data for the DQSK steel. The flow stress difference, as a function of test direction, in the sheet means that an isotropic yield function assumption cannot be used to predict the constitutive response of this steel. An alternative would be to use the 1948 Hill quadratic yield function. This yield function currently exists as material model 33 in the Livermore version of DYNA 3-D. This version would provide a more realistic fit to the anisotropy in the DQSK steel. We have performed balanced biaxial tension experiments on the DQSK steel using a hydraulic bulge tester. Comparison of these data to the through-thickness compression data shows that the two test methods produce very similar test results. This supports the classical observation that the sign of the hydrostat is not dominant. Therefore, we believe that the best option for a crash-worthiness scenario, where punching type loads are critical, can be determined using the through-thickness data for model construction. Without an isotropic yield function one needs to consider selecting a true-stress/true-strain behavior intermediate to the through-thickness and in-plane properties or either loading direction as representative and most germane to the crash-worthiness objectives. Alternately, the lowest stress/strain curves could be used in the analysis of the constitutive models. This will add to the factor of safety, although it will also add weight to the product.

We have also investigated the apparent fall-off in the strain hardening rate at intermediate strain rates for all the sheet steels. This behavior is unusual because the work-hardening response of most BCC metals shows hardening that is primarily rate and temperature independent if deformation is controlled by slip processes. In order to understand the flattening of the strain hardening at intermediate strain rates in the sheet steel stock additional experiments were conducted on several different materials and machines (3/8/96 progress report). Tantalum, a BCC material, has been extensively studied and the stress/strain response expected is an increasing yield strength and parallel work hardening rates. The curves show parallel work hardening up to approximately 15% plastic strain, beyond which we again observe a drop in the

work hardening coefficient. We believe that the drop is due to adiabatic heating effects. At high strain rates we observe an increasing hardening rate which could be caused by additional formation of dislocations within the grains which are stored because of the suppression of dynamic recovery at high strain rates. In this case the decrease in strain hardening due to adiabatic heating is negated by the formation of deformation twins within individual grains. Adiabatic heating promotes the recovery process and decreases the possibility of any additionally stored dislocations. Additional high strain rate experiments can be conducted to minimize the formation of dislocations. This is accomplished by using a multiple strike method and minimizing the amount of strain introduced during a single strike. Figure 20 shows experimental results for this process and the MTS model prediction for isothermal, the process just described, and the prediction for adiabatic heating without the formation of dislocations. An additional confirmation of the belief that drop in the flow stress is related to the material and not the machine is seen in the stress/strain behavior at intermediate rates for two different machines. For both machines we observe a yield point, hardening to some strain level (usually less than 15%) followed by a fall-off in the hardening rate. Because the behavior has been seen to be independent of the test machine used we believe the load drop is dependent on the material.

It is possible to hypothesize many possible explanations for the dropping hardening rates in the sheet steels, but we believe that a relatively high yield strength and/or partially cold worked substructure of the material will result in the drop in the work hardening as seen in the materials tested (DQSK, HSLA, M-190, IF steels). Materials that have low yield strengths, higher defect storage rates, and lower dependence of their flow stress on temperature, like the copper and the annealed 304 stainless, have the expected and previously observed stress/strain behavior at intermediate rates (3/8/96 progress report). Our assessment concerning the fall-off in hardening being substructurally-controlled is also consistent with the intermediate-rate data for the IF steel (Fig. 7c). In the case of this steel utilizing identical testing, sample size, and lubrication conditions as for the previous sheet steels (DQSK, M-190, HSLA) we observe a more stable hardening behavior at a strain rate of 100/s.

Although we are now confident that the stress/strain behavior is accurate for the materials tested, we are still evaluating the test results to definitively quantify the drop in the hardening. We would like to assure you that we believe that the constitutive modeling results are accurate for the A/S Partnership sheet steels regardless of this fall-off in hardening behavior at intermediate rates. We believe this is true because the data up to approximately 15% is parallel (in BCC materials) for the whole range of strain rates tested, and our constitutive modeling predictions not only use the entire range of strain rates and temperatures, but also because the fits are set to strain limits of ~20%.

Data Sets

As part of the fulfillment of the contract we are providing a compilation of all information generated from mechanical tests. In addition to the data sets provided as text files in the ASCII format we have also included the modeling fits, a directory containing progress reports presented earlier, and Kaleidagraph plots and data sets. In order to access the reports Microsoft Word is necessary. If A/SP members are interested in accessing the Kaleidagraph files there is now a PC version of this program available. The CD containing the data also includes a list, "index", of the data sets for each of the four steels tested. The indexes are also listed at the end of this report in appendix A.

Table 1. Fitting parameters of the JC and ZA models for DQSK and HSLA steels

JC model	A, MPa	B, MPa	n	C	m	T _m , K
DQSK	13	730	0.15	0.045	0.5	1808
HSLA	13	910	0.21	0.019	1.9	1808
M-190	80	197	0.061	0.014	1.08	1808
IF	287	640	0.399	0.053	0.7	1808
ZA model	C ₀ , MPa	C ₁ , MPa	C ₃ , K ⁻¹	C ₄ , K ⁻¹ s ⁻¹	C ₅ , MPa	n
DQSK	5	1850	0.0109	0.0007	600	0.27
DQSK+ys ¹	110	1800	0.011	0.000725	450	0.28
DQSK+hr ²	150	1820	0.01	0.0006	790	0.65
HSLA	29	1100	0.0138	0.001175	730	0.18
HSLA+ys ¹	300	1910	0.0144	0.00105	700	0.55
HSLA+hr ²	268	1460	0.0142	0.001075	920	0.53
HSLA+lr ³	160	1180	0.00695	0.00049	400	0.61
M-190	70	1890	0.0009	0.00004	610	0.32
IF	240	1390	0.00875	0.00058	940	0.93
IF All	40	1290	0.005	0.00029	650	0.61

1: Fitting parameters for the ZA model emphasizing yield strength of each data set.

2: Fitting parameters found for the ZA model emphasizing the high strain rate data.

Johnson - Cook Model:

$$\sigma = (A + B \cdot \epsilon_p^n)(1 + C \cdot \ln \dot{\epsilon})(1 - [(T - 298)/(T_{melt} - 298)]^m)$$

Zerilli - Armstrong Model:

$$\sigma = C_0 + C_1 \cdot \exp(-C_3 \cdot T + C_4 \cdot T \cdot \ln \dot{\epsilon}) + C_5 \cdot \epsilon_p^n$$

Table 2a. Fitting parameters of the MTS models for DQSK steel

<ul style="list-style-type: none"> $\frac{\sigma}{\mu} = \frac{\sigma_a}{\mu} + S_i(\dot{\epsilon}, T) \frac{\hat{\sigma}_i}{\mu_0} + S_\epsilon(\dot{\epsilon}, T) \frac{\hat{\sigma}_\epsilon}{\mu_0}$ 	Where: $\frac{\sigma_a}{\mu} = 0.002$
<ul style="list-style-type: none"> $\mu = \mu_0 - \frac{2910 \text{ MPa}}{\exp\left(\frac{204 \text{ K}}{T}\right) - 1}$ 	Where: $\mu_0 = 7.146 \times 10^4 \text{ MPa}$
<ul style="list-style-type: none"> $S_i(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0i}} \ln\left(\frac{\dot{\epsilon}_{0i}}{\dot{\epsilon}}\right) \right]^{1/q_i} \right\}^{1/p_i}$ 	<p>Where: $\frac{k}{b^3} = 0.90474 \text{ MPa / K},$</p> <p>$k = 1.38 \times 10^{-23} \text{ Joule/K}, \quad b = 2.48 \times 10^{-10} \text{ m}$</p> <p>$\dot{\epsilon}_{0i} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0i} = 0.107555,$</p> <p>$q_i = 1.75, \quad p_i = 0.5,$</p> <p>$\frac{\hat{\sigma}_i}{\mu_0} = 0.018779 \text{ (or } \hat{\sigma}_i = 1342 \text{ MPa)}$</p>
<ul style="list-style-type: none"> $S_\epsilon(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0\epsilon}} \ln\left(\frac{\dot{\epsilon}_{0\epsilon}}{\dot{\epsilon}}\right) \right]^{1/q_\epsilon} \right\}^{1/p_\epsilon}$ 	<p>Where: $\dot{\epsilon}_{0\epsilon} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0\epsilon} = 1.6,$</p> <p>$q_\epsilon = 1, \quad p_\epsilon = 2/3$</p>
<ul style="list-style-type: none"> $\frac{d\hat{\sigma}_\epsilon}{d\epsilon} = \theta_0(\dot{\epsilon}, T) \cdot \left[1 - \frac{\tanh\left(\alpha \frac{\hat{\sigma}_\epsilon}{\hat{\sigma}_{\epsilon s}(\dot{\epsilon}, T)}\right)}{\tanh(\alpha)} \right]$ 	<p>Where: $\alpha = 2.0$</p> <p>$\theta_0 = 5500 ; \text{ MPa}$</p>
<ul style="list-style-type: none"> $\ln \frac{\dot{\epsilon}}{\dot{\epsilon}_{0\epsilon s}} = \frac{\mu b^3 g_{0\epsilon s}}{kT} \ln \frac{\hat{\sigma}_{\epsilon s}}{\hat{\sigma}_{\epsilon s 0}}$ 	<p>Where: $g_{0\epsilon s} = 0.25,$</p> <p>$\hat{\sigma}_{\epsilon s 0} = 600 \text{ MPa},$</p> <p>$\dot{\epsilon}_{0\epsilon s} = 1 \times 10^7 \text{ s}^{-1}$</p>
<ul style="list-style-type: none"> $\Delta T = \frac{\Psi}{\rho C_p} \int \sigma(\epsilon) d\epsilon ; \quad \text{when } \dot{\epsilon} \geq 500 \text{ s}^{-1}$ 	<p>Where: $\Psi = 0.95, \quad \rho = 7.86 \text{ Mg/m}^3$</p> <p>$C_p = 0.0928 + 7.45 \times 10^{-4} \cdot T + \frac{12404}{T^2} ;$</p> <p>$\text{MPa m}^3/\text{Mg/K}$</p>

Table 2b. Fitting parameters of the MTS models for HSLA steel

$\bullet \quad \frac{\sigma}{\mu} = \frac{\sigma_a}{\mu} + S_i(\dot{\epsilon}, T) \frac{\hat{\sigma}_i}{\mu_0} + S_\epsilon(\dot{\epsilon}, T) \frac{\hat{\sigma}_\epsilon}{\mu_0}$	Where: $\frac{\sigma_a}{\mu} = 0.002$
$\bullet \quad \mu = \mu_0 - \frac{2910 \text{ MPa}}{\exp\left(\frac{204 \text{ K}}{T}\right) - 1}$	Where: $\mu_0 = 7.146 \times 10^4 \text{ MPa}$
$\bullet \quad S_i(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0i}} \ln\left(\frac{\dot{\epsilon}_{0i}}{\dot{\epsilon}}\right) \right]^{1/q_i} \right\}^{1/p_i}$ $G_{norm} X = \left[\frac{kT}{\mu b^3} \ln\left(\frac{\dot{\epsilon}_{0i}}{\dot{\epsilon}}\right) \right]^{1/q_i}$	<p>Where: $\frac{k}{b^3} = 0.90474 \text{ MPa / K},$ $k = 1.38 \times 10^{-23} \text{ Joule/K}, \quad b = 2.48 \times 10^{-10} \text{ m}$ $\dot{\epsilon}_{0i} = 1 \times 10^6 \text{ s}^{-1}, \quad q_i = 1.5, \quad p_i = 0.5,$ for $G_{norm} X < 0.115 \quad g_{0i} = 0.087441,$ $\frac{\hat{\sigma}_i}{\mu_0} = 0.021262$ (or $\hat{\sigma}_i = 1519 \text{ MPa}$) for $G_{norm} X \geq 0.115 \quad g_{0i} = 0.616426,$ $\frac{\hat{\sigma}_i}{\mu_0} = 0.005253$ (or $\hat{\sigma}_i = 375 \text{ MPa}$)</p>
$\bullet \quad S_\epsilon(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0\epsilon}} \ln\left(\frac{\dot{\epsilon}_{0\epsilon}}{\dot{\epsilon}}\right) \right]^{1/q_\epsilon} \right\}^{1/p_\epsilon}$	Where: $\dot{\epsilon}_{0\epsilon} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0\epsilon} = 1.6,$ $q_\epsilon = 1, \quad p_\epsilon = 2/3$
$\bullet \quad \frac{d\hat{\sigma}_\epsilon}{d\epsilon} = \theta_0(\dot{\epsilon}, T) \cdot \left[1 - \frac{\tanh\left(\alpha \frac{\hat{\sigma}_\epsilon}{\hat{\sigma}_{\epsilon s}(\dot{\epsilon}, T)}\right)}{\tanh(\alpha)} \right]$	Where: $\alpha = 2.0$ $\theta_0 = 2800 \text{ MPa}$
$\bullet \quad \ln \frac{\dot{\epsilon}}{\dot{\epsilon}_{0\epsilon s}} = \frac{\mu b^3 g_{0\epsilon s}}{kT} \ln \frac{\hat{\sigma}_{\epsilon s}}{\hat{\sigma}_{\epsilon s 0}}$	Where: $g_{0\epsilon s} = 0.1466, \quad \hat{\sigma}_{\epsilon s 0} = 1130 \text{ MPa},$ $\dot{\epsilon}_{0\epsilon s} = 1 \times 10^7 \text{ s}^{-1}$
$\bullet \quad \Delta T = \frac{\Psi}{\rho C_p} \int \sigma(\epsilon) d\epsilon; \quad \text{when } \dot{\epsilon} \geq 500 \text{ s}^{-1}$	Where: $\Psi = 0.95, \quad \rho = 7.86 \text{ Mg/m}^3$ $C_p = 0.0928 + 7.45 \times 10^{-4} \cdot T + \frac{12404}{T^2};$ $\text{MPa m}^3/\text{Mg/K}$

Table 2c. Fitting parameters of the MTS models for M-190 steel

$\bullet \quad \frac{\sigma}{\mu} = \frac{\sigma_a}{\mu} + S_i(\dot{\epsilon}, T) \frac{\hat{\sigma}_i}{\mu_0} + S_\epsilon(\dot{\epsilon}, T) \frac{\hat{\sigma}_\epsilon}{\mu_0}$	Where: $\frac{\sigma_a}{\mu} = 0.002$
$\bullet \quad \mu = \mu_0 - \frac{2910 \text{ MPa}}{\exp\left(\frac{204 \text{ K}}{T}\right) - 1}$	Where: $\mu_0 = 7.146 \times 10^4 \text{ MPa}$
$\bullet \quad S_i(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0i}} \ln\left(\frac{\dot{\epsilon}_{0i}}{\dot{\epsilon}}\right) \right]^{1/q_i} \right\}^{1/p_i}$	<p>Where: $\frac{k}{b^3} = 0.90474 \text{ MPa / K},$ $k = 1.38 \times 10^{-23} \text{ Joule/K}, \quad b = 2.48 \times 10^{-10} \text{ m}$ $\dot{\epsilon}_{0i} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0i} = 1.866,$ $q_i = 1.5, \quad p_i = 0.5,$ $\frac{\hat{\sigma}_i}{\mu_0} = 0.026162 \text{ (or } \hat{\sigma}_i = 1870 \text{ MPa)}$</p>
$\bullet \quad S_\epsilon(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0\epsilon}} \ln\left(\frac{\dot{\epsilon}_{0\epsilon}}{\dot{\epsilon}}\right) \right]^{1/q_\epsilon} \right\}^{1/p_\epsilon}$	Where: $\dot{\epsilon}_{0\epsilon} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0\epsilon} = 1.6,$ $q_\epsilon = 1, \quad p_\epsilon = 2/3$
$\bullet \quad \frac{d\hat{\sigma}_\epsilon}{d\epsilon} = \theta_0(\dot{\epsilon}, T) \cdot \left[1 - \frac{\tanh\left(\alpha \frac{\hat{\sigma}_\epsilon}{\hat{\sigma}_{\epsilon s}(\dot{\epsilon}, T)}\right)}{\tanh(\alpha)} \right]$	Where: $\alpha = 2.0$ $\theta_0 = 3500; \text{ MPa}$
$\bullet \quad \ln \frac{\dot{\epsilon}}{\dot{\epsilon}_{0\epsilon s}} = \frac{\mu b^3 g_{0\epsilon s}}{kT} \ln \frac{\hat{\sigma}_{\epsilon s}}{\hat{\sigma}_{\epsilon s 0}}$	Where: $g_{0\epsilon s} = 0.35,$ $\hat{\sigma}_{\epsilon s 0} = 1000 \text{ MPa},$ $\dot{\epsilon}_{0\epsilon s} = 1 \times 10^7 \text{ s}^{-1}$
$\bullet \quad \Delta T = \frac{\Psi}{\rho C_p} \int \sigma(\epsilon) d\epsilon; \quad \text{when } \dot{\epsilon} \geq 500 \text{ s}^{-1}$	<p>Where: $\Psi = 0.95, \quad \rho = 7.86 \text{ Mg/m}^3$ $C_p = 0.0928 + 7.45 \times 10^{-4} \cdot T + \frac{12404}{T^2};$ $\text{MPa m}^3/\text{Mg/K}$</p>

Table 2d. Fitting parameters of the MTS models for IF steel

$\bullet \quad \frac{\sigma}{\mu} = \frac{\sigma_a}{\mu} + S_i(\dot{\epsilon}, T) \frac{\hat{\sigma}_i}{\mu_0} + S_\epsilon(\dot{\epsilon}, T) \frac{\hat{\sigma}_\epsilon}{\mu_0}$	Where: $\frac{\sigma_a}{\mu} = 0.002$
$\bullet \quad \mu = \mu_0 - \frac{2910 \text{ MPa}}{\exp\left(\frac{204 \text{ K}}{T}\right) - 1}$	Where: $\mu_0 = 7.146 \times 10^4 \text{ MPa}$
$\bullet \quad S_i(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0i}} \ln\left(\frac{\dot{\epsilon}_{0i}}{\dot{\epsilon}}\right) \right]^{1/q_i} \right\}^{1/p_i}$	<p>Where: $\frac{k}{b^3} = 0.90474 \text{ MPa / K},$ $k = 1.38 \times 10^{-23} \text{ Joule/K}, \quad b = 2.48 \times 10^{-10} \text{ m}$ $\dot{\epsilon}_{0i} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0i} = 0.145,$ $q_i = 1.5, \quad p_i = 0.5,$ $\frac{\hat{\sigma}_i}{\mu_0} = 0.018779 \text{ (or } \hat{\sigma}_i = 1342 \text{ MPa)}$</p>
$\bullet \quad S_\epsilon(\dot{\epsilon}, T) = \left\{ 1 - \left[\frac{kT}{\mu b^3 g_{0\epsilon}} \ln\left(\frac{\dot{\epsilon}_{0\epsilon}}{\dot{\epsilon}}\right) \right]^{1/q_\epsilon} \right\}^{1/p_\epsilon}$	Where: $\dot{\epsilon}_{0\epsilon} = 1 \times 10^7 \text{ s}^{-1}, \quad g_{0\epsilon} = 1.6,$ $q_\epsilon = 1, \quad p_\epsilon = 2/3$
$\bullet \quad \frac{d\hat{\sigma}_\epsilon}{d\epsilon} = \theta_0(\dot{\epsilon}, T) \cdot \left[1 - \frac{\tanh\left(\alpha \frac{\hat{\sigma}_\epsilon}{\hat{\sigma}_{\epsilon s}(\dot{\epsilon}, T)}\right)}{\tanh(\alpha)} \right]$	Where: $\alpha = 2.0$ $\theta_0 = 3500; \text{ MPa}$
$\bullet \quad \ln \frac{\dot{\epsilon}}{\dot{\epsilon}_{0\epsilon s}} = \frac{\mu b^3 g_{0\epsilon s}}{kT} \ln \frac{\hat{\sigma}_{\epsilon s}}{\hat{\sigma}_{\epsilon s 0}}$	Where: $g_{0\epsilon s} = 0.25,$ $\hat{\sigma}_{\epsilon s 0} = 650 \text{ MPa},$ $\dot{\epsilon}_{0\epsilon s} = 1 \times 10^7 \text{ s}^{-1}$
$\bullet \quad \Delta T = \frac{\Psi}{\rho C_p} \int \sigma(\epsilon) d\epsilon; \quad \text{when } \dot{\epsilon} \geq 500 \text{ s}^{-1}$	Where: $\Psi = 0.95, \quad \rho = 7.86 \text{ Mg/m}^3$ $C_p = 0.0928 + 7.45 \times 10^{-4} \cdot T + \frac{12404}{T^2};$ $\text{MPa m}^3/\text{Mg/K}$

LIST OF FIGURES

- Figure 1. Direct comparison of the quasi-static strain rate tests for the four sheet steels.
- Figure 2. Direct comparison of the test data at a strain rate of 0.1/s for the four sheet steels.
- Figure 3. Intermediate strain rate tests showing the stress/strain response of the four test steels at similar strain rates.
- Figure 4. High strain rate tests showing the stress/strain response of the four test steels at similar strain rates
- Figure 5. Biaxial bulge test results for DQSK, HSLA, IF, and M-190 sheet steels. The stress-strain results are nearly identical to the through-thickness compression results (Fig. 1).
- Figure 6. The tensile stress/strain response for the DQSK showing the different material characteristics for sample with and without the temper rolled surface.
- Figure 7. The stress/strain response for each steel sheet over the range of strain rates tested (a) DQSK, (b) HSLA, (c) IF, and (d) M-190.
- Figure 8. Summary of the stress/strain response of the DQSK mild sheet steel over the range of strain rates and temperatures.
- Figure 9. Summary of the stress/strain response of the HSLA steel sheet over the range of strain rates and temperatures.
- Figure 10. Summary of the stress/strain response of the interstitial free (IF) steel sheet over the range of strain rates and temperatures.
- Figure 11. Summary of the stress/strain response for the M-190 high strength steel over the range of strain rates and temperatures.
- Figure 12. Heat treatment effects on the (a) DQSK steel and the (b) M-190 high strength steel. there is little change in the flow strength of the DQSK steel. However, heat treating the M-190 steel produces a significant drop in both the yeild and flow strength.
- Figure 13. Relationship of the aspect ratio to the stress/strain behavior of the a) DQSK and b) IF sheet steels
- Figure 14. Fitting to the JC model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The equations and their parameters are also listed in Table 1.
- Figure 15. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The hardening behavior exhibited at medium and low strain rate was used to optimized the parameters for the DQSK and HSLA steels. The equations and their parameters are also listed in Table 1.

- Figure 16. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the two sheet steels (a) DQSK, (b) HSLA for room temperature tests at various strain rates. The equations and their parameters are also listed in Table 1.
- Figure 17. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the two sheet steels (a) DQSK, (b) HSLA. The yield stresses were used to optimized the parameters for the model. The equations and their parameters are also listed in Table 1.
- Figure 18. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the two sheet steels (a) DQSK, (b) HSLA. The hardening behavior exhibited at high strain rates was used to optimized the parameters for the model. The equations and their parameters are also listed in Table 1.
- Figure 19. Fitting to the MTS model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The equations and their parameters were listed in Table 2.
- Figure 20. Multiple sequential loading of the DQSK steel, also shown on this plot is the predicted isothermal and adiabatic curves using the mechanical threshold strength (MTS) model.

Figure 1. Direct comparison of the quasi-static strain rate tests for the four sheet steels.

Figure 2. Direct comparison of the test data at a strain rate of 0.1/s for the four sheet steels.

Figure 3. Intermediate strain rate tests showing the stress/strain response of the four test steels at similar strain rates.

Figure 4. High strain rate tests showing the stress/strain response of the four test steels at similar strain rates.

Figure 5. Biaxial bulge test results for DQSK, HSLA, IF, and M-190 sheet steels. The stress-strain results are nearly identical to the through-thickness compression results (Fig. 1).

Figure 6. The tensile stress/strain response for the DQSK showing the different material characteristics for sample with and without the temper rolled surface.

(a)

(b)

7
Figure 6. The stress/strain response for each steel sheet over the range of strain rates tested (a) DQSK, (b) HSLA, (c) IF, and (d) M-190.

(c)

(d)

Figure 6. The stress/strain response for each steel sheet over the range of strain rates tested (a) DQSK, (b) HSLA, (c) IF, and (d) M-190.

Figure 7. Summary of the stress/strain response of the DQSK mild sheet steel over the range of strain rates and temperatures.

Figure 8. Summary of the stress/strain response of the HSLA steel sheet over the range of strain rates and temperatures.

Figure 9. Summary of the stress/strain response of the interstitial free steel sheet over the range of strain rates and temperatures.

Figure 10. Summary of the stress/strain response for the M-190 high strength steel over the range of strain rates and temperatures.

Figure 12(b). Heat treatment effects on the (a) DQSK steel and the (b) M-190 high strength steel. there is little change in the flow strength of the DQSK steel. However, heat treating the M-190 steel produces a significant drop in both the yield and flow strength.

(a)

(b)

Figure 12 Relationship of the aspect ratio to the stress/strain behavior of the a) DQSK and b) IF sheet steels

(a)

(b)

Figure 13. Fitting to the JC model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The equations and their parameters are also listed in Table 1.

Figure 14. Fitting to the JC model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The equations and their parameters are also listed in Table 1.

(a)

(b)

Figure 14. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The hardening behavior exhibited at medium and low strain rate was used to optimized the parameters for the DQSK and HSLA steels. The equations and their parameters are also listed in Table 1.

Figure 14. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The hardening behavior exhibited at medium and low strain rate was used to optimized the parameters for the DQSK and HSLA steels. The equations and their parameters are also listed in Table I.

(a)

(b)

Figure 15. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the two sheet steels (a) DQSK, (b) HSLA for room temperature tests at various strain rates. The equations and their parameters are also listed in Table 1.

17
Figure 16. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the two sheet steels (a) DQSK, (b) HSLA. The yield stresses were used to optimized the parameters for the model. The equations and their parameters are also listed in Table 1.

(a)

(b)

Figure 18. Fitting to the ZA model (symbols) and the corresponding experimental data (lines) for the two sheet steels (a) DQSK, (b) HSLA. The hardening behavior exhibited at high strain rates was used to optimized the parameters for the model. The equations and their parameters are also listed in Table 1.

19
 Figure 18. Fitting to the MTS model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The equations and their parameters were listed in Table 2.

Figure 18. Fitting to the MTS model (symbols) and the corresponding experimental data (lines) for the four sheet steels (a) DQSK, (b) HSLA, (c) IF, and (d) M-190. The equations and their parameters were listed in Table 2.

20
 Figure 19. Multiple sequential loading of the DQSK steel, also shown on this plot is the predicted isothermal and adiabatic curves using the mechanical threshold strength (MTS) model.

APPENDIX A

INDEX AND DESCRIPTION OF DATA FILES FOR ALL SHEET STEELS

Index of files for DQSK steel

Index of files for DQSK steel

This folder contains six directories (or folders):

- DATA.P : experimental data files in the format of true plastic strain versus true stress [MPa].
- JCMODEL : Final fits to the Johnson-Cook Model. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
- MTSMODEL : Final fits to the MTS Model. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
- RAW.DAT : experimental data files in the format of true strain versus true stress [MPa].
 - COMPRESS : Experimental data obtained from free compression tests.
 - HIGHRATE : Experimental data obtained from high-rate tests.
 - LOWRATE : Experimental data obtained from low-rate tests.
 - MEDRATE : Experimental data obtained from medium-rate tests.
 - TENSILE : Experimental data obtained from tensile tests.
- ZAMODEL : Final fits to the ZA Model for BCC. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
- BESTFIT : Best fitting results to the strain hardening behavior of low to medium strain-rate tests.
- HIGHRATE : Optimized to the hardening behavior exhibited by the data obtained at high strain rate using Hopkinson pressure bar.
- YIELD : When the yield stresses were used as part of the input to derive the fitting parameters for DQSK. The hardening behavior of low to medium strain rate tests was used.
- ADDIT.INF : This folder contains additional information not included on the diskette previously handed out the the A/SP members. It includes additional data on low, medium and high rate tests, as well as heat treatment data, adiabatic heating effects, micrographs, and kaleidagraph files.

For each directory and its sub-directories, the files are listed in alphabetical order with brief description for each file as below:

- DATA.P: (file format: true-plastic-strain true-stress[MPa])
- DQ20433A.P - Testing temperature=200C, testing strain rate=4300/s, sample was machined from location A (see report for detail).
 - DQ40503A.P - 400C, 5000/s, location A.
 - DQ60433A.P - 600C, 4300/s, location A.
 - DQRT10-3.P - 25C, 0.001/s.
 - DQRT353A.P - 25C, 3500/s, locationn A.
 - DQRT500.P - 25C, 5/s.
 - DQSK100.P - 25C, 100/s.
 - DQSK12.P - 25C, 12/s.
 - DQSK5.P - 25C, 5/s.

DQSK60.P - 25C, 60/s.
 DQSK60A.p - 25C, 60/s.
 DQSK70.P - 25C, 70/s.
 DQSK75.P - 25C, 75/s.
 DQSK85.P - 25C, 85/s.
 DQSK90.P - 25C, 90/s.
 LDQSKA1.P - 25C, 0.001/s.
 LDQSKA3.P - 25C, 0.1/s.
 LDQSKA3A.P - 25C, 0.1/s, repeat test.

JCMODEL : Modeling results for the Johnson-Cook Model

(file format : True-plastic-strain True-stress[MPa])

DQ20433A.JCF - Isothermal strain-stress fit of JC model to a test performed
 at temperature=200C and strain rate=4300/s.
 DQ40503A.JCF - 400C, 5000/s.
 DQRT10-3.JCF - 25C, 0.001/s.
 DQRT353A.JCF - 25C, 3500/s.
 DQRT500.JCF - 25C, 5/s.
 DQSK100.JCF - 25C, 100/s.
 DQSKJZ.JCF - Input file to calculate final fits to the JC model.
 DQSKJZ - Model fit parameters for CM program

MTSMODEL : Modeling results for the MTS Model

(file format : True-plastic-strain True-stress[MPa])

DQ20433A.MTS - Isothermal strain-stress fit of MTS model to a test
 performed at temperature=200C and strain rate=4300/s.
 DQ40503A.MTS - 400C, 5000/s.
 DQRT10-3.MTS - 25C, 0.001/s.
 DQRT353A.MTS - 25C, 3500/s.
 DQRT500.MTS - 25C, 5/s.
 DQSK100.MTS - 25C, 100/s.
 DQSKMTS.MTS - Input file to calculate final fits to the MTS model.
 DQSKMTS - Model fit parameters for CM program

RAW.DAT : Experimental data files

COMPRESS : Test under compression

HIGHRATE : Using Hopkinson Pressure Bar (strain rate greater than 1000/s)

DQ20433A - 200C, 4300/s, location A.
 DQ20443A - 200C, 4400/s, location A.
 DQ20443B - 200C, 4400/s, location B.
 DQ40503A.1A - 400C, 5000/s, location A, first test.
 DQ40503A.1B - 400C, 5000/s, location B, first test.
 DQ40503A.2A - 400C, 5000/s, location A, second test.
 DQ40503A.2B - 400C, 5000/s, location B, second test.
 DQ60433A.1A - 600C, 4300/s, location A, first test.
 DQ60433A.1B - 600C, 4300/s, location B, first test.
 DQ60433A.2A - 600C, 4300/s, location A, second test.
 DQ60433A.2B - 600C, 4300/s, location B, second test.
 DQLN183A.1 - -196C, 1800/s, location A, first test.
 DQLN183A.2 - -196C, 1800/s, location A, second test.
 DQLN373A.1 - -196C, 3700/s, location A, first test.
 DQLN373A.2 - -196C, 3700/s, location A, second test.
 DQLN373B - -196C, 3700/s, location B.
 DQLN453A - -196C, 4500/s, location A.
 DQRT353A.1 - 25C, 3500/s, location A, first test.
 DQRT353A.2 - 25C, 3500/s, location A, second test.
 DQRT353B.1 - 25C, 3500/s, location B, first test.

DQRT353B.2 - 25C, 3500/s, location B, second test.

LOWRATE : Quasi-static tests using Instron load frame,
(strain rates between 0.0001/s and 1/s).

L1PARDQ - 25C, 0.001/s, in-plane, along rolling direction, location B.
L1PERDQ - 25C, 0.001/s, in-plane, perpendicular to rolling direction, loc.A.
L2PARDQ - 25C, 0.001/s, in-plane, along rolling direction, loc.B, second test.
L2PERDQ - 25C, 0.001/s, in-plane, perpendicular to rolling direction, loc.A,
second test.
L3PARDQ - 25C, 0.001/s, in-plane, along rolling direction, loc.B, third test.
L3PERDQ - 25C, 0.001/s, in-plane, perpendicular to rolling direction, loc.A,
third test.
L4PERDQ - 25C, 0.001/s, in-plane, perpendicular to rolling direction, loc.A,
fourth test.
LDQSKA1 - 25C, 0.001/s, thru-thickness, location A, first test.
LDQSKA2 - 25C, 0.001/s, thru-thickness, location A, second test.
LDQSKA3 - 25C, 0.1/s, thru-thickness, location A, first test.
LDQSKA4 - 25C, 0.1/s, thru-thickness, location A, second test.
LDQSKA5 - -196C, 0.001/s, thru-thickness, location A, first test.
LDQSKA6 - -196C, 0.001/s, thru-thickness, location A, second test.
LDQSKB1 - 25C, 0.001/s, thru-thickness, location B, first test.
LDQSKB2 - 25C, 0.001/s, thru-thickness, location B, second test.
LDQSKB3 - 25C, 0.1/s, thru-thickness, location B, first test.
LDQSKB4 - 25C, 0.1/s, thru-thickness, location B, second test.
LDQSKB5 - -196C, 0.001/s, thru-thickness, location B, first test.
LDQSKB6 - -196C, 0.001/s, thru-thickness, location B, second test.

MEDRATE : Medium strain-rate tests using MTS test system,
(strain rates between 5/s and 200/s).

DQSK100 - 25C, 100/s.
DQSK12 - 25C, 12/s.
DQSK12A - 25C, 12/s, second test.
DQSK5 - 25C, 5/s.
DQSK60 - 25C, 60/s.
DQSK75 - 25C, 75/s.
DQSK90 - 25C, 90/s.

TENSILE : Tests under tensile.

LTADQ51 - 25C, 0.001/s, location A, test no. 1.
LTADQ52 - 25C, 0.001/s, location A, test no. 2.
LTBDQ51 - 25C, 0.001/s, location B, test no. 1.
LTBDQ52 - 25C, 0.001/s, location B, test no. 2.

BIAXIAL TENSION : Tests under biaxial loading.

DQSKBI1 - 25C, 0.001/s, 12" X 12" plate #1
DQSKBI2 - 25C, 0.001/s, 12" X 12" plate #2

ZAMODEL : Modeling results for the Zerilli-Armstrong Model
(file format : True-plastic-strain True-stress[MPa])

BESTFIT:

DQ20433A.ZBF - Isothermal strain-stress fit of ZA model to a test performed
at temperature=200C and strain rate=4300/s.
DQ40503A.ZBF - 400C, 5000/s.
DQRT10-3.ZBF - 25C, 0.001/s.
DQRT353A.ZBF - 25C, 3500/s.
DQRT500.ZBF - 25C, 5/s.

DQSK100.ZBF - 25C, 100/s.
DQSKJZ.ZBF - Input file to calculate final fits to the ZA model.
DQSKJZ - Model fit parameters for CM program

HIGHRATE: Optimized to high-strain rate data.

DQ20433A.ZBF - Isothermal strain-stress fit of ZA model to a test performed
at temperature=200C and strain rate=4300/s.
DQ40503A.ZBF - 400C, 5000/s.
DQRT10-3.ZBF - 25C, 0.001/s.
DQRT353A.ZBF - 25C, 3500/s.
DQRT500.ZBF - 25C, 5/s.
DQSK100.ZBF - 25C, 100/s.
DQSKJZHR.ZBF - Input file to calculate final fits to the ZA model.
DQSKJZHR - Model fit parameters for CM program

YIELD: Enforcing yield stresses.

DQ20433A.ZBF - Isothermal strain-stress fit of ZA model to a test performed
at temperature=200C and strain rate=4300/s.
DQ40503A.ZBF - 400C, 5000/s.
DQRT10-3.ZBF - 25C, 0.001/s.
DQRT353A.ZBF - 25C, 3500/s.
DQRT500.ZBF - 25C, 5/s.
DQSK100.ZBF - 25C, 100/s.
DQSKJZYS.ZBF - Input file to calculate final fits to the ZA model.
DQSKJZYS - Model fit parameters for CM program

ADDIT.INF : additional information

LRraw.dat : folder containing additional low rate data including elevated
temperature tests
MRraw.dat : folder containing intermediate strain rate compliance corrected
data
rawht.dat : heat treatment data, low, med., and high strain rate
pictures : Micrographs of the grain structure
stackraw : raw data for the stacked samples: low and intermediate strain
rates.
restrike : restrike data, used to show effects of adiabatic heating
Data.p : this folder contains the information used in the constitutive
modeling all in one location. It is the same as the above folder
KGplots : this folder contains all kaleidagraph data and plots presented to
the A/S partnership
data : folders include: low rate data (lrdata) important files are:
inpl001.QDA - inplane 0.001/s summary, tempsum.QDA - temperature
summary, MTSINSP1.QDA - mts and instron machine summary for 0.1/s
tests, and the last is PlSUM.QDA - Summary of the 0.1/s data,
intermediate rate data (medsr.dat), high strain rate (highsr.dat)
important files are: dqhrtemp.QDA - a summary of the high rate
temperature data, hisr25C.QDA - room temperature summary, tensile
(tensile.dat) tensile.QDA is the data summary, adiabatic or restrike
(restrike.dat) the two important files are restrike.QDA and
restrik2.QDA - both being summaries of data, size effect
(stacked.dat) dqszdep.QDA - size dependent data and stacked.QDA are
the important files here, and heat treatment (HTTREAT.DAT).
dqskht.QDA is the heat treatment summary
FILES : combo.QDA is a file that contains the summary of all the data
steel2.QDA is a summary of the temperature data
jcfPts.QDA is a data set of the Johnson-Cook curve fit points
ysDQSK.QDA is a data set for the ZA model fit to the yield points

plots : folders include: medsrp.plt: these files are fitted data curves to the intermediate strain rate tests.

PLOTS : HEATTR.QPC is a plot of the heat treatment data
HIGHSRP.QPC is the high strain rate plot, room temperature
HISRTEM.QPC is the high strain rate, at all temperatures plot
intsrrt.QPC is the intermediate strain rate, room temperature plot
jcfitted.QPC is the JC model fit plot
LNLOWSR.QPC is the liquid nitrogen test at low strain rates
LNYLDPT.QPC is the liquid nitrogen test at low strain rates
showing the yield points
lrsump.QPC is the low strain rates summary
RESTRKP.QPC is the restrike plot
SIZEFFT.QPC is the size effect plot
STKINTSR.QPC is the intermediate strain rate plot for stacked
samples
sumplp.QPC is the summary plot for 0.1/s tests
sumsrrt.QPC is a summary plot for all strain rates, room
temperature
sumsrtem.QPC is a summary plot for all strain rates and
temperatures
sumsrtm2.QPC is a modified plot of all strain rates and
temperatures
sumtempl.QPC is summary plot for 0.1/s rates at various
temperatures
temp001p.QPC is summary plot for 0.001/s rates at various
temperatures
ttip001p.QPC is a plot of all but biaxial data for 0.001/s rates
at room temperature
YSNORTEM.QPC is a plot of the model fits of the yield strength and
the normalized temperature for 0.001/s rates at various
YSSRRT.QPC is a plot of the model fits of the yield strength and
strain rate

Index of files for HSLA steel

Index of files for HSLA steel

This folder contains six directories (or folders):

DATA.P : experimental data files in the format of true plastic
strain versus true stress [MPa].
JCMODEL : Final fits to the Johnson-Cook Model. The format is true
plastic strain versus true stress [MPa]. The fits are under
isothermal condition.
MTSMODEL : Final fits to the MTS Model. The format is true plastic
strain versus true stress [MPa]. The fits are under
isothermal condition.
RAW.DAT : experimental data files in the format of true strain versus
true stress [MPa].
BIAXIAL : Experimental data obtained from biaxial bulge tests
COMPRESS : Experimental data obtained from free compression tests.
HIGHRATE : Experimental data obtained from high-rate tests.
LOWRATE : Experimental data obtained from low-rate tests.

MEDRATE : Experimental data obtained from medium-rate tests.
 TENSILE : Experimental data obtained from tensile tests.
 ZAMODEL : Final fits to the ZA Model for BCC. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
 BESTFIT : Best fitting results to the strain hardening behavior of low to medium strain-rate tests.
 HIGHRATE : Optimized to the hardening behavior exhibited by the data obtained at high strain rate using Hopkinson pressure bar.
 YIELD : When the yield stresses were used as part of the input to derive the fitting parameters for DQSK. The hardening behavior of low to medium strain rate tests was used.
 ADDIT.INF : This folder contains additional information not included on the diskette previously handed out the the A/SP members. It includes additional data on low, medium and high rate tests, and kaleidagraph files.

For each directory and its sub-directories, the files are listed in alphabetical order with brief description for each file as below:

DATA.P: (file format: true-plastic-strain true-stress[MPa])

- HSLA7K2.P - Testing temperature=200C, testing strain rate=7000/s.
- HSLA4K.P - 25C, 4000/s.
- HS200.P - 200C, 0.1/s.
- HS300.P - 300C, 0.1/s.
- HSLA001.P - 25C, 0.001/s.
- HSLA1.P - 25C, 0.1/s.
- HSLA20.P - 25C, 20/s.
- HSLA50.P - 25C, 50/s.
- HSLA01LN.P - 77K, 0.001/s.

LOW RATE

- HS201-1.P - 200C, 0.1/s, moly, MTS
- HS301-1.P - 300C, 0.1/s, moly, MTS
- HSLAI-3.P - 25C, 0.001/s, teflon/ moly, MTS
- HSLNI-3.P - 77K, 0.001/s, Instron
- HSLNI-3A.P - 77K, 0.001/s, Instron, repeat test.
- HSLNI-3B.P - 77K, 0.001/s, Instron, repeat test.
- HSRT-1.P - 25C, 0.1/s, teflon/ moly, MTS
- HSRT-1A.P - 25C, 0.1/s, teflon/ moly, MTS, repeat test.
- HSRT-1B.P - 25C, 0.1/s, teflon/ moly, MTS, repeat test.
- HSRT-1C.P - 25C, 0.1/s, grease, MTS, repeat test
- HSRT-1D.P - 25C, 0.1/s, grease, MTS, repeat test.
- HSRTI-1.P - 25C, 0.1/s, grease, Instron
- HSRTI-1B.P - 25C, 0.1/s, grease, Instron, repeat test.
- HSRTI-1C.P - 25C, 0.1/s, grease, Instron, repeat test.
- HSRTI-1D.P - 25C, 0.1/s, grease, Instron, repeat test.
- HSRTI-1E.P - 25C, 0.1/s, grease, Instron, repeat test.
- HSRTI-1F.P - 25C, 0.1/s, teflon/ moly, Instron, repeat test.
- HSRTI-3.P - 25C, 0.001/s, Instron
- HSRTI-3A.P - 25C, 0.001/s, grease, Instron, repeat test.
- HSRTI-3B.P - 25C, 0.001/s, grease, Instron, repeat test.

MED RATE

- HSLA118.P - 25C, 118/s, MTS
- HSRT100.P - 25C, 100/s, MTS
- HSRT140.P - 25C, 140/s, MTS
- HSRT20.P - 25C, 20/s, MTS
- HSRT37.P - 25C, 37/s, MTS

HSRT50.P - 25C, 50/s, MTS
 HSRT50A.P - 25C, 50/s, MTS, repeat test.
 HIGH RATE
 HS20703.P - 200C, 7000/s, MTS
 HS20703A.P - 200C, 7000/s, MTS, repeat test.
 HSLN203.P - 77K, 2000/s, MTS
 HSLN203A.P - 77K, 2000/s, MTS, repeat test.
 HSRT403.P - 25C, 4000/s, MTS
 HSRT403A.P - 25C, 4000/s, MTS, repeat test.
 HSRT403B.P - 25C, 4000/s, MTS, repeat test.
 JCMODEL : Modeling results for the Johnson-Cook Model
 (file format : True-plastic-strain True-stress[MPa])
 HSLA7K2.JCF - Isothermal strain-stress fit of JC model to a test performed
 at temperature=200C and strain rate=7000/s.
 HSLA001.JCF - 25C, 0.001/s.
 HSLA1.JCF - 25C, 0.1/s.
 HSLA20.JCF - 25C, 20/s.
 HSLA50.JCF - 25C, 50/s.
 HSLA4K.JCF - 25C, 4000/s.
 HSLAjc.JCF - Input file to calculate final fits to the JC model.
 HSLAjc - Model fit parameters for CM program
 MTSMODEL : Modeling results for the MTS Model
 (file format : True-plastic-strain True-stress[MPa])
 HSLA7K2.MTS - Isothermal strain-stress fit of MTS model to a test
 performed at temperature=200C and strain rate=7000/s.
 HSLA001.MTS - 25C, 0.001/s.
 HSLA1.MTS - 25C, 0.1/s.
 HSLA20.MTS - 25C, 20/s.
 HSLA50.MTS - 25C, 50/s.
 HSLA4K.MTS - 25C, 4000/s.
 HSLAmts.MTS - Input file to calculate final fits to the MTS model.
 HSLAjc - Model fit parameters for CM program
 RAW.DAT : Experimental data files
 COMPRESS : Test under compression
 HIGHRATE : Using Hopkinson Pressure Bar (strain rate greater than 1000/s)
 HS207031 - 200C, 4300/s, first test.
 HS207032 - 200C, 4400/s, second test.
 HSLN2031 - -196C, 2000/s, first test.
 HSLN2032 - -196C, 2000/s, second test.
 HSRT4031 - 25C, 4000/s, first test.
 HSRT4032 - 25C, 4000/s, second test.
 HSRT4033 - 25C, 4000/s, third test.
 LOWRATE : Quasi-static tests using Instron load frame,
 (strain rates between 0.0001/s and 1/s).
 HS2001C.DAT -200C, 0.1/s, thru-thickness, teflon/moly lubricant, 1st test.
 HS2001C.DAT -300C, 0.1/s, thru-thickness, teflon/moly lubricant, 1st test.
 HSLA11C.DAT -25C, 0.1/s, thru-thickness, teflon/moly lubricant, 1st test.
 HSLA12C.DAT -25C, 0.1/s, thru-thickness, teflon/moly lubricant, 2nd test.
 HSLA13C.DAT -25C, 0.1/s, thru-thickness, teflon/moly lubricant, 3rd test
 HSLA14C.DAT -25C, 0.1/s, thru-thickness, teflon/moly lubricant, 4th test
 HSLA15C.DAT -25C, 0.1/s, thru-thickness, teflon/moly lubricant, fifth test
 HSLA1C.DAT - 25C, 0.1/s, thru-thickness, moly lubricant, first test.
 HSLA2SC.DAT - 25C, 0.001/s, thru-thickness, moly lubricant, second test.

HSLA3SC.DAT - 25C, 0.001/s, thru-thickness, moly lubricant, third test.
 LALSP1 - 25C, 0.001/s, thru-thickness, first test.
 LALSP2 - 25C, 0.001/s, thru-thickness, second test.
 LALSP3 - 25C, 0.1/s, thru-thickness, first test.
 LALSP4 - 25C, 0.1/s, thru-thickness, second test.
 LALSP5 - -196C, 0.001/s, thru-thickness, first test.
 LALSP6 - -196C, 0.001/s, thru-thickness, second test.
 LALSP7 - -196C, 0.001/s, thru-thickness, third test.
 LALSP8 - 25C, 0.001/s, thru-thickness, third test.
 LALSP9 - 25C, 0.1/s, thru-thickness, third test.
 LALSP10 - 25C, 0.1/s, thru-thickness, fourth test.
 LALSP11 - 25C, 0.1/s, thru-thickness, fifth test.
 LALSP12 - 25C, 0.1/s, thru-thickness, sixth test.
 LALSP13 - 25C, 0.1/s, thru-thickness, seventh test

MEDRATE : Medium strain-rate tests using MTS test system,
 (strain rates between 5/s and 200/s).

HSLA101.DAT - 25C, 100/s.
 HSLA112.DAT - 25C, 112/s.
 HSLA118.DAT - 25C, 118/s, second test.
 HSLA140.DAT - 25C, 140/s.
 HSLA21.DAT - 25C, 21/s.
 HSLA37.DAT - 25C, 37/s.
 HSLA50A.DAT - 25C, 50/s.
 HSLA50B.DAT - 25C, 50/s, second test.
 HSLA8.DAT - 25C, 8/s.

TENSILE : Tests under tensile.

LHSSTA1 - 25C, 0.001/s, location A, test no. 1.
 LHSSTA2 - 25C, 0.001/s, location A, test no. 2.
 LHSSTB1 - 25C, 0.001/s, location B, test no. 1.
 LHSSTB2 - 25C, 0.001/s, location B, test no. 2.

BIAXIAL : Tests under biaxial loading.

biax1 - 25C, 0.001/s, 12" X 12" PLATE
 biax2 - 25C, 0.001/s, 12" X 12" PLATE, test no. 2.

ZAMODEL : Modeling results for the Zerilli-Armstrong Model
 (file format : True-plastic-strain True-stress[MPa])

BESTFIT:

HSLA7K2.ZBF - Isothermal strain-stress fit of ZA model to a test performed
 at temperature=200C and strain rate=7000/s.
 HSLA001.ZBF - 25C, 0.001/s.
 HSLA1.ZBF - 25C, 0.1/s.
 HSLA20.ZBF - 25C, 20/s.
 HSLA50.ZBF - 25C, 50/s.
 HSLA4K.ZBF - 25C, 4000/s.
 HSLAza.ZBF - Input file to calculate final fits to the ZA model.
 HSLAza - Model fit parameters for CM program

HIGHRATE: Optimized to high-strain rate data.

HSLA7K2.ZBF - Isothermal strain-stress fit of ZA model to a test performed
 at temperature=200C and strain rate=7000/s.
 HSLA1.ZBF - 25C, 0.1/s.
 HSLA50.ZBF - 25C, 50/s.
 HSLA4K.ZBF - 25C, 4000/s.
 HSLAZAHR.ZBF - Input file to calculate final fits to the ZA model.
 HSLAZAHR - Model fit parameters for CM program

YIELD: Enforcing yield stresses.

HSLA7K2.ZBF - Isothermal strain-stress fit of ZA model to a test performed at temperature=200C and strain rate=7000/s.

HSLA001.ZBF - 25C, 0.001/s.

HSLA1.ZBF - 25C, 0.1/s.

HSLA50.ZBF - 25C, 50/s.

HSLA4K.ZBF - 25C, 4000/s.

HSLAazys.ZBF - Input file to calculate final fits to the ZA model.

HSLAazys - Model fit parameters for CM program

ADDIT.INF : additional information

Data.p : this folder contains the information used in the constitutive modeling all in one location. It is the same as the above folder

KGstuff : this folder contains all kaleidagraph data and plots presented to the A/S partnership

data : folders include: low rate data (low) important file is:

lowall.QDA - inplane 0.001/s summary

high strain rate (high) important files are: hisrall.QDA - a summary of the high rate data

biaxial (biaxial) tensile.QDA is the data summary,

adiabatic or restrike (restrike.dat) the two important files are

restrike.QDA and restrik2.QDA - both being summaries of data,

size effect (stacked.dat) dqszdep.QDA - size dependent data and

stacked.QDA are the important files here , and

heat treatment (HTTREAT.DAT) dqskht.QDA is the heat treatment summary

FILES : medsrall.QDA is a file that contains the summary of the intermediate rate data

tension.QDA is a file that contains the summary of the tensile data

allsumm.QDA is a data set of all strain rates and temperatures

plots : folders include: low: these files are fitted data curves to the low strain rate tests plots include

sum001.QPC is the summary plot of the 0.001/s rate at room temp. for 2 machines

sumpl.QPC is the summary plot of the 0.1/s rate

sumpllub.QPC is the plot of the 0.1/s rate with a comparison of lubrications

lowsrall.QPC is the summary plot of the 0.001/s rate at all temps.

instp.QPC this plot compares lubrication on the Instron at 0.1/s

tstcond.QPC is the plot of all test conditions conducted at room temperature and at a strain rate of 0.001/s

grtefp3.QPC is the grease teflon comparison plot at low rates.

med: these files are fitted data curves to the intermediate strain rate tests. medium strain rate tests plots include:

intsrsum.QPC - the summary plot of intermediate strain rate tests

sr100.QPC is the summary plot of the strain rates greater than 100/s

sr20to50.QPC is the summary plot of the strain rates between 20/s and 50/s

PLOTS : hirtall.QPC is the high strain rate, at all temperatures plot

Biaxial.QPC - plot of the biaxial and compression data at 0.001/s

Tensall.QPC is a summary plot of the tensile data (S.R. = 0.001/s)

HSsum.QPC is a summary plot for all strain rates and temperatures

hslasum2.QPC is a modified plot of all strain rates and temps.

Index of files for IF steel

Index of files for IF steel

This directory contains six sub-directories (or folders):

DATA.P : experimental data files in the format of true plastic strain versus true stress [MPa].
JCMODEL : Final fits to the Johnson-Cook Model. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
MTSMODEL : Final fits to the MTS Model. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
RAW.DAT : experimental data files in the format of true strain versus true stress [MPa].
BIAXIAL : Experimental data obtained from biaxial bulge tests
COMPRESS : Experimental data obtained from free compression tests.
HIGHRATE : Experimental data obtained from high-rate tests.
LOWRATE : Experimental data obtained from low-rate tests.
MEDRATE : Experimental data obtained from medium-rate tests.
TENSILE : Experimental data obtained from tensile tests.
ZAMODEL : Final fits to the ZA Model for BCC. The format is true plastic strain versus true stress [MPa]. The fits are under isothermal condition.
ADDIT.INF : This folder contains additional information not included on the diskette previously handed out the the A/SP members. It includes additional data on low, medium and high rate tests, and kaleidagraph files.

For each directory and its sub-directories, the files are listed in alphabetical order with brief description for each file as below:

DATA.P: (file format: true-plastic-strain true-stress[MPa])

LOW RATE

IF1003.P - Testing temperature=100C, testing strain rate=0.001/s.
IFRTP1.P - 25C, 0.1/s.
IF2003.P - 200C, 0.001/s,
IFRTP3.P - 25C, 0.001/s,
IF3003.P - 300C, 0.001/s.

MED RATE

IFRT100.P - 25C, 100/s, MTS
IFRT50.P - 25C, 50/s, MTS

HIGH RATE

IF10653.P - 100C, 6500/s, SHPB
IFRT6K.P - 25C, 6000/s, SHPB.
IF20703.P - 200C, 7000/s, SHPB
IF30753.P - 300C, 7500/s, SHPB.

JCMODEL : Modeling results for the Johnson-Cook Model

(file format : True-plastic-strain True-stress[MPa])

IF10653.JCF - Isothermal strain-stress fit of JC model to a test performed at temperature=100C and strain rate=6500/s.
IF2003.JCF - 200C, 0.001/s.
IF20703.JCF - 200C, 7000/s.

IF30753.JCF - 300C, 7500/s.
 IFRT50.JCF - 25C, 50/s.
 IFRT6K.JCF - 25C, 6000/s.
 IFRTP1.JCF - 25C, 0.1/s.
 IFRTP3.JCF - 25C, 0.001/s.
 IF_jc.JCF - Input file to calculate final fits to the JC model.
 IF_jc - Model fit parameters for CM program

MTSMODEL : Modeling results for the MTS Model
 (file format : True-plastic-strain True-stress[MPa])
 IF10653.MTS - Isothermal strain-stress fit of MTS model to a test
 performed at temperature=100C and strain rate=6500/s.
 IF20703.MTS - 200C, 7000/s.
 IF30753.MTS - 300C, 7500/s.
 IFRT100.MTS - 25C, 100/s.
 IFRT6K.MTS - 25C, 6000/s.
 IFRTP1.MTS - 25C, 0.1/s.
 IFRTP3.MTS - 25C, 0.001/s.
 IFmts.MTS - Input file to calculate final fits to the MTS model.
 IFmts - Model fit parameters for CM program

RAW.DAT : Experimental data files

COMPRESS : Test under compression

HIGHRATE : Using Hopkinson Pressure Bar (strain rate greater than 1000/s)

IF10753C.T - 100C, 7500/s, first test.
 IF10653C.T - 100C, 6500/s, second test.
 IF20703C.T - 200C, 7000/s, first test.
 IF20753C.T - 200C, 7500/s, second test.
 IF30743C.T - 300C, 7400/s, first test.
 IF30753C.T - 300C, 7500/s, second test.
 IFRT6K1C.T - 25C, 6000/s, first test.
 IFRT6K2C.T - 25C, 6000/s, second test.
 IFR6K32C.T - 25C, 6000/s, stacked specimens.
 IFLN453C.T - -196C, 4500/s, first test.
 IFLN463C.T - -196C, 4600/s, second test.

LOWRATE : Quasi-static tests using Instron load frame,
 (strain rates between 0.0001/s and 1/s).

IF1003C.DAT - 100C, 0.001/s, thru-thickness, 0.08".
 IF2003C.DAT - 200C, 0.001/s, thru-thickness, 0.08".
 IF3003C.DAT - 300C, 0.001/s, thru-thickness, 0.08".
 IFP1.DAT - 25C, 0.1/s, thru-thickness, 0.08".
 IFTP1C.DAT - 25C, 0.1/s, thru-thickness, 0.08".
 IFSP1C.DAT - 25C, 0.1/s, thru-thickness, 0.063".
 IFTP3AC.DAT - 25C, 0.001/s, thru-thickness, 0.08".
 L63IF1LU - 25C, 0.001/s, thru-thickness, first test, 0.063".
 L63IF2LU - 25C, 0.001/s, thru-thickness, second test, 0.063".
 L63IF4LU - 25C, 0.1/s, thru-thickness, first test, 0.063".
 L63IF7LU - 25C, 0.1/s, thru-thickness, second test, 0.063".
 L63IF9LU - 25C, 0.1/s, thru-thickness, stacked, 0.063" X 2.
 L80IF1LU - 25C, 0.1/s, thru-thickness, first test, 0.08".
 L80IF2LU - 25C, 0.1/s, thru-thickness, second test, 0.08".
 L80IF3LU - 25C, 0.001/s, thru-thickness, first test, 0.08".
 L80IF4LU - 25C, 0.001/s, thru-thickness, second test, 0.08".
 L80IF7LU - 25C, 0.001/s, thru-thickness, stacked, 0.08" X 2.
 L80IF8LU - 25C, 0.001/s, thru-thickness, third test, 0.08".

L80IF9LU - 25C, 0.001/s, thru-thickness, fourth test, 0.08".
 L8010LU - 25C, 0.001/s, thru-thickness, fifth test, 0.08".
 L8011LU - 25C, 0.001/s, thru-thickness, sixth test, 0.08".
 P0018AC.T - 25C, 0.001/s, thru-thickness, compliance corrected L80IF3LU.
 P0018BC.T - 25C, 0.001/s, thru-thickness, compliance corrected L80IF4LU.
 P0018CC.T - 25C, 0.001/s, thru-thickness, compliance corrected L80IF8LU.
 P0018DC.T - 25C, 0.001/s, thru-thickness, compliance corrected L80IF9LU.
 P0018EC.T - 25C, 0.001/s, thru-thickness, compliance corrected L8010LU.
 P0018FC.T - 25C, 0.001/s, thru-thickness, compliance corrected L8011LU.
 P00163AC.T - 25C, 0.001/s, thru-thickness, compliance corrected L63IF1LU.
 P00163BC.T - 25C, 0.001/s, thru-thickness, compliance corrected L63IF2LU.

MEDRATE : Medium strain-rate tests using MTS test system,
 (strain rates between 5/s and 200/s).

IFSC100.DAT - 25C, 100/s, short stack, load cell.
 IFSW100.DAT - 25C, 100/s, short stack, load washer.
 IFTD20AC.DAT - 25C, 20/s, tall stack.
 IFTW100.DAT - 25C, 100/s, tall stack.
 IFTD20BC.DAT - 25C, 20/s, tall stack, second test.
 IFTD50AC.DAT - 25C, 50/s, tall stack.
 IFTD50BC.DAT - 25C, 50/s, tall stack, second test.

TENSILE : Tests under tensile.

LIFAT1E - 25C, 0.001/s, location A, test no. 1.
 LIFAT2E - 25C, 0.001/s, location A, test no. 2.
 LIFAT3E - 25C, 0.001/s, location A, test no. 3.
 LIFBT1E - 25C, 0.001/s, location B, test no. 1.
 LIFBT2E - 25C, 0.001/s, location B, test no. 2.

BIAXIAL : Tests under biaxial loading.

IF biaxial - 25C, 0.001/s, 12" X 12" PLATE

ZAMODEL : Modeling results for the Zerilli-Armstrong Model
 (file format : True-plastic-strain True-stress[MPa])

BESTFIT:

IF10653.JCF - Isothermal strain-stress fit of ZA model to a test performed
 at temperature=100C and strain rate=6500/s.
 IF2003.ZBF - 200C, 0.001/s.
 IF1003.ZBF - 100C, 0.001/s.
 IF20703.ZBF - 200C, 7000/s.
 IF30753.ZBF - 300C, 7500/s.
 IF3003.ZBF - 300C, 0.001/s.
 IFRT50.ZBF - 25C, 50/s.
 IFRT100.ZBF - 25C, 100/s.
 IFRT6K.ZBF - 25C, 6000/s.
 IFRTP1.ZBF - 25C, 0.1/s.
 IFRTP3.ZBF - 25C, 0.001/s.
 IF _za.ZBF - Input file to calculate final fits to the ZA model.
 IF _za - Model fit parameters for CM program

ADDIT.INF : additional information

Data.p : this folder contains the information used in the constitutive
 modeling all in one location. It is the same as the above folder
 kgstuff : this folder contains all kaleidagraph data and plots presented
 to the A/S partnership

data : folders include: low rate data (low) important file is:
 IFp3.QDA - inplane 0.001/s summary, 2 machines and plates
 ifexp3.QDA - data for bialial and compression, (S.R. = 0.001/s)
 IFp1.QDA data for the 0.1/s tests
 sizedat.QDA data for determining the size dependence of the IF steel
 ifallp3.QDA data for all test conditions, biaxial, comp. 0.001/s
 heat treatment (HTTREAT.DAT) dqskht.QDA is the heat treatment summary
 FILES : medif.QDA contains the summary of the intermediate rate data
 highif.QDA contains the summary of the high rate data
 tenif.QDA contains the summary of the tensile data
 IFbiax.QDA contains the summary of the biaxial data
 iftalsum.QDA - data summary of the tall plate:low, med, high sr

plots :folders include: low: these files are fitted data curves to the
 low strain rate tests plots include
 IFp3p.QPC summary of the 0.001/s rate at room temp. for 2 frames
 ifallp3.QPC summary at 0.001/s rate, biaxial, tension, and comp.
 IFP1.QPC - the 0.1/s rate, stack and plate size comparison
 temsump3.QPC - summary of the 0.001/s rate at all temps.

PLOTS : IFIntSR.QPC is the intermediate strain rate plot at room temp.
 IFhighrt.QPC is the high strain rate, at all temperatures plot
 IFBiax.QPC - the biaxial data at a strain rate of 0.001/s
 IFTen.QPC - summary of the tensile data (S.R. = 0.001/s)
 RTSRsum.QPC - summary for all strain rates at room temperature
 sizefft.QPC is a plot at low and high rates to the size effect
 allsrtall.QPC - summary for all strain rates and sizes at room
 temp.

Index of files for M-190 steel

Index of files for M-190 steel

This directory contains six sub-directories (or folders):

DATA.P : experimental data files in the format of true plastic
 strain versus true stress [MPa].

JCMODEL : Final fits to the Johnson-Cook Model. The format is true
 plastic strain versus true stress [MPa]. The fits are under
 isothermal condition.

MTSMODEL : Final fits to the MTS Model. The format is true plastic
 strain versus true stress [MPa]. The fits are under
 isothermal condition.

RAW.DAT : experimental data files in the format of true strain versus
 true stress [MPa].

BIAXIAL : Experimental data obtained from biaxial bulge tests

COMPRESS : Experimental data obtained from free compression tests.

HIGHRATE : Experimental data obtained from high-rate tests.

LOWRATE : Experimental data obtained from low-rate tests.

MEDRATE : Experimental data obtained from medium-rate tests.

TENSILE : Experimental data obtained from tensile tests.

ZAMODEL : Final fits to the ZA Model for BCC. The format is true
 plastic strain versus true stress [MPa]. The fits are under
 isothermal condition.

ADDIT.INF : This folder contains additional information not included on the diskette previously handed out the the A/SP members. It includes additional data on low, medium and high rate tests, and kaleidagraph files.

For each directory and its sub-directories, the files are listed in alphabetical order with brief description for each file as below:

DATA.P: (file format: true-plastic-strain true-stress[MPa])

LOW RATE

RTP001.P - Testing temperature=25C, testing strain rate=0.001/s.
RTP1.P - 25C, 0.1/s.
M9100P1.P - 100C, 0.1/s.
M9200P1.P - 200C, 0.1/s.
M9300P1.P - 300C, 0.1/s.
LNP001.P - 77K, 0.001/s, Instron.

MED RATE

RT10.P - 25C, 10/s, MTS
RT40.P - 25C, 40/s, MTS
RT80.P - 25C, 80/s, MTS

HIGH RATE

T2004K.P - 200C, 4000/s, SHPB
T3006K.P - 300C, 6000/s, SHPB.
T10035K.P - 100C, 3500/s, SHPB
RT2000.P - 25C, 2000/s, SHPB.
LN1500.P - 77K, 1500/s, SHPB

JCMODEL : Modeling results for the Johnson-Cook Model

(file format : True-plastic-strain True-stress[MPa])

M9300P1.JCF - Isothermal strain-stress fit of JC model to a test performed at temperature=300C and strain rate=0.1/s.
M9100P1.JCF - 100C, 0.1/s.
RT2000.JCF - 25C, 2000/s.
RT40.JCF - 25C, 40/s.
RTP001.JCF - 25C, 0.001/s.
T10035K.JCF - 100C, 3500/s.
T2004K.JCF - 200C, 4000/s.
M190jc.JCF - Input file to calculate final fits to the JC model.
M190jc - Model fit parameters for CM program

MTSMODEL : Modeling results for the MTS Model

(file format : True-plastic-strain True-stress[MPa])

M9300P1.MTS - Isothermal strain-stress fit of JC model to a test performed at temperature=300C and strain rate=0.1/s.
M9100P1.MTS - 100C, 0.1/s.
RT2000.MTS - 25C, 2000/s.
RT40.MTS - 25C, 40/s.
RTP001.MTS - 25C, 0.001/s.
T10035K.MTS - 100C, 3500/s.
T2004K.MTS - 200C, 4000/s.
M190mts.MTS - Input file to calculate final fits to the MTS model.
M190mts - Model fit parameters for CM program

RAW.DAT : Experimental data files

COMPRESS : Test under compression

HIGHRATE : Using Hopkinson Pressure Bar (strain rate greater than 1000/s)

M9RT2K1C.T - 25C, 2000/s, first test.
M9RT2K1C.T - 25C, 2000/s, second test.
M910363C.T - 100C, 3600/s, first test.
M910353C.T - 100C, 3500/s, second test.
M920353C.T - 200C, 3500/s, first test.
M920403C.T - 200C, 4000/s, second test.
M930553C.T - 300C, 5500/s, first test.
M930603C.T - 300C, 6000/s, second test.
M9LN153C.T - -196C, 1500/s, first test.
M9LN203C.T - -196C, 2000/s, second test.

LOWRATE : Quasi-static tests using Instron load frame,
(strain rates between 0.0001/s and 1/s).

M9RTP1A.DAT - 25C, 0.1/s, thru-thickness, first test.
M9RTP1B.DAT - 25C, 0.1/s, thru-thickness, second test.
M9300P1.DAT - 300C, 0.1/s, thru-thickness, first test.
M9200P1A.DAT - 200C, 0.1/s, thru-thickness, first test.
M9200P1B.DAT - 200C, 0.1/s, thru-thickness, second test.
M9100P1.DAT - 100C, 0.1/s, thru-thickness, first test.
L1M190 - 25C, 0.001/s, thru-thickness, first test.
L2M190 - 25C, 0.001/s, thru-thickness, second test.
L3M190 - 25C, 0.1/s, thru-thickness, first test.
L4M190 - 25C, 0.1/s, thru-thickness, second test.
L5M190 - -196C, 0.001/s, thru-thickness, first test.
L6M190 - -196C, 0.001/s, thru-thickness, second test.

MEDRATE : Medium strain-rate tests using MTS test system,
(strain rates between 5/s and 200/s).

M190H1.DAT - 25C, 19/s.
M190H2A.DAT - 25C, 40/s.
M190H3.DAT - 25C, 50/s, second test.
M190H4.DAT - 25C, 80/s.
M190H5.DAT - 25C, 80/s, second test.
M190H6.DAT - 25C, 12/s.

TENSILE : Tests under tensile.

LM19A1 - 25C, 0.001/s, location A, test no. 1.
LM19A2 - 25C, 0.001/s, location A, test no. 2.
LM19B2 - 25C, 0.001/s, location B, test no. 1.
LM19B3 - 25C, 0.001/s, location B, test no. 2.

BIAXIAL : Tests under biaxial loading.

bim190L - 25C, 0.001/s, 12" X 12" PLATE, 0.08" thick.
bim190S - 25C, 0.001/s, 12" X 12" PLATE, 0.03 " thick.

ZAMODEL : Modeling results for the Zerilli-Armstrong Model
(file format : True-plastic-strain True-stress[MPa])

BESTFIT:

M9300P1.ZBf - Isothermal strain-stress fit of JC model to a test performed
at temperature=300C and strain rate=0.1/s.
M9100P1.ZBf - 100C, 0.1/s.
RT2000.ZBf - 25C, 2000/s.
RT40.ZBf - 25C, 40/s.
RTP001.ZBf - 25C, 0.001/s.

T10035K.ZBf - 100C, 3500/s.
T2004K.ZBf - 200C, 4000/s.
T3006K.ZBf - 300C, 6000/s.
M190za.ZBf - Input file to calculate final fits to the ZA model.
M190za - Model fit parameters for CM program

ADDIT.INF : additional information

Data.p : this folder contains the information used in the constitutive modeling all in one location. It is the same as the above folder
m190httr : this folder contains the information from the heat treatment of the M190 steel folders include: raw data (rawht.dat), and kaleidagraph data (kgdata)

Kaleidagraph files :

m190ht.QPC - plot of the heat treatment data compared with as-received
m190ht.QDA - data the plot of the heat treatment plot

kgstuff : this folder contains all kaleidagraph data and plots presented to the A/S partnership

data : folders include: intermediate rate data (med), important data file:

medsr.QDA - compression data at intermediate strain rates

high rate data (high) the important data file is:

hrm190.QDA - compression data at high

biaxial test data (biaxial)

tensile test data (tension) the important data files are:

m190ten.QDA - tensile data at low strain rates

modtens.QDA - compliance corrected tensile data

FILES : lowsrr.QDA - the summary of the low rate data

summ190.QDA - summary of the m190 plate data: low, med, high sr

plots : folders include: low: these files are fitted data curves to the low strain rate tests plots include

lowIns.QPC - instron data at rates of 0.001/s and 0.1/s

lowsrsum.QPC - summary of all temps.at rates 0.001/s and 0.1/s

lowtemp.QPC is the summary plot of the 0.1/s rate at all temps.

M9P3all.QPC - summary of the 0.001/s rate, biaxial, and comp.

PLOTS : m190int.QPC - intermediate strain rate plot at room temperature

hrsum.QPC - high strain rate, at all temperatures plot

m190bulg.QPC - the biaxial data at a strain rate of 0.001/s

tensile2.QPC - summary of the tensile data (S.R. = 0.001/s)

m90Lins.QPC is a plot the low and intermediate strain rates

m9totsr.QPC - summary for all strain rates and temperatures

Index of files for CCDATA

CCDATA folder: This folder contains compliance corrected data collected at low rates. Each file has been modified to eliminate the "soft" response of the test frame. There are folders for each of the four materials tested. Some include the tensile data others did not need the tensile data compliance corrected. The files are the same as those found in each database in the raw.dat folders. Files that end in ____C.T have been corrected.

DQSK: Two folders containing the compliance corrected data for the low rate compression and tensile tests are in this folder

HSLA: the compliance corrected data for the low rate compression tests are in a folder marked "low."

M190: the compliance corrected data for the low rate compression tests and tensile tests are in this folder. The tensile data is found in the folder marked "tensile" and the compression data is under the M190 folder.

IF: the compliance corrected data for the low rate compression tests and tensile tests are in this folder. The tensile data is found in the folder marked "tensile" and the compression data is under the IF folder.