# TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AWG-ERIF-9-16

## TEST CASE ID AWG-ERIF-9

## Single Element Comparison Tests

Tested with LS-DYNA® R11.1 Revision 139325

Tuesday 13th August, 2019

LSTC
Livermore Software Technology Corp.

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|---|---|
| Confidentiality | **external use** |
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# Contents

# 1 Introduction

## 1.1 Purpose of this Document

This document specifies the test case AWG-ERIF-9. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.
A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. The test case specifications also state the target measures for testing and the expected results, as well as their pass and fail criteria.
Testing results are provided in section 5 for the therein mentioned LS-DYNA® version and platforms.

# 2 Test Case Information

| Test Case Summary | |
|---|---|
| Confidentiality | external use |
| Test Case Name | Single Element Comparison Tests |
| Test Case ID | AWG-ERIF-9 |
| Test Case Status | active |
| Test Case Classification | Example |
| Test Case Source | NCAC / George Washington University |
| Tested Keyword | *MAT_TABULATED_JOHNSON_COOK,<br>*MAT_PIECEWISE_LINEAR_PLASTICITY,<br>*MAT_JOHNSON_COOK |
| Member of Test Suite | AWG ERIF SUITE |
| Metadata | AWG ERIF |

Table 1: Test Case Summary

# 3 Test Case Specification

## 3.1 Test Case Purpose

The purpose of Test Case ID AWG-ERIF-9 is the comparison of *MAT_TABULATED_JOHNSON_COOK (*MAT_224) to *MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_024) and *MAT_JOHNSON_COOK (*MAT_015) , and, in particular, demonstrating the influence of thermal softening and stress triaxiality.
The reliability and consistency of LS-DYNA® as a finite element solver for the single solid element models is evaluated by performing analyses on different cpu architecture platforms and comparing *MAT_224 with reliable implemented material laws in LS-DYNA®.

## 3.2 Test Case Description

This Test Case contains 24 elements (6 rows times 4 columns) see figure 2. Each of the 4 columns specifies a different load case (see table 2 and figure 1), and each of the 6 rows contain elements with different material descriptions and input parameters (see table 3). The specification of element id's with load case, material type, and input properties can be found in table 4.

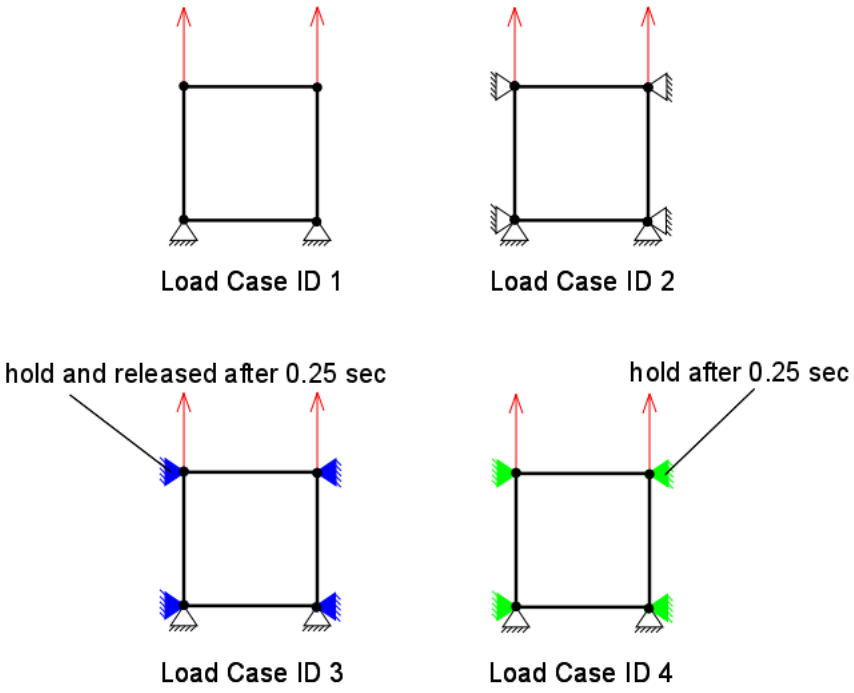


Figure 1: Load Cases

| Load Cases ID | Load case specification |
|---|---|
| 1 | Uniaxial tension, orthogonal directions free |
| 2 | Uniaxial tension, orthogonal directions hold |
| 3 | Uniaxial tension, orthogonal directions hold and released after 0.25 seconds |
| 4 | Uniaxial tension, orthogonal directions hold after 0.25 seconds |

Table 2: Load cases for the single elements test

| Material ID | Material specification and parameters |
|---|---|
| 1 | Johnson-Cook (MAT_015), vp=1 viscoplastic formulation, m=0, thermal decoupled |
| 2 | Piecewise Linear Plasticity (MAT_024), vp =1 viscoplastic formulation |
| 3 | Johnson Cook (MAT_015), vp=1 visco plastic formulation, m=1 fully thermal coupling |
| 4 | Tabulated Johnson-Cook (MAT_224), beta = 1 Amount of plastic work converted into heat |
| 5 | Tabulated Johnson-Cook (MAT_224), beta= 0.6 Amount of plastic work converted into heat |
| 6 | Tabulated Johnson-Cook (MAT_224), beta = 1 Amount of plastic work converted into heat, kt = 0 |

Table 3: Material types for the single elements test

| Element ID | Material ID | Load Case ID |
|---|---|---|
| 1 | 1 | 1 |
| 2 | 1 | 2 |
| 3 | 1 | 3 |
| 4 | 1 | 4 |
| 5 | 2 | 1 |
| 6 | 2 | 2 |
| 7 | 2 | 3 |
| 8 | 2 | 4 |
| 9 | 3 | 1 |
| 10 | 3 | 2 |
| 11 | 3 | 3 |
| 12 | 3 | 4 |
| 13 | 4 | 1 |
| 14 | 4 | 2 |
| 15 | 4 | 3 |
| 16 | 4 | 4 |
| 17 | 5 | 1 |
| 18 | 5 | 2 |
| 19 | 5 | 3 |
| 20 | 5 | 4 |
| 21 | 6 | 1 |
| 22 | 6 | 2 |
| 23 | 6 | 3 |
| 24 | 6 | 4 |

Table 4: Material ID and load case ID for the single elements

## 3.3 Model Description

The model contains 24 solid elements (see figure2). There are 4 columns each with different loading conditions defined on figure 1. Each row contains six solid elements each with different material types and input properties (see table 3).
The model specifications can be found in table 5, and table 6 defines the sub test case specification.

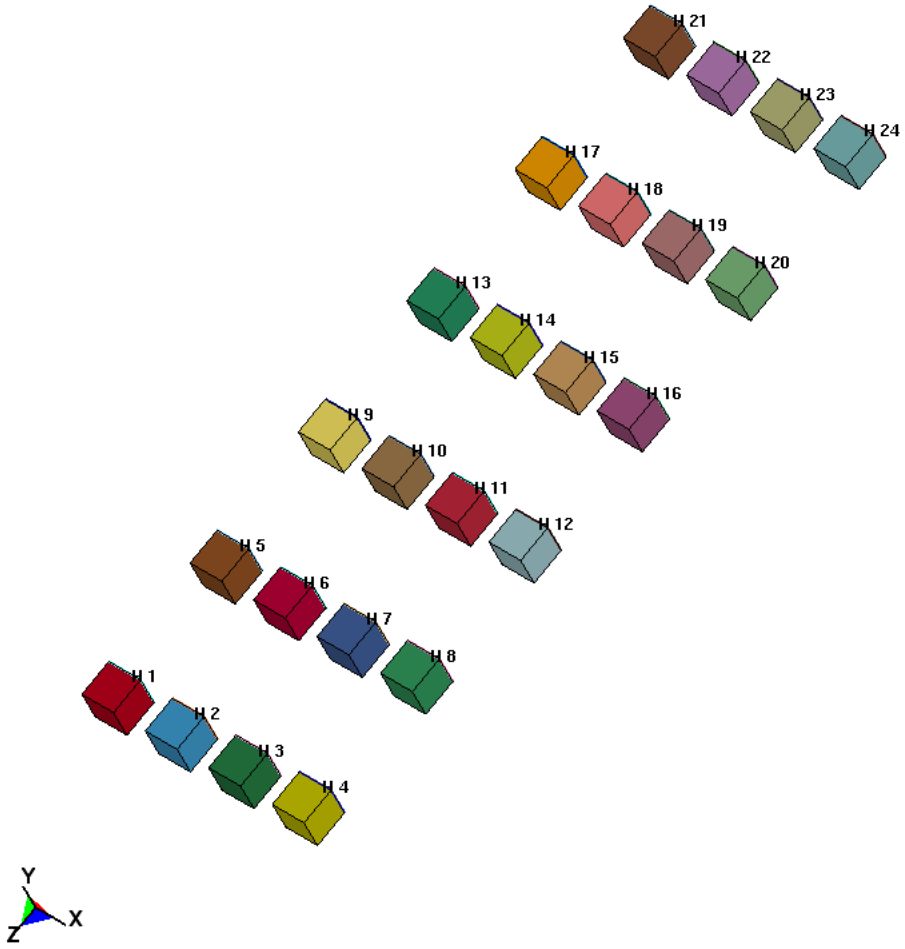


Figure 2: FEA model: 24 elements test, for detailed specifications see table 3

The material definitions and their parameters can be found in the input decks.

| FEA Model information | |
|---|---|
| Nodes | 192 |
| Solid elements | 24 |
| Solid materials | 24 |
| Parts | 24 |
| Units | mm (length), sec. (time), tonne (mass), N/mm$^2$ (stress), Nmm (energy) |

Table 5: FEA Model Information

| Sub Test Case ID | Input Deck Name |
|---|---|
| 1 | MAT_224_single_element.k |

Table 6: Specification of sub test cases

# 4 Test Specifications

## 4.1 Test Case Targets

Table 7 displays the test case targets. The test case targets specify values or a series of values taken from the finite element analysis solution of the test case and they are used in comparisons with each other.

| **Test Case Targets** | | | | |
|---|---|---|---|---|
| Target number | output | component type | component id | retrieved from |
| 1 | sigma zz | elout | 1 | binout/elout file |
| 2 | sigma zz | elout | 2 | binout/elout file |
| 3 | sigma zz | elout | 3 | binout/elout file |
| 4 | sigma zz | elout | 4 | binout/elout file |
| 5 | sigma zz | elout | 5 | binout/elout file |
| 6 | sigma zz | elout | 6 | binout/elout file |
| 7 | sigma zz | elout | 7 | binout/elout file |
| 8 | sigma zz | elout | 8 | binout/elout file |
| 9 | sigma zz | elout | 9 | binout/elout file |
| 10 | sigma zz | elout | 10 | binout/elout file |
| 11 | sigma zz | elout | 11 | binout/elout file |
| 12 | sigma zz | elout | 12 | binout/elout file |
| 13 | sigma zz | elout | 13 | binout/elout file |
| 14 | sigma zz | elout | 14 | binout/elout file |
| 15 | sigma zz | elout | 15 | binout/elout file |
| 16 | sigma zz | elout | 16 | binout/elout file |
| 17 | sigma zz | elout | 17 | binout/elout file |
| 18 | sigma zz | elout | 18 | binout/elout file |
| 19 | sigma zz | elout | 19 | binout/elout file |
| 20 | sigma zz | elout | 20 | binout/elout file |
| 21 | sigma zz | elout | 21 | binout/elout file |
| 22 | sigma zz | elout | 22 | binout/elout file |
| 23 | sigma zz | elout | 23 | binout/elout file |
| 24 | sigma zz | elout | 24 | binout/elout file |

Table 7: Test Case targets for Test Case ID AWG-ERIF-9

Test case targets 1 to 24 are used to evaluate the cross cpu architecture consistency.

## 4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the cross cpu architecture consistency of the Test Case ID AWG-ERIF-9.

The sub test case passes if all of the following criteria are reached:

- The test case target data falls within the corridor bounds.
- The sigma zz time history of targets 1, 5 and 21 are equal (excluding failure)
- The sigma zz time history of targets 2, 6 and 22 are equal (excluding failure)
- The sigma zz time history of targets 3, 7 and 23 are equal (excluding failure)
- The sigma zz time history of targets 4, 8 and 24 are equal (excluding failure)
- The sigma zz time history of targets 9 and 13 are equal (excluding failure)
- The sigma zz time history of targets 10 and 14 are equal (excluding failure)
- The sigma zz time history of targets 11 and 15 are equal (excluding failure)
- The sigma zz time history of targets 12 and 16 are equal (excluding failure)
- The sigma zz time history of target 17 lies in between targets 13 and 21 (excluding failure)
- The sigma zz time history of target 18 lies in between targets 14 and 22 (excluding failure)
- The sigma zz time history of target 19 lies in between targets 15 and 23 (excluding failure)
- The sigma zz time history of target 20 lies in between targets 16 and 24 (excluding failure)

Otherwise the the cross cpu architecture consistency fails.

The test case corridors are upper and lower bounds for the test case targets. They were defined based on the test target data obtained with LS-DYNA® R9.0 Revision 108899 binaries by the following process:

- For a specific test case target, interpolate the data from different platform and executable (R9.0 Revision 108899) combinations, so that the time domain is the same.
- Calculate the upper and lower bounds by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$
$$bound_{low}(i) = min(i) - 0.2 \times [max(i) - min(i)] - 0.05 \times peak$$

  where $max(i)$, $min(i)$ are the maximum and minimum values at the $i_{th}$ time step across all platforms and executable (R9.0 Revision 108899) combinations the test case was calculated with, $peak$ is the maximum absolute y value across the whole time domain, $bound_{up}(i)$ and $bound_{low}(i)$ are the upper and lower bounds for the $i_{th}$ time step.

# 5 Test Case Results

## 5.1 Software and Hardware Specifications

In order to ensure cross-platform consistency, the herein mentioned sub test cases are run on platforms specified in table 8 and the results are calculated with software versions defined in table 9.

| Platform Name | Operating system | CPU type | MPI-Protocol | Number of cpu's [1] |
|---|---|---|---|---|
| mars | CentOS 6.5 | Intel® Xeon® E5- 2640 @ 2.50GHz | Platform MPI 8.2.0.0 | 4 |
| dinar3b | SUSE LES 11 | AMD® Opteron ® 6276 @ 2300MHz | Platform MPI 8.2.0.0 | 4 |

[1] Number of cpu's used for calculation of the test case

Table 8: Used Platforms and CPU Type's

| Product | Version | Release | Revision | Parallel type [1] | Precision [2] | executable |
|---|---|---|---|---|---|---|
| LS-DYNA® | 971 | R11.1 | 139325 | SMP | SP | ls971.139325.R11.1 |
| LS-DYNA® | 971 | R11.1 | 139325 | SMP | DP | ld971.139325.R11.1 |
| LS-DYNA® | 971 | R11.1 | 139325 | MPP | SP | mpp971.139325.R11.1 |
| LS-DYNA® | 971 | R11.1 | 139325 | MPP | DP | mpd971.139325.R11.1 |

[1] MPP = Massively Parallel Processing, SMP = Symmetric Multiprocessing

[2] SP = single precision, DP = double precision

Table 9: Tested LS-DYNA® version

## 5.2 Results Summary

Table 10 contains the results of the Test Case ID AWG-ERIF-9 completed with all combinations of software and hardware defined in section 5.1 (1 * 4 * 3 total calculation runs).

Details on the test results can be found in the section 5.3.

The table 10 cross cpu architecture consistency and validation summary is:

- **PASS** - Pass criteria in section 4.2 is attained.
- **FAILED** - Pass criteria in section 4.2 is not attained.
- **ERROR** - sub test case terminates due to error.
- **N/A** - sub test case was not calculated.

| Sub Test Case ID | PASS/FAILED |
|---|---|
| 1 | **PASS** |

Table 10: Validation results summary for Test Case ID AWG-ERIF-9

## 5.3 Result Details

The following subsections contain detailed results for the Test Case ID AWG-ERIF-9 for LS-DYNA® R11.1 Revision 139325.

For each sub test case defined in section 3.3 there is a graph displaying the time history of the result target defined in section 4.1 for the platform and software version combinations defined in section 5.1.

The title of the graph states the test case ID and the name of input deck. The legend contains the result file name, output, platform, executable and number of cpu's separated by comma. A minus sign before the number of cpu's refers to the compatibility option for SMP calculations (see [1] for details on this option).

**Example for title and legend:**

*Title:*

'AWG_ERIF_TEST_CASE_9: MAT_224_single_element.k' states the test case ID 9 and name of the input deck for sub test case 1.

*Legend:*

'glstat_internal_energy,ham,ls971.139325.R11.1,4' states that the graph shows the internal energy derived from the 'glstat' output file for an input deck which was calculated on the 'ham' platform with a LS-DYNA® R11.1 Revision 139325 binary (SMP, single precision) on four processors.

### 5.3.1 Sub Test Case ID 1 - Test Target 1

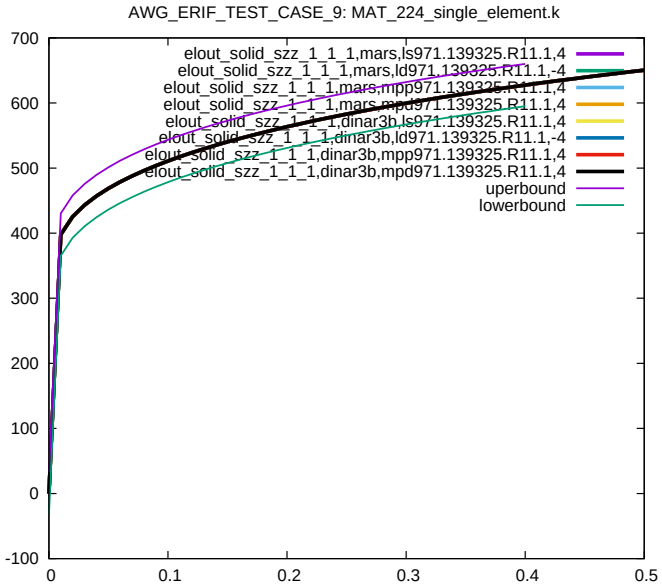


Figure 3: Cross platform results, zz stress element id 1, sub test case ID 1

### 5.3.2 Sub Test Case ID 1 - Test Target 2

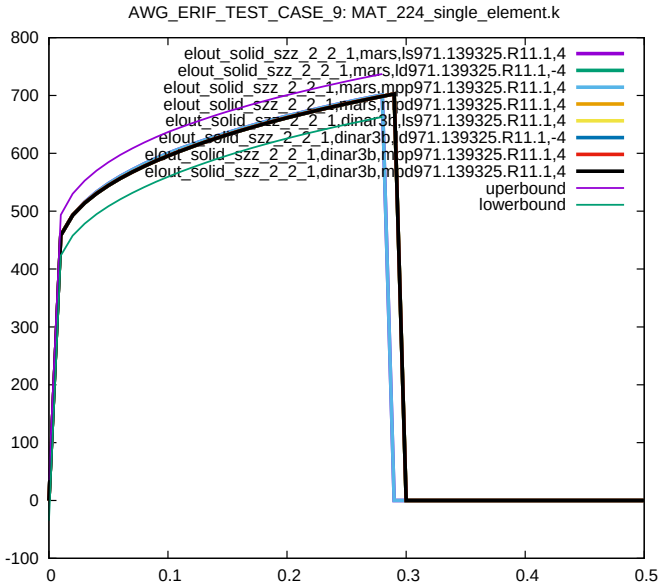


Figure 4: Cross platform results, zz stress element id 2, sub test case ID 1

### 5.3.3 Sub Test Case ID 1 - Test Target 3

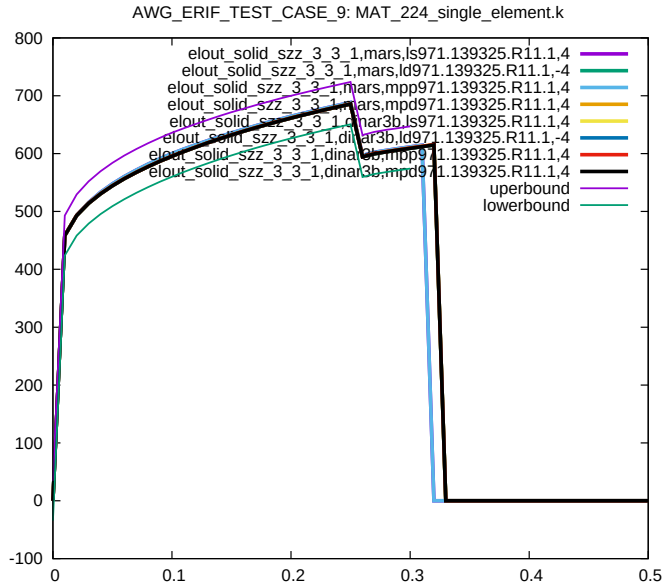


Figure 5: Cross platform results, zz stress element id 3, sub test case ID 1

### 5.3.4 Sub Test Case ID 1 - Test Target 4

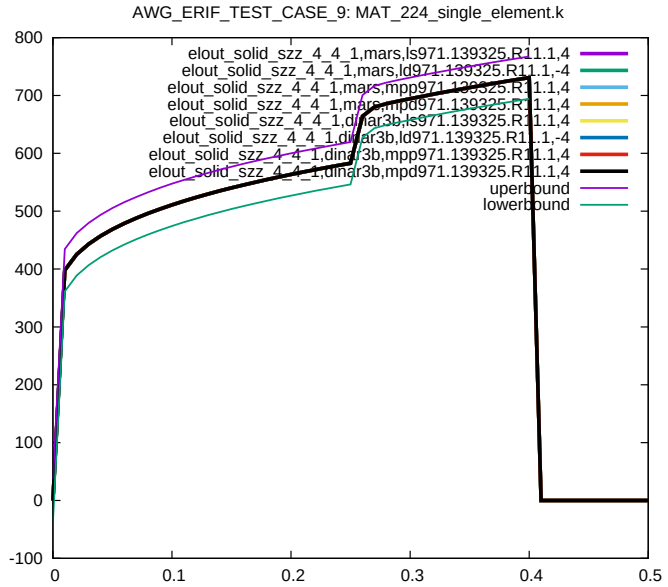


Figure 6: Cross platform results, zz stress element id 4, sub test case ID 1

### 5.3.5 Sub Test Case ID 1 - Test Target 5

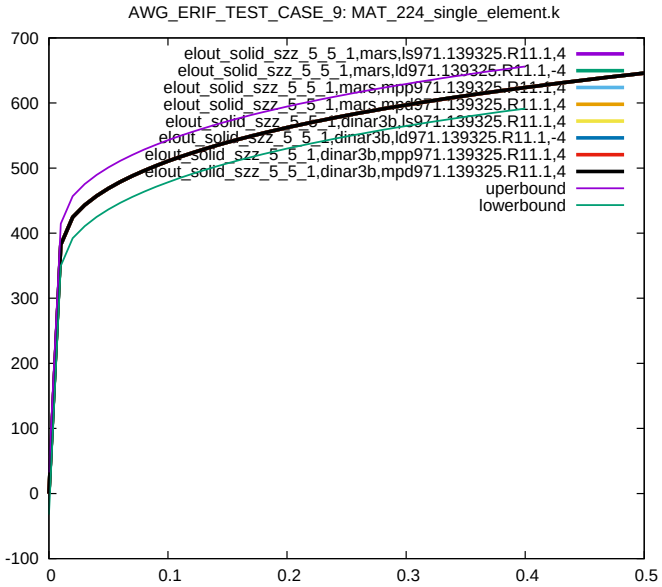


Figure 7: Cross platform results, zz stress element id 5, sub test case ID 1

### 5.3.6 Sub Test Case ID 1 - Test Target 6

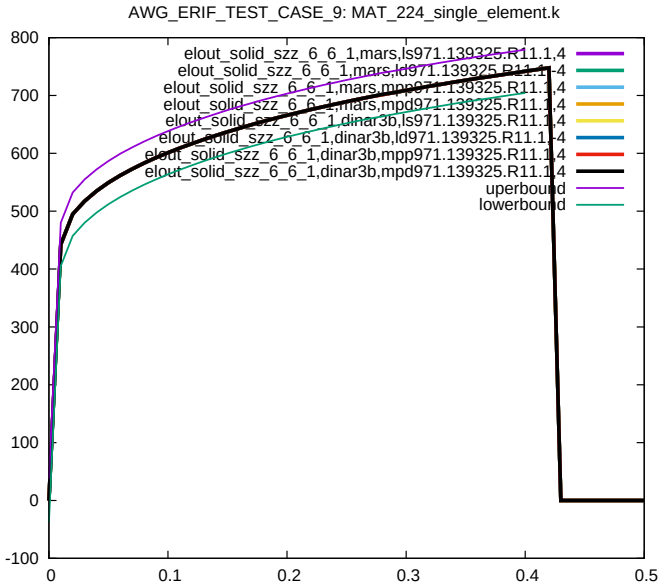


Figure 8: Cross platform results, zz stress element id 6, sub test case ID 1

### 5.3.7 Sub Test Case ID 1 - Test Target 7

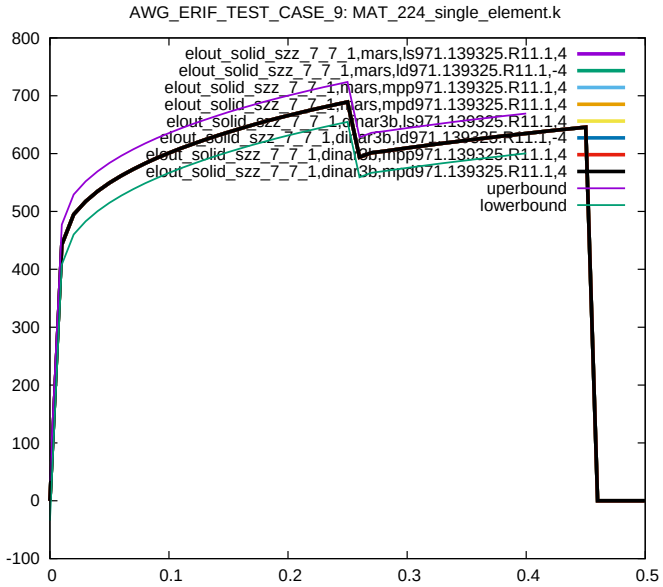


Figure 9: Cross platform results, zz stress element id 7, sub test case ID 1

### 5.3.8 Sub Test Case ID 1 - Test Target 8

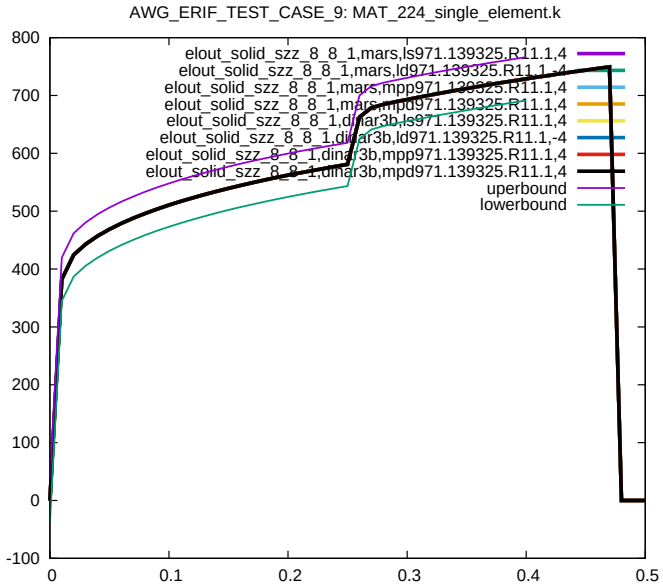


Figure 10: Cross platform results, zz stress element id 8, sub test case ID 1

### 5.3.9 Sub Test Case ID 1 - Test Target 9

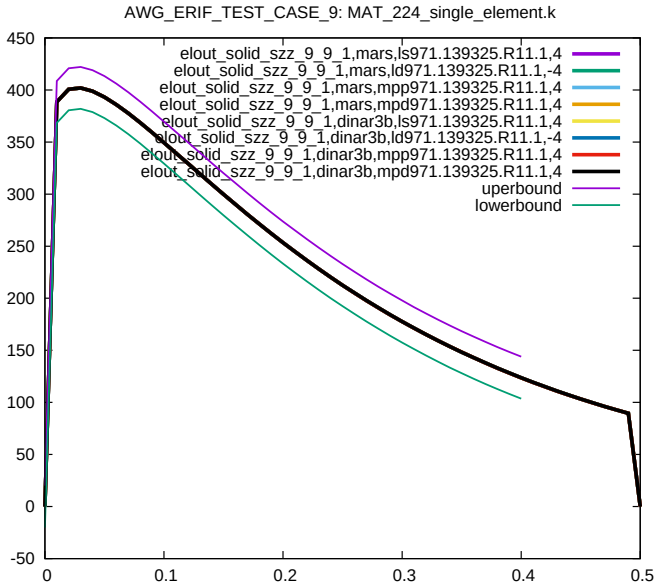


Figure 11: Cross platform results, zz stress element id 9, sub test case ID 1

### 5.3.10 Sub Test Case ID 1 - Test Target 10

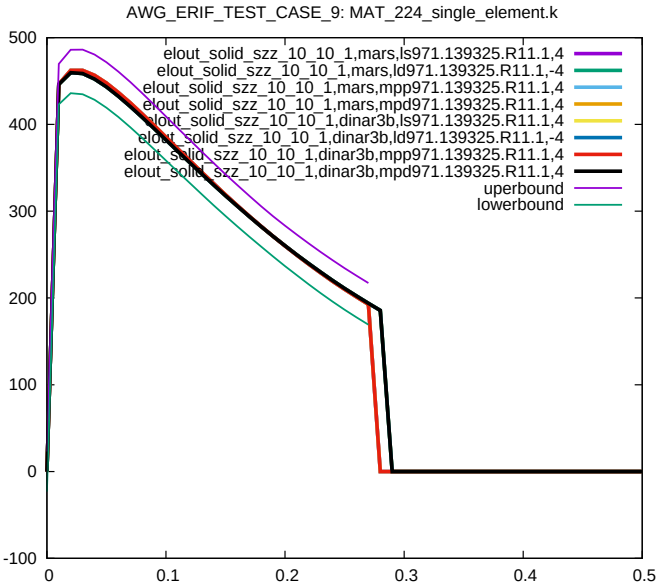


Figure 12: Cross platform results, zz stress element id 10, sub test case ID 1

### 5.3.11 Sub Test Case ID 1 - Test Target 11

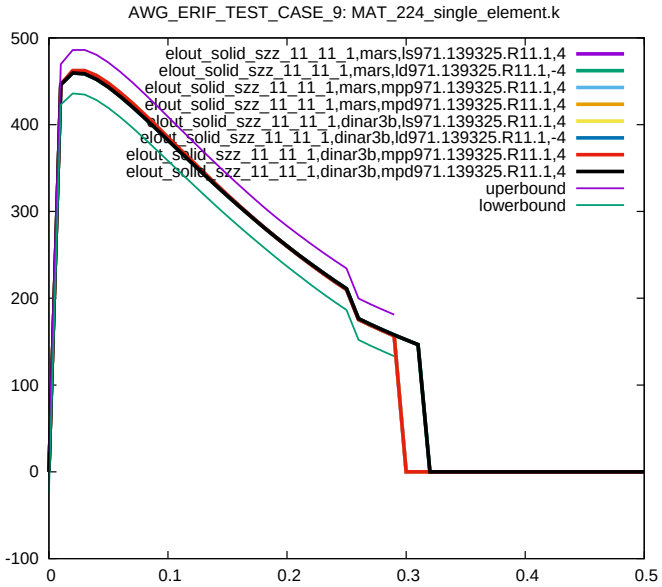


Figure 13: Cross platform results, zz stress element id 11, sub test case ID 1

### 5.3.12 Sub Test Case ID 1 - Test Target 12

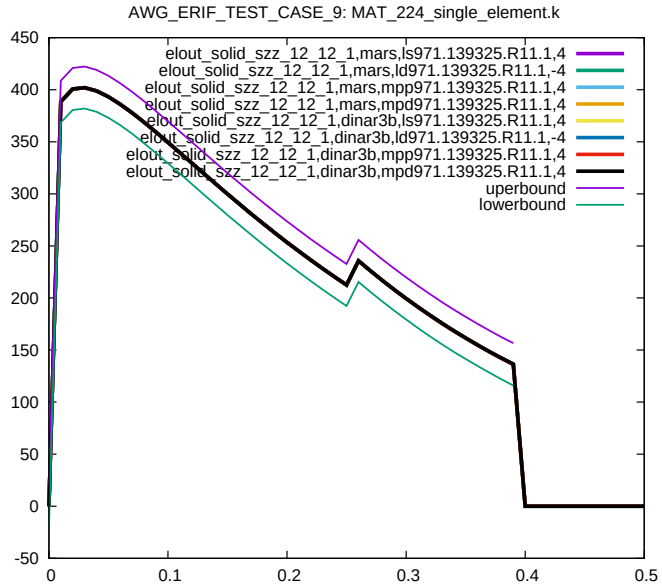


Figure 14: Cross platform results, zz stress element id 12, sub test case ID 1

### 5.3.13 Sub Test Case ID 1 - Test Target 13

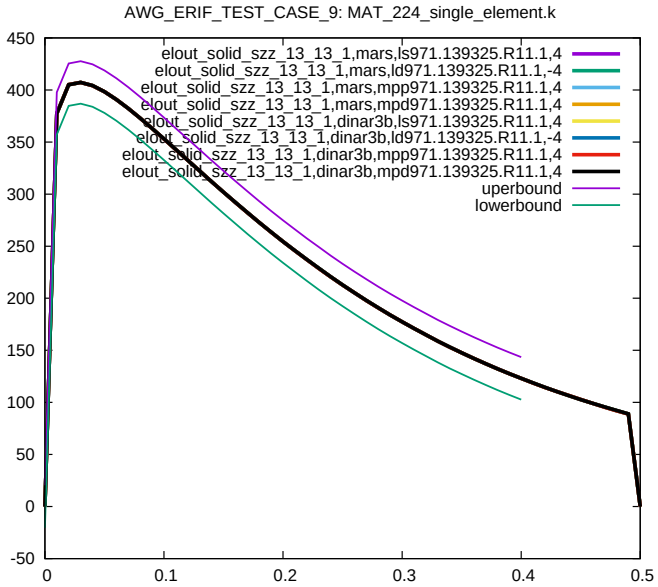


Figure 15: Cross platform results, zz stress element id 13, sub test case ID 1

### 5.3.14 Sub Test Case ID 1 - Test Target 14

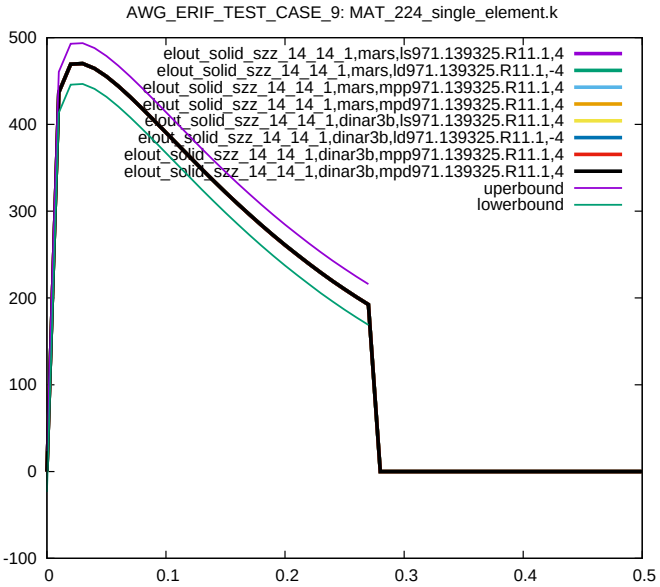


Figure 16: Cross platform results, zz stress element id 14, sub test case ID 1

### 5.3.15 Sub Test Case ID 1 - Test Target 15

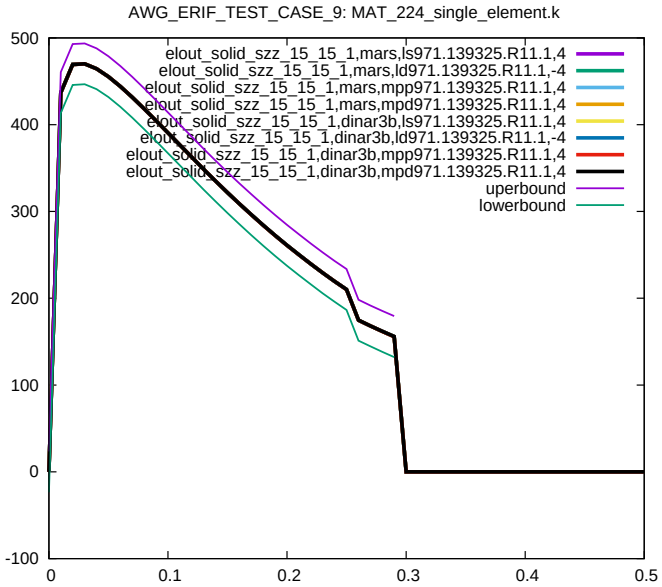


Figure 17: Cross platform results, zz stress element id 15, sub test case ID 1

### 5.3.16 Sub Test Case ID 1 - Test Target 16

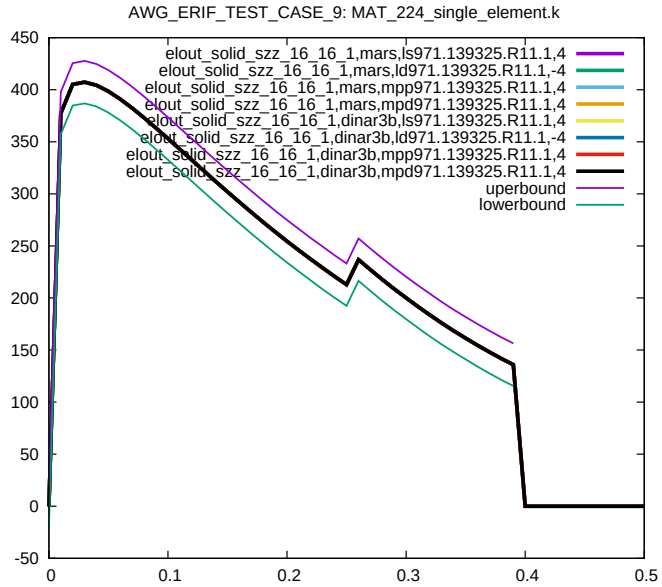


Figure 18: Cross platform results, zz stress element id 16, sub test case ID 1

### 5.3.17 Sub Test Case ID 1 - Test Target 17

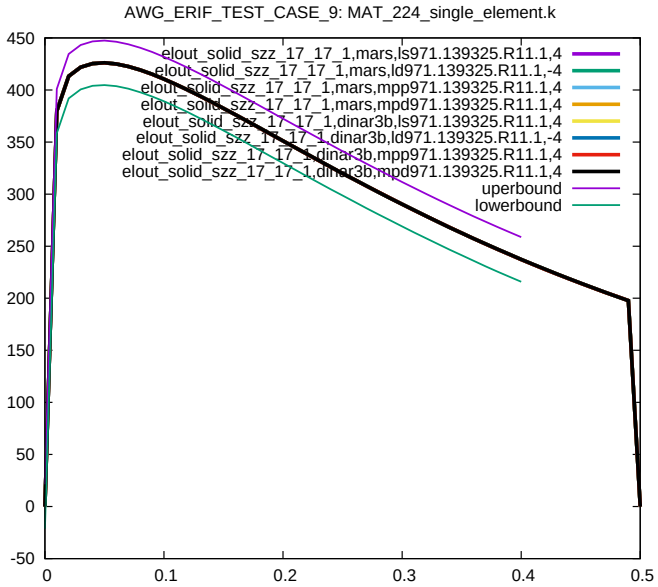


Figure 19: Cross platform results, zz stress element id 17, sub test case ID 1

### 5.3.18 Sub Test Case ID 1 - Test Target 18

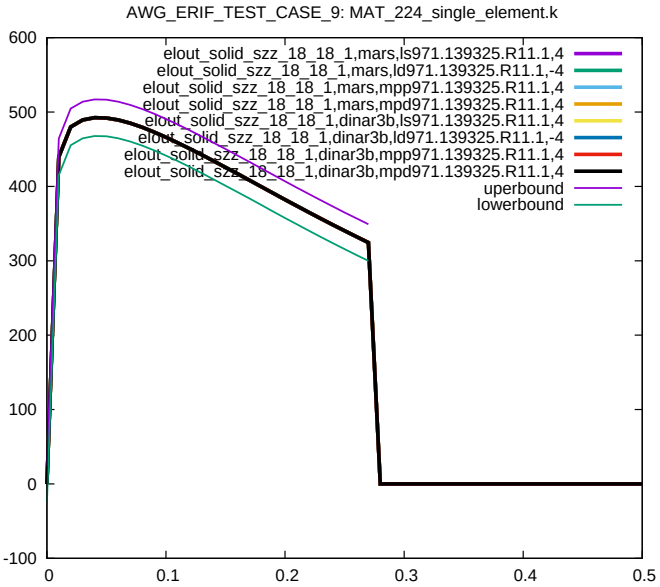


Figure 20: Cross platform results, zz stress element id 18, sub test case ID 1

### 5.3.19 Sub Test Case ID 1 - Test Target 19

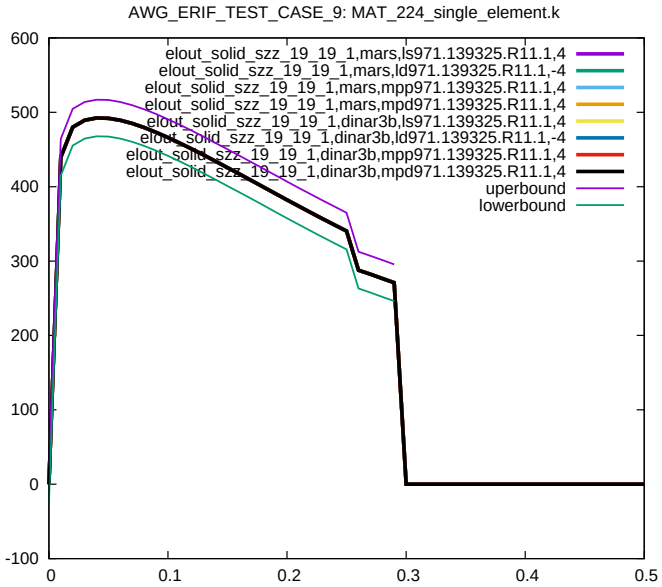


Figure 21: Cross platform results, zz stress element id 19, sub test case ID 1

### 5.3.20 Sub Test Case ID 1 - Test Target 20

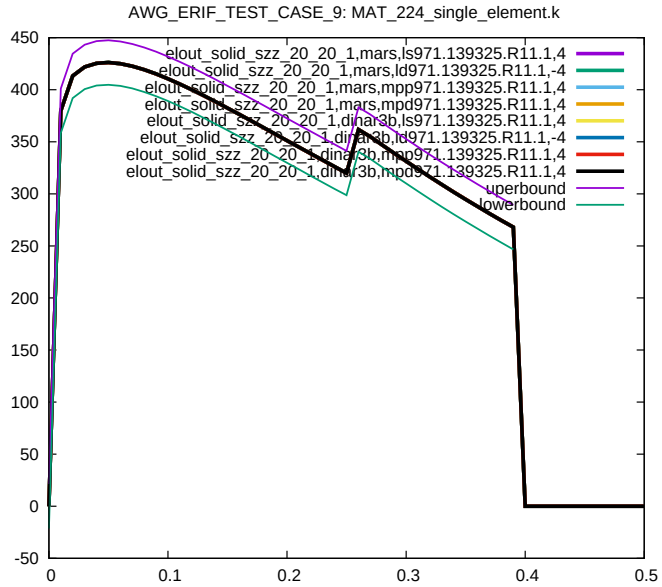


Figure 22: Cross platform results, zz stress element id 20, sub test case ID 1

### 5.3.21 Sub Test Case ID 1 - Test Target 21

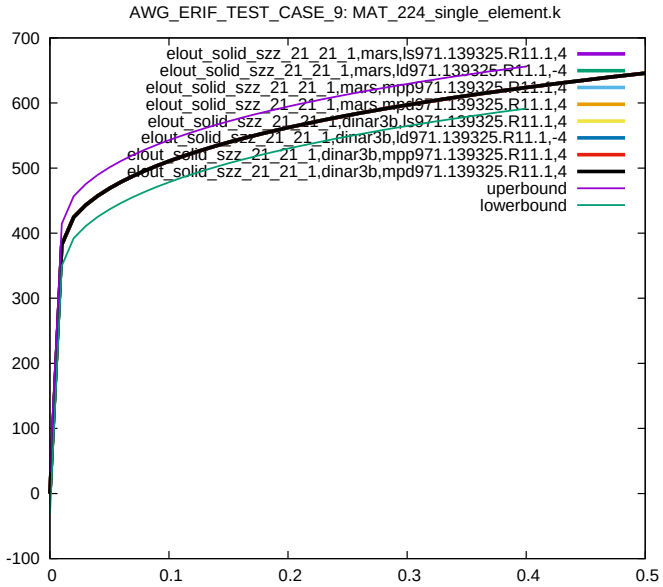


Figure 23: Cross platform results, zz stress element id 21, sub test case ID 1

### 5.3.22 Sub Test Case ID 1 - Test Target 22

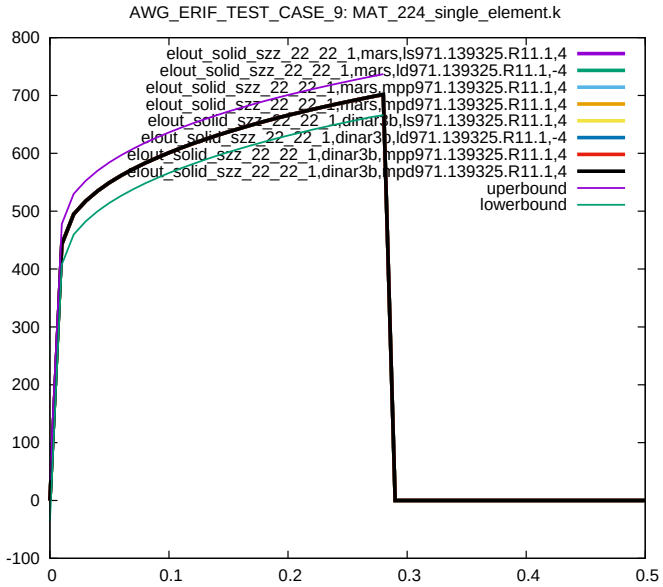


Figure 24: Cross platform results, zz stress element id 22, sub test case ID 1

### 5.3.23 Sub Test Case ID 1 - Test Target 23

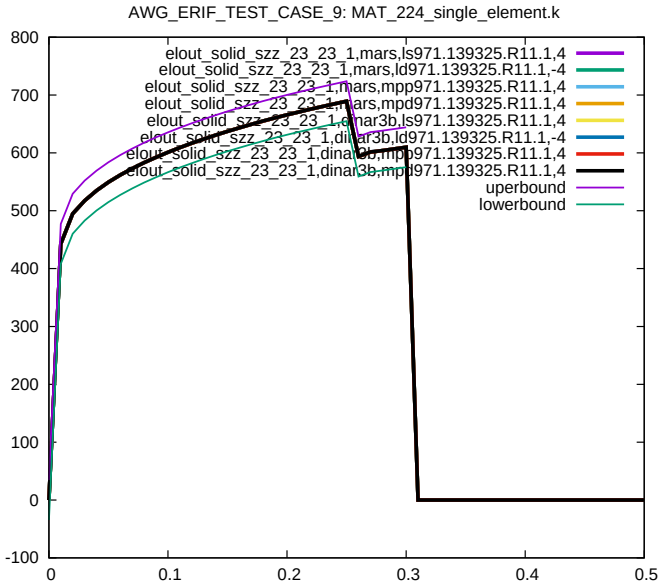


Figure 25: Cross platform results, zz stress element id 23, sub test case ID 1

### 5.3.24 Sub Test Case ID 1 - Test Target 24

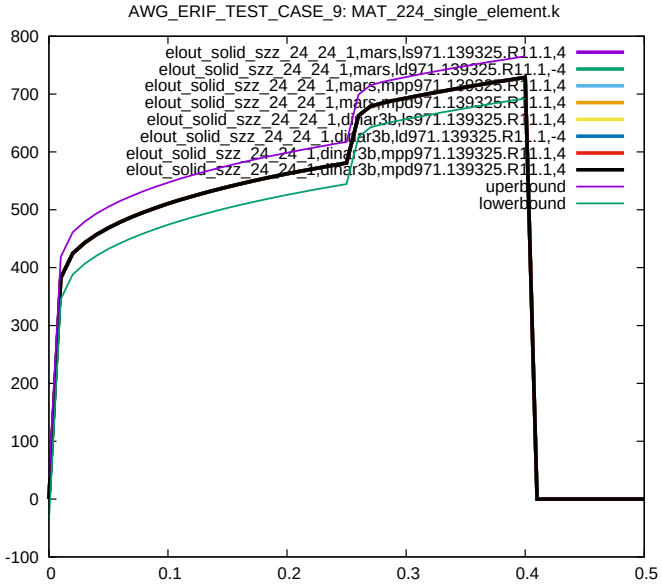


Figure 26: Cross platform results, zz stress element id 24, sub test case ID 1

## References

[1] LSTC, *LS-DYNA KEYWORD USER MANUAL*, 7374 Las Positas Road, Livermore, CA, 94551, USA, version 971 ed., May 2007.