CDPM2 UMAT Verification Guide

2026-11-09 | Research preview

Verification with plots, conditions and numerical criteria

Part A contains OOFEM/UMAT comparisons; Part B contains regression and additional tests for the distributed source. Source identities are distinguished: Part A curves are not reruns of Part B. Editorial and implementation history is maintained in the separate change-history PDF.

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Part A retains campaign provenance and OOFEM classifications for 312 conditions. Part B reports current-source results and unmet criteria. Solver completion and numerical acceptance remain distinct.

CDPM2 UMAT

Verification Guide / Constitutive response

Lattice Co., Ltd. | 2026-10-15

1 Purpose and results

The constitutive response of the CDPM2 UMAT for Abaqus/Standard is compared with the native C++ implementation in OOFEM and analytical linear elasticity. Material constants, characteristic length and strain histories are matched. Stress tensors and tensile/compressive damage are assessed over the complete histories.

Item	Measured result
Distinct material/path combinations	312
Comparisons including refinements	342
Conditions passing their latest test	307
Conditions failing their latest test	5
Not evaluated / incomplete conditions	0
Loading paths x material sets	24 x 13

This guide reports verification of the constitutive-response tests defined here. It does not establish experimental validation of structures, contact-analysis convergence or suitability for arbitrary applications.

The five conditions exceeding the comparison criteria originate from different shear weights in the plastic-strain-increment norm used for damage history by the public UMAT and the referenced OOFEM version. All five satisfy the original criteria in a diagnostic copy that aligns only this definition and its derivative. The public UMAT and the original assessments are retained unchanged. Section 8 presents the isolation tests.

All UMAT cases use viscosity $\mu = 1.0 \times 10^{-3}$. OOFEM is rate-independent. The loading period is 1000 with 240 equal increments in the main suite. Conditions not satisfying the criteria are additionally tested with 960 or 3840 increments; original results are retained.

GitHub: https://github.com/lattice-naraoka/cdpm2-umat

2 Model and comparison conditions

Each specimen is one cubic hexahedron, with a side length of 1 mm (2 mm for length_2): C3D8 in Abaqus and LSpace in OOFEM. All eight integration points are assessed. Abaqus batches contain disconnected specimens without shared nodes, contact or coupling equations.

All nodal displacements are prescribed to produce homogeneous deformation. Lateral strains are also prescribed: axial-loading cases are not uniaxial-stress tests with traction-free lateral faces. Global Newton convergence of the material tangent is not assessed by these tests.

Abaqus uses Static General with NLGEOM=YES. For constant principal axes Q and prescribed principal strains e_i, Abaqus receives $F = Q\,\mathrm{diag}(\exp(e_i))\,Q^T$, while OOFEM receives $\varepsilon = Q\,\mathrm{diag}(e_i)\,Q^T$. Abaqus logarithmic strains therefore match OOFEM small strains at comparison times.

Component ordering and engineering-shear conventions are reconciled before comparison. Nonproportional paths with fixed principal axes are included; continuously rotating principal directions and finite-rotation objectivity tests are not included.

Baseline material	Value
E / ν	30000 MPa / 0.2
f_c / f_t	40 MPa / 3 MPa
e_cc / q_h0 / H_p	0.525 / 0.3 / 0.01
D_f / A_s / B_s	0.85 / 15 / 1
A_h / B_h / C_h / D_h	0.08 / 0.003 / 2 / 1e-6
h / f_t1 / w_f1 / w_f	1 mm / 0.9 MPa / 0.02 mm / 0.15 mm
ε_fc / μ	1e-4 / 1e-3

3 Materials and loading paths

Material set	Change from baseline
baseline	None
E_low	E = 20000 MPa
E_high	E = 40000 MPa
nu_low	ν = 0.1
fc_high	f_c = 60 MPa
ft_high	f_t = 4.5 MPa; f_t1 = 1.35 MPa
Hp_05	H_p = 0.5
As_5	A_s = 5
As_30	A_s = 30
Df_075	D_f = 0.75
Gf_half	w_f1 = 0.01 mm; w_f = 0.075 mm
Efc_double	ε_fc = 2e-4
length_2	Cube side length L = 2 mm

The UMAT characteristic length h is the initial geometric span projected along the maximum-principal-strain direction. For the cubic specimens it is the side length L for axial directions and sqrt(2) L for the 45-degree shear tests. These geometric reference values are supplied to OOFEM. The length_2 set doubles the physical cube dimensions; it is not a multi-element mesh-refinement test.

Numerical definitions are provided in manifest.json and the generator. The seed for seeded_diagonal is 1242026. Material values define comparison tests and are not a calibration to a specific experiment.

4 Loading-path catalogue

ID	Description
elastic_x	Elastic axial strain
elastic_hydro	Elastic hydrostatic strain
elastic_dev	Elastic deviatoric strain
elastic_xy	Elastic shear
tension_constrained	Laterally constrained tension
compression_constrained	Laterally constrained compression
pure_shear_xy	Pure shear
reversal_x	Tension/compression reversal
tension_lateral_contraction	Tension with lateral contraction
compression_lateral_expansion	Compression with lateral expansion
biaxial_tension	Biaxial tension
biaxial_compression	Biaxial compression
triaxial_compression	Triaxial compression
hydro_tension	Hydrostatic tension
hydro_compression	Hydrostatic compression
mixed_sign	Mixed tension/compression
tension_cycles	Increasing tensile cycles
compression_cycles	Increasing compressive cycles
shear_reversal	Reversed shear
tension_hold	Tensile hold and unloading
compression_hold	Compressive hold and unloading
nonproportional_diagonal	Nonproportional fixed-axis path
alternating_12cycles	Twelve alternating cycles
seeded_diagonal	Seeded multiaxial history

5 Metrics and acceptance criteria

The stress scale S_0 is the larger of tensile strength and the largest absolute OOFEM stress component over all times and integration points in that case. The maximum error is $\max|\sigma_{UMAT} - \sigma_{OOFEM}| / S_0$; RMS error uses the same scale.

Check	Limit
Elastic maximum stress error	1e-4
Nonlinear maximum stress error	0.01 (1%)
Stress RMS error	0.002 (0.2%)
Maximum absolute damage difference	0.01
Maximum prescribed/LE strain difference	1e-9
Maximum within-element stress spread	1e-7 MPa

Elastic cases are also checked against analytical isotropic elasticity. For nonlinear damage, the relaxed UMAT variables used in stress evaluation (SDV59 and SDV60) are compared with OOFEM damage. PASS requires successful completion, every specified comparison time and all applicable criteria.

FAIL denotes a completed comparison exceeding a criterion. INCOMPLETE denotes an unfinished history; NOT_EVALUATED denotes missing comparison data. Solver completion alone is not verification success.

The finite precision of OOFEM stress text output contributes to the measured differences. Criteria were specified before the full campaign and were not relaxed to fit the results.

Increment-refinement results

Test	N	PASS	FAIL	Other
refine_Hp_960	960	22	2	0
refine_Ehigh_960	960	1	0	0
refine_shear_960	960	0	3	0
refine_Hp_3840	3840	0	2	0

Assessment summary

This table counts individual executions, including refinements. The opening summary gives the latest assessment per condition; original failures and incomplete runs remain in this table.

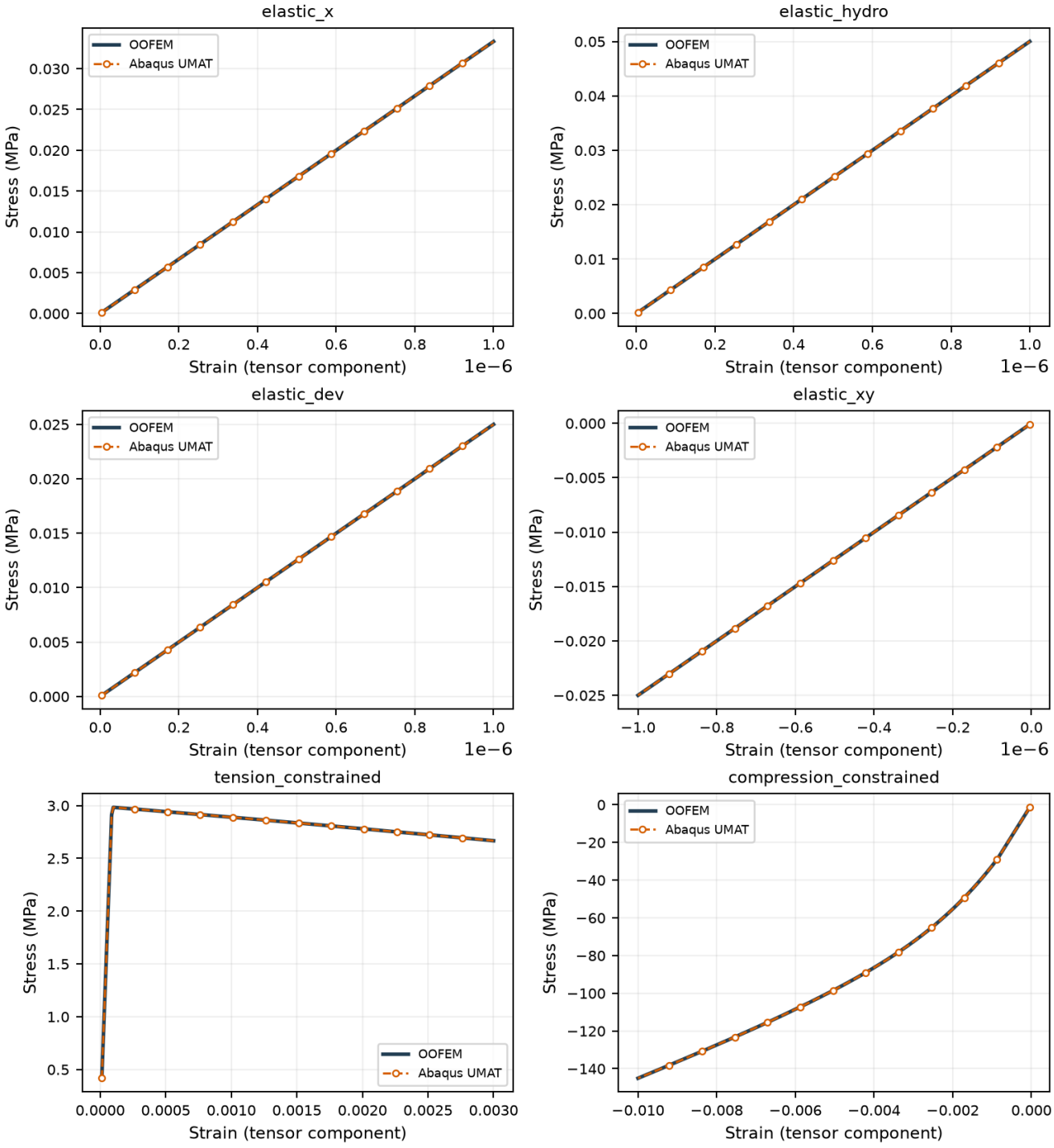
Material set	PASS	FAIL	Other
baseline	24	0	0
E_low	24	0	0
E_high	24	1	0
nu_low	24	0	0
fc_high	24	0	0
ft_high	24	0	0
Hp_05	22	4	24
As_5	23	2	0
As_30	24	0	0
Df_075	24	0	0
Gf_half	23	2	0
Efc_double	24	0	0
length_2	23	2	0

Cases not satisfying the criteria

Material / case	Status and observation
E_high / compression_cycles (N=240)	FAIL; max stress 1.462e-05; damage 0.001238; GP spread 0.003614 MPa
As_5 / shear_reversal (N=240)	FAIL; max stress 0.0001346; damage 0.02013; GP spread 1.847e-13 MPa
Gf_half / shear_reversal (N=240)	FAIL; max stress 9.489e-05; damage 0.01288; GP spread 1.847e-13 MPa
length_2 / shear_reversal (N=240)	FAIL; max stress 9.489e-05; damage 0.01288; GP spread 1.563e-13 MPa
Hp_05 / pure_shear_xy (N=960)	FAIL; max stress 0.02972; damage 0.003833; GP spread 1.306e-13 MPa
Hp_05 / shear_reversal (N=960)	FAIL; max stress 0.05673; damage 0.004478; GP spread 1.665e-13 MPa
As_5 / shear_reversal (N=960)	FAIL; max stress 0.0001353; damage 0.02004; GP spread 2.345e-13 MPa
Gf_half / shear_reversal (N=960)	FAIL; max stress 9.755e-05; damage 0.01285; GP spread 2.345e-13 MPa
length_2 / shear_reversal (N=960)	FAIL; max stress 9.755e-05; damage 0.01285; GP spread 1.918e-13 MPa
Hp_05 / pure_shear_xy (N=3840)	FAIL; max stress 0.02922; damage 0.003778; GP spread 1.79e-13 MPa
Hp_05 / shear_reversal (N=3840)	FAIL; max stress 0.05439; damage 0.004319; GP spread 1.867e-13 MPa
Hp_05 / 24 cases	The batch terminated before the full history. Specimens are mechanically independent, but a termination interrupts all remaining histories in that batch.

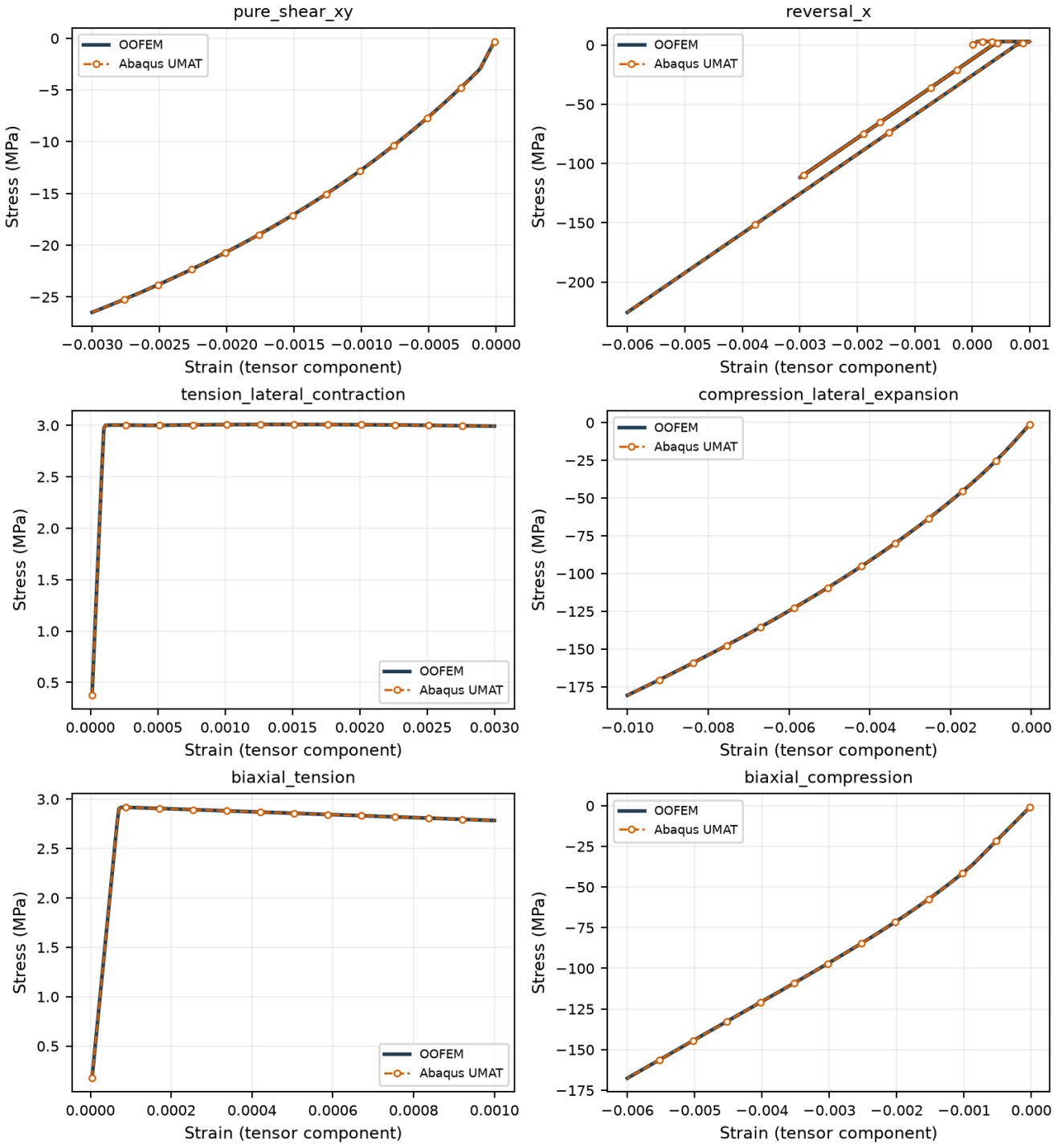
6 Stress-history comparisons

Baseline material. Solid: OOFEM; dashed: Abaqus UMAT. Figures show representative components; numerical checks include every component and integration point.



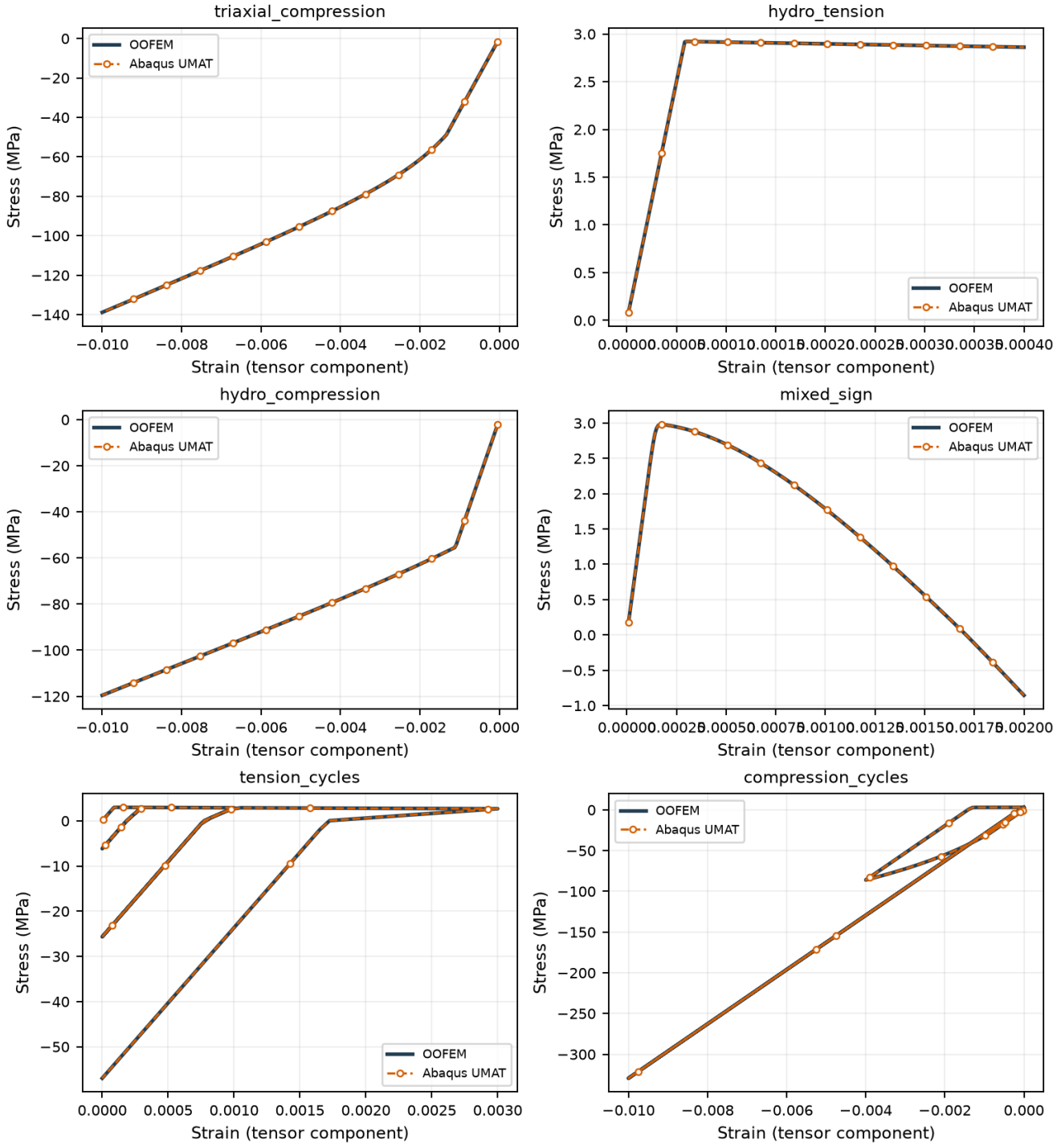
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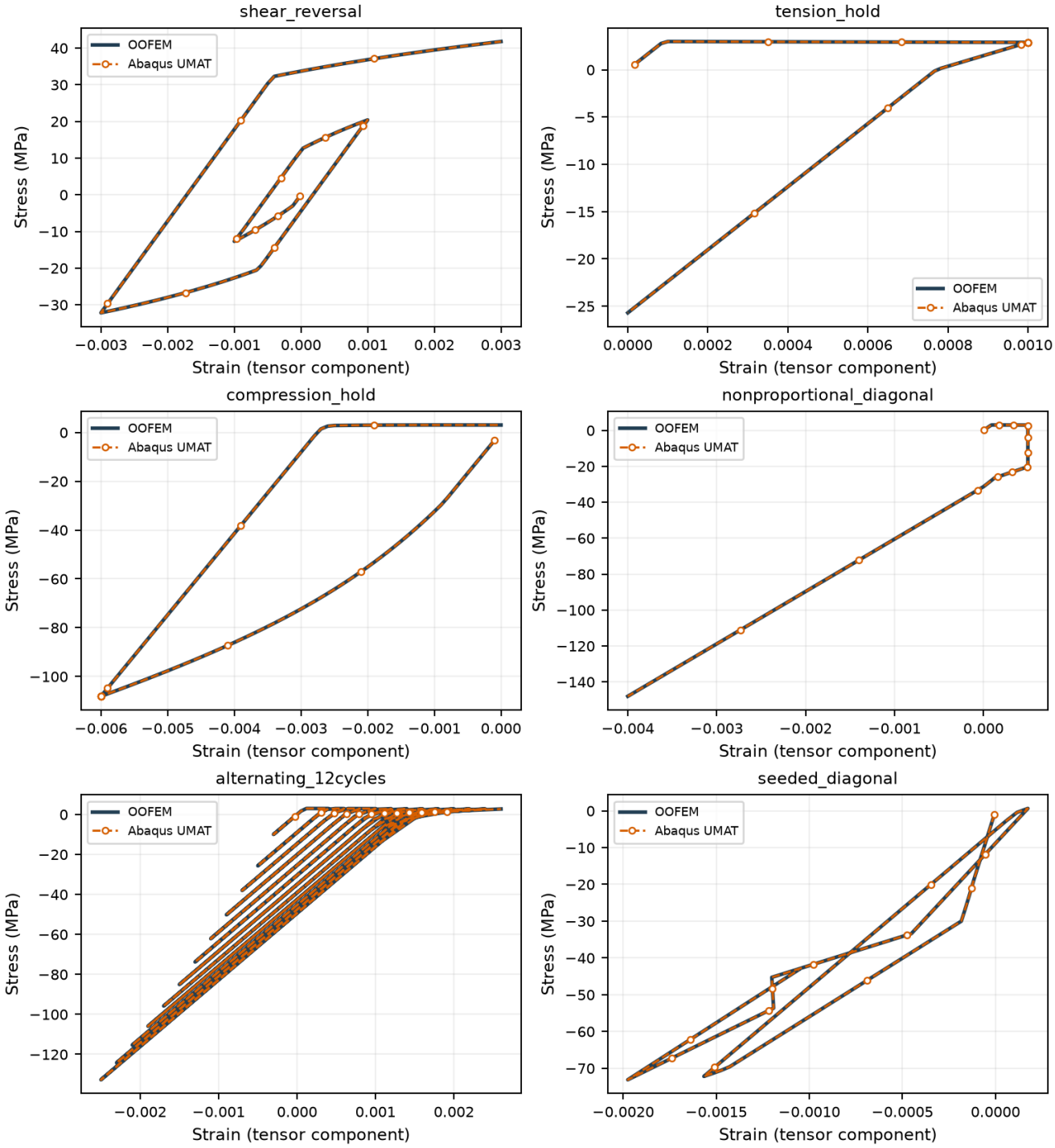
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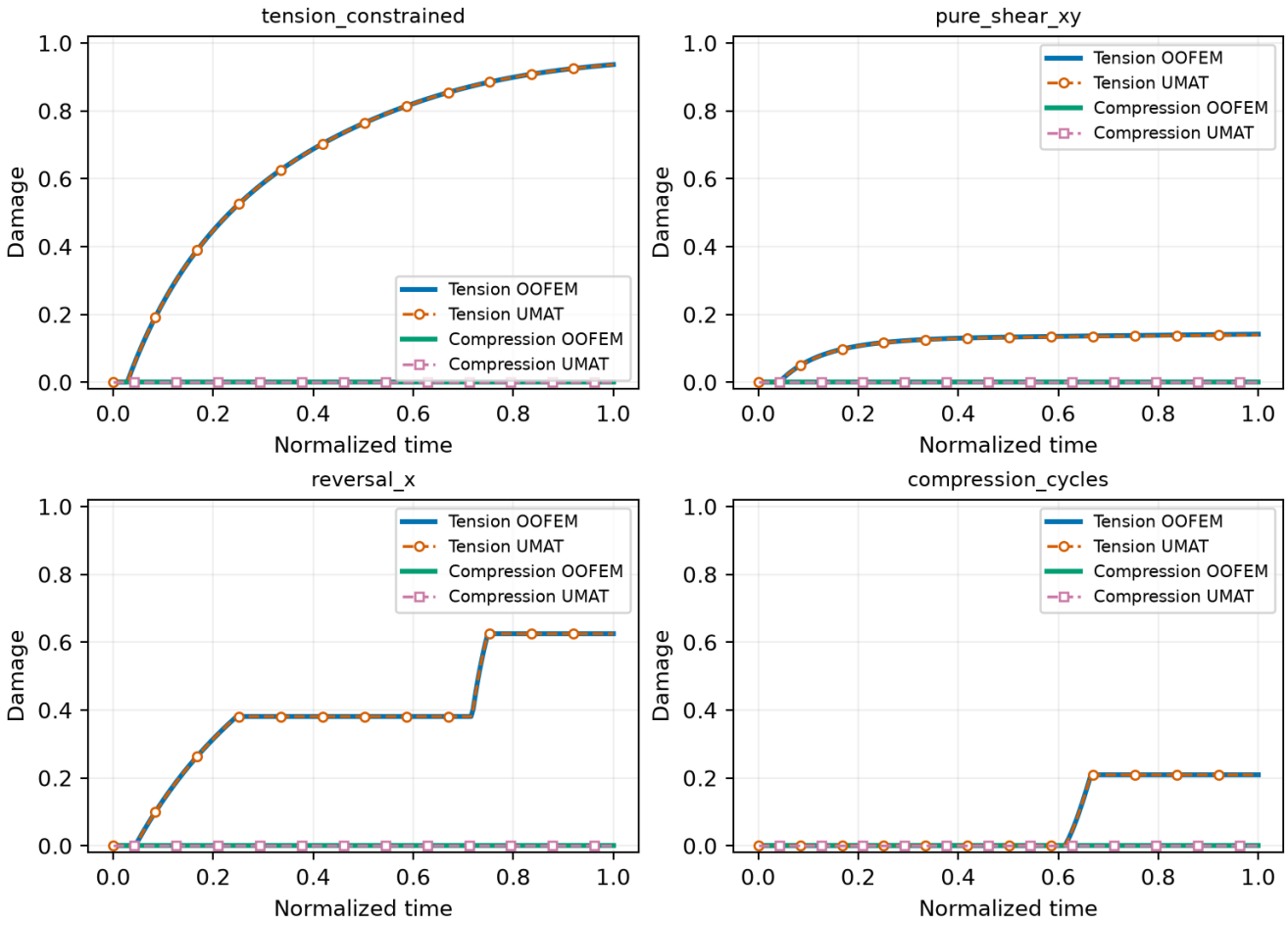


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Baseline material. Solid: OOFEM; dashed: Abaqus UMAT. Figures show representative components; numerical checks include every component and integration point.



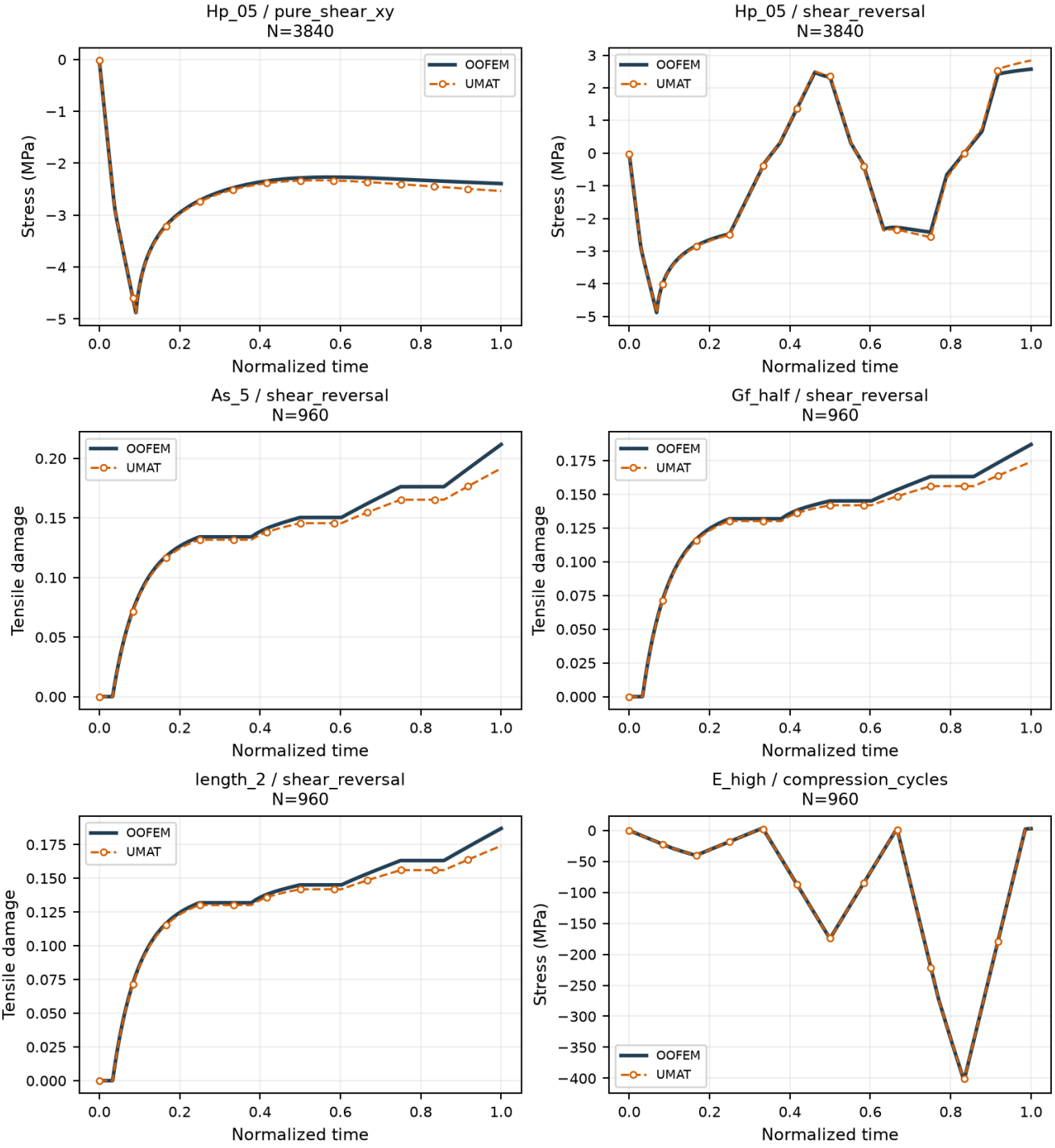
7 Damage-history comparisons



Across all comparisons, maximum normalized stress difference: 0.0567288; maximum absolute damage difference: 0.0201305. Per-case results are provided in results.csv.

Responses in follow-up tests

Follow-up responses for conditions not meeting the criteria. N denotes the increment count. Numerical assessment includes all components, damage variables and within-element homogeneity even where curves appear coincident.



8 Shear-response differences and norm definitions

The plastic-increment magnitude entering damage history was compared. With engineering shear $\gamma^p_{ij} = 2\varepsilon^p_{ij}$, the public UMAT uses the tensor Frobenius norm. The corresponding routines in the referenced OOFEM version apply a Euclidean norm directly to the six-component vector containing engineering shear.

$$n_{tensor}^2 = \Sigma_i(\Delta\varepsilon^p_{ii})^2 + [(\Delta\gamma^p_{12})^2 + (\Delta\gamma^p_{13})^2 + (\Delta\gamma^p_{23})^2]/2$$

$$n_{vector}^2 = \Sigma_i(\Delta\varepsilon^p_{ii})^2 + [(\Delta\gamma^p_{12})^2 + (\Delta\gamma^p_{13})^2 + (\Delta\gamma^p_{23})^2]$$

The difference concerns the plastic contribution accumulated in damage history, rather than a change in yield function or material constants. A diagnostic copy aligns only the shear weight in this norm and its derivative with the reference OOFEM implementation. Material inputs, geometry, characteristic length, loading history, increment count, viscosity 1e-3 and acceptance criteria remain unchanged.

Condition	Max stress error (%) Public / diagnostic	Damage difference Public / diagnostic
Hp_05 / pure_shear_xy N = 3840	2.922 / 0.003412	0.0037785 / 3.3577e-05
Hp_05 / shear_reversal N = 3840	5.4393 / 0.0040372	0.0043187 / 4.5288e-05
As_5 / shear_reversal N = 960	0.013527 / 0.0023184	0.020042 / 2.4108e-06
Gf_half / shear_reversal N = 960	0.0097554 / 0.0023184	0.012847 / 2.7889e-06
length_2 / shear_reversal N = 960	0.0097554 / 0.0023184	0.012847 / 2.7889e-06

All five diagnostic comparisons satisfy the original criteria. These five isolation tests are reported separately and are not included in the 342 comparisons of the public UMAT. The five original FAIL assessments have not been replaced with PASS.

Plastic hardening κ_p is nearly identical, and the change due to viscous relaxation is smaller than the observed discrepancies. These results identify the damage-history norm definition as their principal cause.

8.1 Independent coordinate-representation check

An isotropic material response should not change solely because the same physical state is expressed in a different coordinate system. Pure shear ε^{p}_{12} = a becomes (a, -a, 0) in principal axes after a 45-degree rotation. The tensor norm squared is $2a^2$ in both representations. The unweighted six-component norm squared is $4a^2$ in engineering-shear representation but $2a^2$ in principal axes.

The original OOFEM received identical principal-strain histories in principal axes and in a 45-degree-rotated representation. Stresses were transformed to common axes before comparison. Both use H_p = 0.5, 960 increments, characteristic length sqrt(2) mm and loading period 1000. The explicitly matched characteristic length excludes geometric-length differences.

Comparison	Maximum normalized stress difference
Original OOFEM: principal-axis versus 45-degree representation	0.04141668 (4.1417%)
Public UMAT in rotated axes versus original OOFEM in principal axes	3.449417e-05 (0.0034494%)

This test exposes coordinate-representation dependence in the corresponding routine of the referenced OOFEM version. The unchanged public UMAT agrees closely with original OOFEM when the latter uses principal axes without engineering shear. This finding applies to the fixed version and tested path; it is not a general assessment of all OOFEM versions or capabilities.

Reference identity was also checked. The material source in the fixed archive matches the source used in the execution environment. Recompiling that material source with the same settings and relinking produces an executable whose SHA-256 is identical to the reference binary used here.

The public UMAT retains its tensor norm. Differences against original OOFEM are identified as definition differences, and diagnostic-copy results are reported separately. These tests alone do not establish objectivity under arbitrary rotations and histories or implementation equivalence over all conditions.

9 Reproduction and scope

Generate inputs: python generate.py
OOFEM: oofem -f reference.in in each case directory
Abaqus: run test.inp in each material directory using src/cdpm2.f90
Extract: abaqus python extract.py <material directory>
Compare: python analyze.py <suite directory>

UMAT source SHA-256
78cc9a681a3526cd1d04e7232ada14ecb18cb116ecd4426b186029ef5536b2de

OOFEM 2.6 reference executable SHA-256
2cc3f8abb5670bf65addf4ad301601ada8f57ed63a1721a88d7a5319d4e38780

OOFEM concretedpm2.C SHA-256
fd3beb8fa510b41b191deb1f16e51ccea3b48009daec01716b1461746f511d13

The reference source is pinned to commit 1c1dbd2b4b8c95dcc26878bf5009d44ed535e1a6. The hash above identifies the CRLF execution-source file. After line-ending normalization its code matches the official GitHub LF source at that commit. The LF-source hash is recorded in provenance.json.

The assessment covers homogeneous fixed-axis strain paths, geometric characteristic lengths of cubes, the listed materials and the specified time scale. Finite rotations, traction-free uniaxial stress, global tangent/convergence, time-step convergence, characteristic lengths of arbitrary shapes, multi-element mesh objectivity and experimental validation are outside these acceptance claims.

References

Grassl et al. (2013), CDPM2: A damage-plasticity approach to modelling the failure of concrete. International Journal of Solids and Structures 50, 3805-3816.

OOFEM, ConcreteDPM2 implementation. https://github.com/oofem/oofem

Abaqus 2026 Verification Guide: User Subroutines / UMAT and UHYPER. SIMACAEVERRefMap/simaver-c-umatuhyper.htm.

Abaqus 2026 Output: Abaqus/Standard Output Variable Identifiers. SIMACAEOUTRefMap/simaout-c-stdoutputvar.htm.

Abaqus 2026 User Subroutines: UMAT / Storage of Stress and Strain Components. SIMACAESUBRefMap/simasub-c-umat.htm.

NAFEMS (2024), Guidelines for Validation of Engineering Simulations, R0134. Public overview and contents. https://www.nafems.org/publications/resource_center/r0134/

1. Regression across 312 conditions

Reference and distributed sources were run with identical environment, materials, viscosity and increment grids. Reference-source SHA-256:

78cc9a681a3526cd1d04e7232ada14ecb18cb116ecd4426b186029ef5536b2de

284 conditions use 240 increments, 26 use 960 and two use 3840. All 36 analyses (18 batches per source) completed with zero MSG errors. Time grids and outputs were compared at all saved times and all eight integration points for 312 conditions.

Quantity	Maximum absolute difference
S	3.81149e-9 MPa
LE	2.97912e-57
SDV14	8.49859e-8
SDV37 / SDV38	1.92469e-10 / 7.59535e-11
SDV39	0
SDV59 / SDV60	1.92423e-10 / 7.58806e-11

Maximum stress difference scaled by max(1 MPa, reference-history maximum) is 3.37009e-11. No appreciable response difference is observed in this scope. No post-hoc acceptance threshold is assigned; comparison status is COMPARED.

This is a UMAT-to-UMAT regression, not an independent OOFEM comparison or proof of global Newton robustness on general structures.

Evidence: evidence/regression312_summary.json; evidence/regression312_comparison.json

2. Material-point and tangent tests

Test	Result
Archived failed Example 2 local attempts	91 / 91 locally converged
Broader archived trials	1094: 724 converged, 370 rejected
Independent spectral test	160 / 160; max relative error 3.1148e-15
Tangent width sweep	700 / 724; 24 unqualified

Tangent criterion

The specified 15 widths from 1e-5 to 1e-12 require errors below 1e-4 at three consecutive widths. The corresponding 11-width grid qualifies 685 points. Counts from different width sets must not be combined into an improvement rate.

At fixed width 1e-9 the maximum error is about 0.832. Perturbations may cross principal-stress sign boundaries; small error is not uniform across points and widths. Trial 947 has protected multiple-root rejection under perturbation.

Reproducibility

Archived replay inputs are private; replay counts are internal archived evidence. The independent spectral test is publicly reproducible. Local convergence is not full-model completion.

```
python tests/spectral_reference.py --compiler gfortran
```

Stubs are only for the standalone test. Never link them into Abaqus or interpret them as validation of Abaqus utilities or parallel safety.

3. Small finite-element tests

The comparator is the preceding characteristic-length-tangent candidate, not the 312-condition reference. S, LE, SDV, U and RF were extracted at all saved frames.

Test	Observed result
C3D8: prescribed traction	40 increments / 40 iterations, no cutback; saved values identical
C3D8: mixed-boundary axial reversal	41 increments, one cutback each, 47 to 46 iterations; max stress difference 1.9001e-5 MPa
Rotated two-C3D8 shear reversal	40 increments / 43 iterations, no cutback; saved values identical
Two-C3D6 wedge shear	40 increments / 44 iterations, no cutback; saved values identical
Serial / requested two-thread / repeat	Saved values identical

These small verification decks use As=15, unlike As=5 in Example 2. Requested two-thread smoke tests are not a race-free proof or MPI validation.

Execution checks

Separate work directories and source/library hashes were used, with successful datacheck before analysis. Execution instructions are in the manual. Document reorganization does not constitute a new solver campaign.

4. Restart and scope limitations

Automatic FIL geometry with 89 state entries and same-source restart completed. Restart used transferred restart/ODB files without the original FIL or external geometry table. Twenty-two common frames were compared.

Quantity	Maximum difference
27 geometry entries	0
S / material SDV	3.58e-13 / 3.56e-13
U	2.63e-18
RF: all 22 frames	5.666e-9
RF: 21 later frames	4.247e-15

Initial-frame RF difference 5.666e-9 exceeds the original absolute 1e-9 criterion. The cause is unresolved; all-frame/all-field equivalence remains not passed. Lack of a persistent later difference does not override the original criterion.

Evidence: evidence/FE_RESTART_RESULTS.json; evidence/RESTART_RF_AUDIT.json

Not established

Production qualification, large-scale/MPI behavior, arbitrary rotations and meshes, general global Newton robustness and experimental validity are not established. Saved examples are not reruns of this distributed source. Independent application-specific checks are required.

Documentation: SIMULIA Abaqus 2026 > User Subroutines > UMAT (initial single-element testing, tangent and state variables), SIMACAESUBRefMap/simasub-c-umat.htm. The official manual does not certify this implementation.