This is a description of the UMAT implementation of CDPM2 for LSDYNA provided by Peter Grassl on https://github.com/githubgrasp/cdpm2. Last updated: 15.05.2021

CDPM2 is a damage plastic concrete model based on work published in Grassl et al. (2011, 2013). It is an extension of CDPM proposed in Grassl and Jirásek (2006). This model has been developed to simulate the failure process of concrete. It describes the failure process of concrete subjected to multi-axial and rate-dependent loading. The model is based on effective stress plasticity combined with a damage model which is based on both plastic and elastic strain measures. This material model is available only for solids.

The LSDYNA user material implementation was originally implemented by Dimitrios Xenos and Peter Grassl in 2014. Since then, updates and corrections of the model have been made. Because of these updates and corrections, the user material is not exactly the same as in the official LSDYNA version.

Below are is an example of the input cards for the material model shown. In total, five cards are required. The first two are mainly related to the use of user materials in LSDYNA. The last three contain the CDPM2 specific parameters.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | MID | RO | MT | LMC | NHV | IORTHO | IBULK | IG |
| Type | A8 | F | F | F | F | F | F | F |
| Input | none | none | 50 | 26 | 27 | 0 | 25 | 26 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | IVECT | IFAIL | ITHERM | IHYPER | IEOS | LMCA |  |  |
| Type | A8 | F | F | F | F | F |  |  |
| Default | none | none | none | none | none | none |  |  |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | E | PR | ECC | QH0 | FT | FC | HP | AH |
| Type |  |  | F | F | F | F | F | F |
| Default |  |  | AUTO | 0.3 | None | None | 0.01 | 0.08 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | BH | CH | DH | AS | DF | ERT | TYPE | BS |
| Type | F | F | F | F | F | F | F | F |
| Default | 0.003 | 2 | 1.0E-6 | 15 | 0.85 | 0 | 1 | AUTO |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | WF | WF1 | FT1 | STRFLG | FAILFLG | EFC | DAMFLG | PFLG |
| Type | F | F | F | F | F | F | F | F |
| Default | None | 0.15\*WF | 0.3\*FT | 0 | None | 1.0E-4 | 0.0 | 0 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Card 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | K | G |  |  |  |  |  |  |
| Type | F | F |  |  |  |  |  |  |
| Default | None | None |  |  |  |  |  |  |

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| --- | --- |
| VARIABLE | DESCRIPTION |
| MID | Material identification. A unique number or label not exceeding 8 characters must be specified. |
| RO | Mass density. |
| MT | Type of user material routine used. We use umat50v. |
| LMC | Number of model input parameters. We have 26 including K and G. |
| NHV | Number of history variables. The model has 27 variables which are listed below. |
| IORTHO | Parameter which allows for local coordinate system to be used. Here not needed. Therefore, it is set to zero. |
| IBULK | Input parameter number where K is specified. Here it is 25. |
| IG | Input parameter number where K is specified. Here it is 26. |
| IVECT | Flag specifying if vector format is used. Here it is used so that it is set to 1. |
| IFAIL | Flag which allows for element deletion. It is normally set to zero for CDPM2. |
| ITHERM | Flag which allows for consideration of temperatures in material model. Not used here. |
| IHYPER | This flag allows for the use of deformation gradient. Not used here, so set to zero. |
| IEOS | This flag allows for the use of equation state. Not used here, so set to zero. |
| LMCA | Additional memory of material data. Not used here. Set to zero. |
| E | Young's modulus. If the value of the Young's modulus E is not available, it can be estimated from the uniaxial compressive strength according to, for instance, the CEB-FIP Model Code 2010. |
| PR | Poisson's ratio. |
| ECC | Eccentricity parameter. If not provided (or set to zero), then ECC is calculated from Jirásek and Bazant (2002) as |
| QH0 | Onset of hardening. Default is 0.3. |
| FT | Uniaxial tensile strength. If the value of the uniaxial tensile strength is not available, the tensile strength can be estimated from the uniaxial compressive strength according to, for instance, the CEB-FIP Model Code 2010. |
| FC | Uniaxial compression strength. |
| HP | Hardening parameter. Default is 0.01. However, note the following:  1) For applications without strain rate effect (STRFLG = 0) a value of HP = 0.01 is recommended.  2) For strain rate dependent material response ((STRFLG = 1), HP = 0.5 is recommended. |
| AH | Hardening ductility parameter 1 (see default value in card 3) |
| BH | Hardening ductility parameter 2 (see default value in card 4) |
| CH | Hardening ductility parameter 3 (see default value in card 4) |
| DH | Hardening ductility parameter 4 (see default value in card 4) |
| AS | Ductility parameter during damage. (see default value in card 4) |
| DF | Flow rule parameter. (see default value in card 4) |
| EFLG | Flag for the way how fracture energy is related to the Dynamic Increase factor (DIF) if STRFLG = 1.  EQ.0.0: fracture energy is not increased.  EQ.1.0: fracture energy is increased by DIF  EQ.2.0: fracture energy is increased by square of DIF |
| TYPE | Flag for tensile damage type.  EQ.0.0: Linear damage formulation  EQ.1.0: Bi-linear damage formulation  EQ.2.0: Exponential damage formulation  EQ.3.0: No damage  Default = 0.0. However, the best results are obtained with the bi-linear formulation. |
| BS | Damage ductility exponent during damage. |
| WF | Tensile threshold value for linear tensile damage formulation.  Parameter controlling tensile softening branch for exponential tensile damage formulation. For TYPE=0 (linear softening), WF = 2 GF/FT where GF is the total fracture energy. For TYPE=1 (bilinear softening), and the default values for WF1 and FT1, WF = 4.444 GF/FT. Finally, for TYPE = 2 (exponential softening), WF = GF/FT. For tetrahedral element, the value of WF should be multiplied with 0.56.  If the value of the fracture energy GF is not available, it can be estimated from the uniaxial compressive strength according to, for instance, the CEB-FIP Model Code 2010.  In some cases, softening down to zero stress might result into numerical problems, which are not directly related to the constitutive model. To overcome these problems, it might be necessary to use an exponential softening law. |
| WF1 | Tensile threshold value for the second part of the bi-linear damage formulation. Default is 0.15 WF |
| FT1 | Tensile strength threshold value for bi-linear damage formulation. Default is 0.3 FT |
| STRFLG | Strain rate flag for strength.  EQ.0.0: No strain rate dependence (default)  EQ.1.0: Strain rate dependence using first branch of MC2010 DIF.  EQ 2.0: Strain rated dependence using first and second branch of MC2010 DIF. |
| FAILFLG | Failure flag.  EQ.0.0: Not active ⇒ No erosion.  GT.0.0: Active and element will erode if wt and wc is equal to 1 in FAILFLG percent of the integration points. If FAILFLG=0.60, 60% of all integration points must fail before erosion. |
| EFC | Parameter controlling compressive damage softening branch in the exponential compressive damage formulation. See default value in card 5. |
| DAMFLG | Flag to determine the type of damage formulation that is used.  EQ.0.0: No damage  EQ.1.0: Two damage variables with a split of effective stress in tensile and compressive part (default)  EQ.2.0: One damage variable but still taking into account tensile and compressive damage.  EQ.3.0: One damage variable (tensile damage) |
| K | Bulk modulus calculated as E/(3.0\*(1.-2.\*PR) |
| G | Shear modulus calculated as E/(2.0\*(1.+PR) |

History variables

1 kappa

2 equivalent strain

3 plastic strain xx

4 plastic strain yy

5 plastic strain zz

6 plastic strain xy

7 plastic strain zy

8 plastic strain xz

9 kappa tension kdt

10 kappa tension kdt1

11 kappa tension kdt2

12 kappa compression kdc

13 kappa compression kdc1

14 kappa compression kdc2

15 damage variable tension omegaT

16 damage variable compression omegaC

17 strain rate factor

18 compression factor, alphac

19 equivalent strain - tension

20 equivalent strain - compression

21 total xx strain

22 total yy strain

23 total zz strain

24 total xy strain

25 total yz strain

26 total xz strain

27 old equivalent strain

**References**

P. Grassl and M. Jirásek. "Damage-plastic model for concrete failure". International Journal of Solids and Structures. Vol. 43, pp. 7166-7196, 2006.

P. Grassl, U. Nyström, R. Rempling and K. Gylltoft, "A damage-plasticity model for the dynamic failure of concrete", 8th International Conference on Structural Dynamics, Leuven, Belgium, 2011.

P. Grassl, D. Xenos, U. Nyström, R. Rempling, K. Gylltoft. "CDPM2: A damage-plasticity approach to modelling the failure of concrete". International Journal of Solids and Structures. Volume 50, Issue 24, pp. 3805-3816, 2013.