



AD FALCON API Manual

Phase Properties

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1 Phase Properties

Phase properties define the physical characteristics of the solid, liquid, and gas phases in FALCON materials. They are required for all analysis types; liquid and gas phases become relevant in coupled and fully coupled analyses where multiple phases interact.

1.1 Overview

FALCON supports three phases: - **Solid**: The soil skeleton - **Liquid**: Water phase (for coupled and fully coupled analyses) - **Gas**: Air phase (for fully coupled analyses)

Each phase requires specific properties that define its density, bulk modulus, and viscosity (where applicable).

1.2 Syntax

Phase properties are specified using the @PhaseChar: directive in the % Materials section:

```
@PhaseChar: Solid rhos <density>
@PhaseChar: Liquid rhow <density> K_l <bulk_modulus> l_viscosity <viscosity>
@PhaseChar: Gas rhog <density> k_g <bulk_modulus> g_viscosity <viscosity>
```

1.2.1 Directive Format

- **Case-insensitive**: @PhaseChar:, @phasechar:, @PHASECHAR: are all equivalent
- **Colon spacing**: Both @PhaseChar: Solid ... and @PhaseChar:Solid ... are accepted
- **Parameters**: Space-separated name value pairs (not name=value)

1.3 Phase Definitions

1.3.1 Solid Phase

Format: @PhaseChar: Solid rhos <density>

Parameter	Description	Dimensions	Required
rhos	Solid density parameter	M/L ³	Yes

Example:

```
@PhaseChar: Solid rhos 2.7
```

Notes: - Required for all analysis types - In *NonCoupled / *UnCoupled analyses, FALCON uses ρ_{hos} directly as the continuum density ρ in inertia and body-force terms (i.e., $\rho = \rho_{\text{hos}}$) - In *Coupled and *FullyCoupled analyses, FALCON computes the bulk density ρ from ρ_{hos} , porosity (from void ratio), saturation, and (when present) $\rho_{\text{how}} / \rho_{\text{hog}}$ - Dimensions: M (mass), L (length)

1.3.2 Liquid Phase

Format: @PhaseChar: Liquid ρ_{how} <density> K_{l} <bulk_modulus> l_viscosity <viscosity>

Parameter	Description	Dimensions	Required
ρ_{how}	Liquid (water) density	M/L^3	Yes
K_{l}	Liquid bulk modulus	$M/(L \cdot T^2)$	Yes
l_viscosity	Liquid viscosity	$M/(L \cdot T)$	Yes

Example:

```
@PhaseChar: Liquid rho_how 0.997 K_l 2.25e6 l_viscosity 1e-6
```

Notes: - Required for coupled (*Coupled) and fully coupled (*FullyCoupled) analyses - Used in pore pressure calculations and flow equations - Dimensions: M (mass), L (length), T (time)

1.3.3 Gas Phase

Format: @PhaseChar: Gas ρ_{hog} <density> k_{g} <bulk_modulus> g_viscosity <viscosity>

Parameter	Description	Dimensions	Required
ρ_{hog}	Gas (air) density	M/L^3	Yes
k_{g}	Gas bulk modulus	$M/(L \cdot T^2)$	Yes
g_viscosity	Gas viscosity	$M/(L \cdot T)$	Yes

Example:

```
@PhaseChar: Gas rho_hog 1.1e-3 k_g 1.01e2 g_viscosity 1.8e-5
```

Notes: - Required for fully coupled (*FullyCoupled) analyses only - Used in air pressure calculations and two-phase flow - Dimensions: M (mass), L (length), T (time)

1.4 Material Requirements by Analysis Type

Analysis Type	Required Phases
*NonCoupled / *UnCoupled	Solid only
*Coupled	Solid + Liquid
*FullyCoupled	Solid + Liquid + Gas

Important: In fully coupled analyses, **all materials must include all three phases** (@PhaseChar: Solid, @PhaseChar: Liquid, @PhaseChar: Gas). Missing any phase property will result in an error.

1.5 Complete Material Example

1.5.1 Uncoupled Analysis

```
% Materials
Clay
@UMAT:/path/to/LinearElasticUMAT.cpp /path/to/LinearElasticUMAT.hpp
Mechanical YoungsModulus=2.0e8 PoissonsRatio=0.3
@PhaseChar: Solid rhos 2.7
%%%
```

1.5.2 Coupled Analysis

```
% Materials
Clay
@UMAT:/path/to/MohrCoulombUMAT.cpp /path/to/MohrCoulombUMAT.hpp Mechanical
Cohesion=10000 FrictionAngle=30
@Perm: Constant k_sat 1e-10
@PhaseChar: Solid rhos 2.7
@PhaseChar: Liquid rhow 0.997 K_l 2.25e6 l_viscosity 1e-6
%%%
```

1.5.3 Fully Coupled Analysis

```
% Materials
Clay
@UMAT:/path/to/GCCUMAT.cpp /path/to/GCCUMAT.hpp Mechanical lambda=0.2
kappa=0.05 M=1.25
```

```
@SWRC: Hysteretic alpha_1 0.5 n 1.4 m 0.5 omega_prime 0.1 alpha_2 0.2 bd
0.05 bw 0.05 SW_max 0.45 SW_min 0.05 b_s_c 0.01
@EffectiveStress: GhorbaniKodikara Beta1 0.55 Beta2 0.25
@Perm: Constant k_sat 1e-12
@PhaseChar: Solid rhos 2.7
@PhaseChar: Liquid rhow 0.997 K_l 2.25e6 l_viscosity 1e-6
@PhaseChar: Gas rhog 1.1e-3 k_g 1.01e2 g_viscosity 1.8e-5
%%%
```

1.6 Physical Significance

1.6.1 Density (rhos, rhow, rhog)

Densities determine the mass of each phase per unit volume. They are used in: - Mass balance equations - Inertial effects in dynamic analyses - Body force calculations

Dimensions: M/L^3 where M (mass), L (length)

1.6.2 Bulk Modulus (K_l, k_g)

Bulk moduli characterize the compressibility of fluids: - **Liquid bulk modulus (K_l):** Controls liquid compressibility; typically much larger than gas bulk modulus, making liquids nearly incompressible - **Gas bulk modulus (k_g):** Controls gas compressibility; typically much smaller than liquid bulk modulus, making gases highly compressible

These moduli are critical for: - Pore pressure calculations - Volume change predictions - Coupling between mechanical and hydraulic behavior

Dimensions: $M/(L \cdot T^2)$ where M (mass), L (length), T (time)

1.6.3 Viscosity (l_viscosity, g_viscosity)

Viscosities control the resistance to flow: - **Liquid viscosity (l_viscosity):** Affects liquid flow through porous media (Darcy's law) - **Gas viscosity (g_viscosity):** Affects gas flow in unsaturated soils

Viscosities are used in: - Permeability calculations - Flow rate predictions - Relative permeability models

Dimensions: $M/(L \cdot T)$ where M (mass), L (length), T (time)

1.7 Common Issues and Troubleshooting

1. **Missing phase properties:** Ensure all required phases are defined for your analysis type
2. **Dimensional consistency:** Verify that all input values use consistent dimensions (M, L, T, F) throughout the analysis
3. **Unrealistic values:** Check that density, bulk modulus, and viscosity values are physically reasonable relative to each other

4. **Temperature effects:** Note that viscosity and density can vary with temperature; use values appropriate for your simulation conditions

1.8 Related Documentation

- [Materials](#) - General material property definitions
- [Input File Structure](#) - Overall input file syntax
- [Coupled Analysis Theory](#) - Theory behind coupled analyses
- [Fully Coupled Analysis Theory](#) - Theory behind fully coupled analyses

