UCF/DSI-CM-1 Simulant Spec Sheet

The CM asteroid simulant is based on the average composition of the Murchison carbonaceous chondrite meteorites. This is a high-fidelity simulant, targeting the modal mineral composition specified by D.T. Britt. This simulant has intentional differences from the composition reported in the literature to improve the safety of the simulant and to provide adequate strength and morphology.

1. Safety Considerations

The components of this simulant are selected to be safe; hazardous materials have been avoided. Most of the source minerals are commonly found in soils and/or households. Others such as sodium metasilicate (binder) are not found naturally on the Earth's crust. Note that these minerals in powder form all can be a nuisance dust hazard, and dust masks should be worn when handling these powders. Also, they should not be eaten.

1.1 Serpentine

This family of minerals includes variants that can form asbestos fibers. This simulant uses the serpentine minerals Cronstedtite and Antigorite, which do not form asbestos. Note that the cronstedtite has been substituted by an iron-rich silicate processed from fayalite (ferrous silicate aka copper slag grit).

1.2 Kerogen

Carbonaceous chondrite meteorites generally have several percent of carbon present as complex polycyclic aromatic hydrocarbons (PAHs), compounds generally considered to be carcinogenic. We have substituted sub-bituminous coal, which is considered safe while having the correct ratio of C to H.

1.3 Sulfides

Asteroids typically contain iron sulfides such as troilite (FeS) or pyrrhotite (~$Fe_{0.8}S$). These are hazardous during the manufacturing process since fine powders can be explosive in air. We substitute pyrite (FeS_2) as a safety consideration for ourselves.

2. Morphologies

The CM simulants are available in several forms:

2.1 Regolith

This form has been properly mixed, dried/lithified, and shattered into a power-law size distribution to match a possible asteroid regolith.

2.2 Slabs / Cobble

Wet mix has been pressed into molds and carefully dried/lithified to produce slabs or cobble.

2.3 Ready-to-prepare Dry Mix

This form consists of dry mixed powder. When ready to use:

2.3.1 Add water to the dry powder.

Each 3.5 gallon bucket contains 16.5 kg of dry mix. However, these instructions are appropriate for 2 kg batches. Measure 2.06 kg of dry powder into a metal or plastic bowl. Add 400 ml of distilled water and mix thoroughly BY HAND; this results in a very thick, crumbly mixture. Note that machine mixing results in an excessively wet mixture, which will form a skin when lithified. No more than 320 ml of water (per 2.06 kg dry mix) should be used when machine mixing.

2.3.2 This results in 2.46 kg of wet mix.

This should be shaped into the desired form, or pressed into a mold. We line our molds (typically ordinary clay pots or pot bases) with parchment paper to prevent the mixture from adhering to it. Once the wet mix has been firmly pressed into the mold, it is lithified by baking (in a 1000 watt microwave oven) for 40 minutes at 80% power, then 15 minutes at 70% power, followed by cooling. Other masses (or ovens) will require microwave timing adjustments which may not be linearly extrapolated due to surface effects. Note that the surface will appear quickly rock-like while the interior is still crumbly until the entire sequence is completed.

The dried mixture should mass 2.0 kg, having lost the added water plus the water of hydration in the sodium metasilicate pentahydrate. Our process temperatures are 120°C to 130°C (as measured by an IR thermometer targeting the surface), high enough to precipitate sodium silicate polymers but low enough to not drive off the water and other volatiles bound into the antigorite or coal.

2.4 Bagged Un-Mixed Source Minerals

Each bucket contains the proper source materials to produce 16 kg of CR simulants, in individual labelled bags totaling 16.5 kg. The purpose is to allow a researcher the ability to change the composition either using a different ratio of source minerals or by replacing some with alternates, such as replacing antigorite with chrysotile (asbestos) serpentine, or using hazardous kerogens instead of coal.

The process is to carefully mix all source materials, taking care to avoid or disrupt clumps (we sift and then use cement mixers and tumble the dry powders with steel balls for 30 minutes, which results in a uniform powder). Then follow the steps in 2.3 above to prepare a wet mix.

2.5 Notes

Using the wrong proportion of water, or not carefully following the lithification instructions, may result in a simulant mixture which does not – and will not – completely set. The lithification is due to the polymerization of sodium silicate, and if that process is disrupted, the polymer units may be too short to achieve a good cementation, and will no longer dissolve in water. The final product is not affected by water. Using too much water – or excessively mixing or using vacuum or vibration to reduce porosity – may result in a wet surface which will likely result in a surface skin, which may separate or may be tightly bound. The ability to create a dense surface layer is why sodium metasilicate (water glass) is sometimes used as a cement sealer.

3. Elemental Composition

Element	Weight %
Fe - Iron	34.96%
Si - Silicon	14.05%
Mg - Magnesium	7.70%
S - Sulfur	1.33%
C - Carbon	2.81%
H - Hydrogen	0.56%
Trace Elements	~2.51%
O - Oxygen	balance

4. Mineralogical Composition

Here is the list of minerals in this simulant. Note these are generally mine sources, and have impurities such that they do not match the pure mineral exactly.

Mineral	Weight %	Notes
Ferrous Silicate	57.0%	An iron rich silicate (Fe_2SiO_4) aka Fayalite or "copper slag grit" substituted for the serpentine mineral Cronstedtite, $(Fe{+}{+}_2,Fe{+}{+}{+})(Si,Fe{+}{+}{+})O_5(OH)_4$
Antigorite	22.0%	A serpentine mineral, $(Mg,Fe{+}{+})_3Si_2O_5(OH)_4$
Olivine	8.1%	Magnesium Iron Silicate – $(Mg_{0.9}Fe_{0.1})_2SiO_4$
Coal	3.5%	Sub-bituminous coal is a kerogen substitute
Pyrite	2.5%	Iron Sulfide (FeS_2), substituted for troilite (FeS)
Pyroxene	2.0%	$Mg_{0.75}Fe_{0.25}SiO_3$
Magnetite	1.0%	Iron Oxide – Fe_3O_4
Dolomite	1.0%	$(Ca, Mg)CO_3$
Sodium Silicate	2.9%	Note that 5.0% of sodium silicate pentahydrate is added, but the water is driven out by the lithification process