UCF/DSI-CI-2 Simulant Spec Sheet

The CI asteroid simulant is based on the carbonaceous chondrite meteorite known as Orgueil. This is a high-fidelity simulant, targeting the modal mineral composition of the Orgueil meteorite as reported by Bland et. al. This simulant approximates the mineralogy of Orgueil, with intentional differences to improve the safety of the simulant.

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 epsomite) are used in agriculture as a fertilizer, and of course Epsom salts are used for soaking and as a laxative. 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 mineral Antigorite, which does not form asbestos.

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, and partially make up the shortage of iron by increasing the percentage of iron in other minerals.

2. Morphologies

The CI simulants are available in several forms:

2.1 Regolith

This form has been properly mixed, dried, 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 to produce slabs or cobble.

2.3 Ready-to-prepare Dry Mix

This form consists of dry mixed powders plus a 1.0 kg bag of epsomite, and an oxygen absorber packet that should be saved (with any unmixed powders) or discarded; it reduces the oxidation of pyrite and other minerals.

When ready to use:

2.3.1 Dissolve the epsomite in 2.4 kg of warm distilled water

(we use and maintain a 40°C temperature as preparing the solution is endothermic). Cool the epsomite solution to room temperature.

2.3.2 Immediately mix with the dry powder.

Each 3.5 gallon bucket contains 15 kg of dry mix. Adding the epsomite solution results in a very thick mixture. Using more water may result in simulant with a lower density (more pore space), which takes a long time to dry. Uneven or slow or excessively fast drying can result in visible and/or hidden fractures, and increased efflorescence.

2.3.3 This results in 18.4 kg of wet mix which should be shaped into the desired form, then dried.

The dried mixture should mass 16.0 kg. Ideally, the wet mix should be rapidly dried at a low temperature to minimize chemical changes. Note that carbonaceous chondrite asteroids may have never been subjected to a temperature in excess of 50°C. Our process temperatures do not exceed 40°C.

2.4 Bagged Un-Mixed Source Minerals

Each bucket will contain the proper source materials to produce 16 kg of CI simulants in individual labelled bags. 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 other than epsomite, taking care to avoid or disrupt clumps (we 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

An efflorescence of epsomite crystals commonly occurs on CI chondrite meteorites exposed to warmth and humidity, and the process of mixing, molding, and drying should be performed rapidly to minimize this. The efflorescence consists of colorless, fine acicular crystals which may form a fine white crust or erupt in a localized spray, especially along sharp edges. Epsomite is highly soluble in water, and a wet sponge readily removes the surface layer.

The regolith may be remixed with 10% water, pressed into a mold, and dried. Natural Orgueil meteorites likely have not been exposed to temperatures in excess of 50^{o}C. Our processes, including drying, do not use temperatures in excess of 40^{o}C. Note that exposure to warmth, oxygen, and humidity will allow chemical oxidation of the pyrite, resulting in the production of oxides of sulfur plus sulfuric acid and possibly melanterite, which may react with other minerals (such as clays) and further change the chemistry. Some researchers suspect that such reactions are the source of epsomite and gypsum identified in some samples.

3. Elemental Composition

Element	Target wt %	Actual wt %
Fe - Iron	18.95%	16.24%
Si - Silicon	10.64%	11.18%
Mg - Magnesium	9.62%	13.54%
S – Sulfur	5.25%	4.19%
C - Carbon	3.22%	3.85%
H - Hydrogen	2.02%	1.67%
Elements < 1%	~4%	2.98%
O Oxygen	balance	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. We have taken these into account during the manufacturing process, where reasonable. For example, several minerals (such as antigorite) include some magnetite, and the added magnetite fraction below is reduced to account for that.

Mineral	Weight %	Notes
Antigorite	48.0%	A serpentine mineral, $(Mg,Fe{+}{+})_3Si_2O_5(OH)_4$
Epsomite	6.0%	Magnesium sulfate heptahydrate – $MgSO_4$*$7H_2O$
Magnetite	13.5%	Iron Oxide – Fe_3O_4 (actually present 14.5%)
Attapulgite	5.0%	AKA palygorskite, $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4(H_2O)$ This clay binds strongly without swelling/shrinking
Olivine	7.0%	Magnesium Iron Silicate – $(Mg_{0.9}Fe_{0.1})_2SiO_4$
Pyrite	6.5%	Iron Sulfide (FeS_2)
Vermiculite	9.0%	A smectite-group clay $(Mg,Fe,Al)_3(Al,Si)_4O_{10}(OH)_2$ - $4H_2O$
Coal	5.0%	Sub-bituminous coal is a kerogen substitute