UCF/DSI-C2-1 Simulant Spec Sheet

The C2 asteroid simulant is based on the carbonaceous chondrite meteorite known as Tagish Lake. This is a high-fidelity simulant, targeting the elemental composition of the Tagish Lake meteorite for the most abundant 6 elements (all those comprising more than 1% by weight in addition to oxygen) to include Fe, Si, Mg, S, C, and H, in proportions described by Bland et al., "Modal Mineralogy of Carbonaceous Chondrites", Meteorites and Planetary Science 39, Nr 1, 3-16 (2004). Oxygen is the most common element, but is generally reported as "balance oxygen and trace elements", so a target weight % is not available. This simulant approximates the mineralogy of Tagish Lake, with intentional differences to improve the safety of the simulant and allow for terrestrial mine sources.

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 and siderite) are used in agriculture as a fertilizer and in horticulture as a feed supplement to treat iron deficiency anemia, 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 ($\sim Fe_{0.8}S$). 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. Note that we target the correct sulfide fraction separately from the correct sulfate fraction.

2. Morphologies

The CI simulants are available in several forms:

2.1 Regolith

This form has been properly mixed, dried, and shattered with a high-speed flail 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.

When ready to use:

2.3.1 Prepare a chilled carbonated water solution.

The ratio is 25% by weight. Thus for 16 kg of regolith, use 4 kg (4 liters) of carbonated water. We simply purchase plain sparkling water and refrigerate it. Distilled water (or even tap water) will work, although the resulting density is ~10% too high. The only purpose of using carbonated water is to create internal bubbles to add microporosity and thus reduce density (and strength to a lesser degree). Less water works to make a loose gravelly mixture; more creates a wet mud. The recommended 25% makes a moderate texture that can be pressed into a mold or shaped by hand.

2.3.2 Immediately mix with the dry powder.

Each 3.5 gallon bucket contains 16 kg of dry mix. Adding the chilled carbonated water 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, and which may show signs of settling. This mixture is quite thick a difficult to stir by hand; we use commercial (restaurant grade) mixers.

2.3.3 This results in 20.0 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, including our drying facility which targets a temperature of 38°C with a relative humidity of 25%, and a great deal of air movement.

2.4 Bagged Un-Mixed Source Minerals

Each bucket contains 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 lizardite with chrysotile (asbestos) serpentine, or using hazardous kerogens instead of coal, or troilite instead of pyrite.

The process is to carefully mix all source materials, 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 which is sifted to remove the steel balls). Also, we recommend that the dolomite, pyrite, and especially the attapulgite be sifted to reduce clumping. Then follow the steps in 2.3 above to prepare a wet mix.

2.5 Notes

Larger pieces such as slabs often dry with a dark or mottled dark and light surface. You may note that the color of the interior matches the lighter areas of the surface. This is normal.

3. Elemental Composition

Target weight % is per Bland et al. (2004).

Element	Target wt %	Actual wt %
Fe - Iron	23.59%	21.94%
Si - Silicon	12.16%	12.16%
Mg - Magnesium	9.60%	16.31%
S – Sulfur	3.51%	4.45%
C - Carbon	1.49%	4.06%
H - Hydrogen	1.27%	0.96%
Elements < 1%	4.39%	1.61%
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 lizardite) include some magnetite, and the added magnetite fraction below is reduced to account for that.

Mineral	Weight %	Notes
Lizardite	30.5%	A serpentine mineral, $Mg_3Si_2O_5(OH)_4$
Olivine	25.0%	Magnesium Iron Silicate – $(Mg_{0.9}Fe_{0.1})_2SiO_4$
Magnetite	22.0%	Iron Oxide – Fe_3O_4
Pyrite	8.5%	Iron Sulfide (FeS_2)
Coal	5.0%	Sub-bituminous coal is a kerogen substitute
Vermiculite	4.0%	A smectite-group clay $(Mg,Fe,Al)_3(Al,Si)_4O_{10}(OH)_2$ - $4H_2O$
Attapulgite	4.0%	AKA palygorskite, $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4(H_2O)$ This clay binds strongly without swelling/shrinking
Dolomite	1.0%	Calcium Magnesium Carbonate – $CaMg(CO_3)_2$