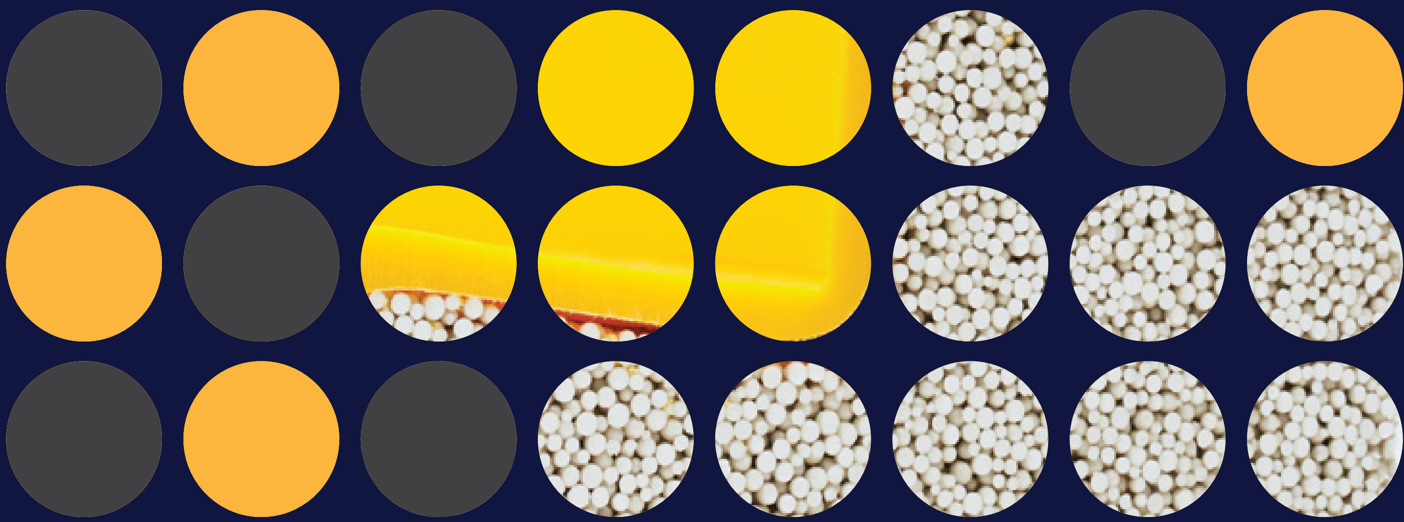
MATRIX SYNTACTIC FOAM

HIGHER STRENGTH | LOW DENSITY



LIGHTER • STRONGER • SMARTER

SYNTACTIC FOAM

SOME HISTORY

The word "syntactic" comes from the same Greek root as syntax – the way you put a sentence together. The original Ancient Greek "συντάσσω" (or "sin.tak.sis") implies arranging or ordering. With a normal foam, the cells are formed at the same time as the foam. For most industrial foams, a gas will be produced within the liquid, nucleating and expanding bubbles to create the foam structure. Alternatively, liquid and gas can be shaken or beaten together mechanically – think meringues or bubbles in the bath. With a syntactic foam, however, the individual cells are formed separately as coherent spherical bubbles of gas within hard ceramic or composite shells. After a process of sorting and grading, these cells are bonded together to create the foam.

This 'assembly' process provides great control over the foam material properties. The material, cell size and wall thickness can all be selected to best suit the application, providing high compressive strength and stiffness, and low density. With such properties, syntactic foams have excelled in providing stable buoyancy for deep sea exploration, which in turn has driven the material's development. Post WWII, the US Navy's adventures to the bottom of Marianas Trench in the Trieste had to be supported by a massive and unwieldy tank holding 85,000 litres of gasoline, like a sub-sea dirigible. Modern submersibles are supported by syntactic foams.

Part of the answer was the development of microscopic glass bubbles (microsphere). Standard Oil had been experimenting with microscopic glass bubbles since the 1950s, but 3M's 1963 breakthrough in the creation of high strength bubbles and a scaleable industrial process brought the technology to the mainstream. This, and the development of epoxy resins and composite macrospheres, provided a suitable material in practical volumes and at a practical cost.

MATRIX - HOME TO THE WORLD'S LARGEST SYNTACTIC FOAM MANUFACTURING FACILITY.

WHAT IS SYNTACTIC FOAM?

Two types of sphere are typically utilised in syntactic foams – microscopic glass bubbles (approximate Ø20-80 µm) and larger composite or injection moulded macrospheres (approx. Ø3-50 mm). A simple way to classify a syntactic foam is to consider the number of different phases within the final composite.

TWO PHASE SYNTACTIC

The simplest type of syntactic consists of only microscopic bubbles and a resin binder.

Many materials can act as the resin binder and most resins are, roughly, neutrally buoyant. Epoxy resin offers the best trade-off between cost and strength and has become the de facto standard.

The bubbles are normally glass but phenolics and PVC bubbles have practical uses, typically as a lightweight filler to reduce the density and stiffness of an adhesive. Where strength and stiffness are required, however, glass is the only practical solution. The microscopic bubbles – in effect tiny Ø50 µm pressure vessels – drive both the low density and compressive strength. When the two are combined – the bubbles encapsulated in the resin – the bubbles are better supported against collapse and develop far higher strength.

It is the selection of the bubble that drives the eventual performance of the foam. A wide range of grades are available, with different particle size distributions, wall thicknesses, strengths and processing limitations.

Ideally, the bubbles should be as low density as possible, robust enough to survive manufacture and strong enough to survive the anticipated loads. The trade-off between these properties determines the eventual grade of foam.

There are also limits to the bubble volume fraction that can be achieved. As more bubbles are added to the mixture the viscosity increases, eventually forming a semi-solid paste. This makes it harder to:

1. Mix in more bubbles
2. Mix in any catalyst required to set the resin
3. Avoid entrapping air in the mixture
4. Avoid damaging the bubbles themselves and
5. Get the material out of the mixer and into the mould.

Understanding and controlling these limits is somewhere on the boundary between art and science. It is also key to effective manufacture.

THREE PHASE SYNTACTIC

Taking the material beyond the limit of practical bubble volume fraction requires a different approach. By adding another phase entirely, this issue can be conveniently side stepped.

The volume fraction that can be achieved by randomly packing bubbles (or any sphere) together is limited to approximately 60%, though the viscosity of the liquid syntactic will become unmanageable around this limit. Adjusting the particle geometry or size distribution can improve this slightly, but the best way is to add spheres that are much (order of magnitude) larger than the glass bubbles. . Composite macrospheres – or 'macros' – are usually used for this, though injection moulded spheres can also be used.

Composite macrospheres are short fibre reinforced polymer shells, typically epoxy and recycled carbon fibre. The shells are accreted gradually onto the surface of a lightweight core in much the same way that sugar shells are accreted onto Smarties. Of course, the colour choices for carbon fibre macros are limited – any colour you like so long as its black. Colourless mineral fibre reinforcement, however, can provide a background for a rainbow of colours.

The accretion process provides an even, isotropic shell, with fine grain control over macrosphere density. Each particle, being spherical, also possesses a high compressive strength. The result is a free flowing, low density bed of particles that can be poured into the mould tool and will, with care, fill the tool completely.

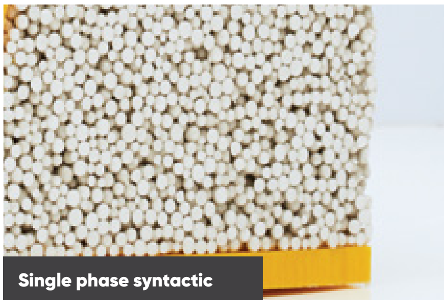
After this, the process is the same as that used for a two-phase foam. The liquid two-phase syntactic is poured into the mould where it flows between the macrospheres and fills the interstitial spaces between. Once cured, the macrospheres are further stabilised and support the resulting composite against collapse.

The same 60% volume fraction limit applies to macrospheres. However, much like a Sierpiński triangle, smaller spheres can fill the interstitial spaces between larger ones, increasing the overall volume fraction achieved by 60% for each level of structure included. The practical limits are usually the patience of those filling the mould tool and the ability of the liquid syntactic to percolate through the remaining interstitial space.

SINGLE PHASE SYNTACTIC

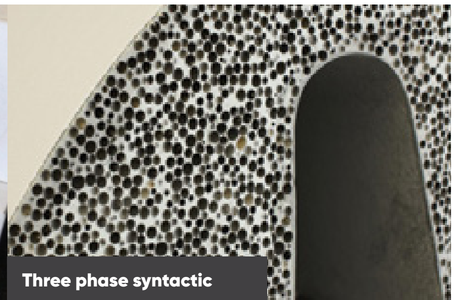
Single phase syntactic materials are also possible. If the macrospheres are coated with adhesive prior to depositing them into the mould, the adhesive will tend to gather, under its own surface tension, at the contact points between the spheres. With the adhesive cured, the macrospheres are bonded together into an open, three-dimensional composite. The process is quick, simple and can be completed on site with a minimum of specialist equipment. With only a thin film of active adhesive employed, large volumes can be cast without any fear of runaway exotherm.

As with other syntactic foams, the material properties can be altered by adjusting the composite reinforcement, the adhesive loading and the shell thickness and diameter. In particular, the structure can be tuned to fail at a particular compressive strength. Given that the open structure allows for a progressive crushing failure, the material can absorb impact energy in a predictable and controlled manner.



Single phase syntactic

Two phase syntactic



Three phase syntactic

SYNTACTIC FOAM
MATERIAL PROPERTIES

Broadly, the properties achieved by syntactic foams are like those achieved by another cellular composite: wood. The advantage – or perhaps disadvantage – being that epoxy syntactic foams are not subject to organic rot and decay. Instead, they maintain their material properties for decades, even when subject to long term immersion.

Like all foams, the tiny pockets of gas produce a good insulator. The thermal conductivity of syntactic foams is low, which can make extracting the heat generated by an exothermic cure difficult and the casting of thick sections impossible. The energy released by the epoxy chemistry and the thermal mass of the microsphere and macrosphere fillers must be carefully managed.

They are not ductile materials, perhaps better thought of as ceramic rather than polymeric. Their compressive strength is typically two or three times higher than their tensile strength. Shear failures are, in fact, tensile failures and the material will fracture rather than yield. There are many similarities to concrete, both in terms of manufacture, the structures that can be achieved and the occasional need for reinforcement.

HYDROSTATIC LOAD

Hydrostatic strength is more subtle. Although global collapse can be achieved, the typical failure is when water breaches the contact point between two spheres. This 'double wall' failure, if extensive, will fill the volume fraction of the spheres but leave the net shape unaltered. The foam will gradually take on water and loose buoyancy, with the different phases usually failing at different pressures.

This kind of failure is very difficult to detect visually, particularly if it is the Ø50 µm glass bubbles that are at fault.

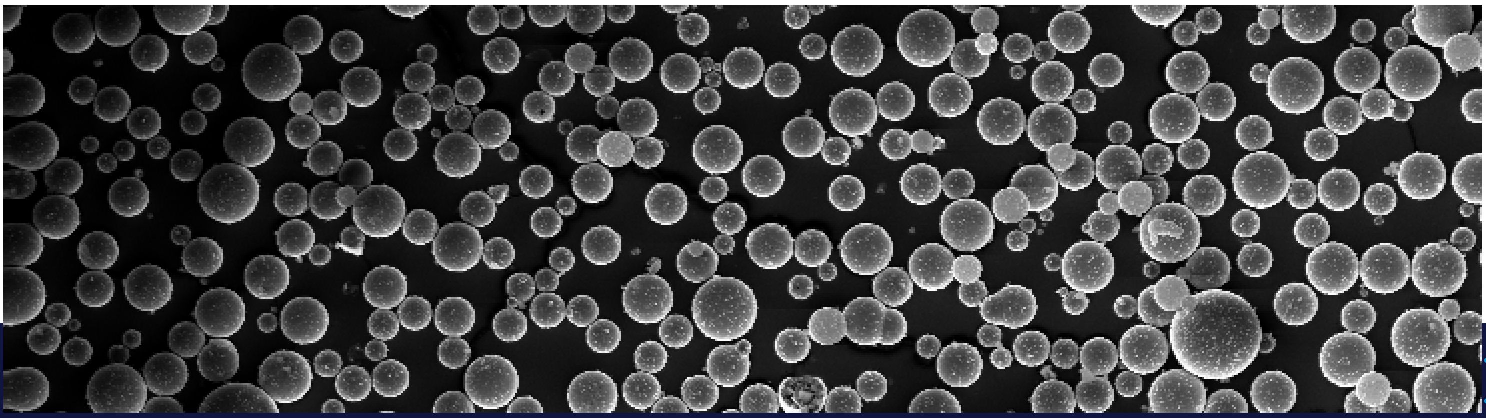
Volume will also be lost elastically. The bulk modulus is high (for a foam) but a 0.5% loss in volume is not unreasonable under a working hydrostatic load. The deep sea buoyancy loss will depend upon the relationship between the bulk modulus of the foam and that of sea water. High stiffness foams can match the bulk modulus of sea water, limiting the buoyancy loss experienced.

Over the long term, the material will also creep. These volume losses are predictable and will stabilise over time, but should nevertheless form part of any calculations. An allowance of 2 to 3% should cope with both elastic and inelastic volume losses over a 20-year service life.

MACHINING

From a machining perspective, be prepared to replace the tips on your cutters. Though reasonably easy to work, the process is closer to abrasion than cutting and high speed steel will lose its edge very quickly. The dust produced can be irritating but is not hazardous chemically. It will, however, make short work of bearings, slides and spindles if care is not taken to protect them. Cutting fluids can help, if only from the perspective of dust suppression. However, those familiar with machining solid glass or carbon laminates will not have any difficulty with syntactics.

It is usually better to mould the parts as close to net shape as possible and minimise – ideally eliminate – machining.



SYNTACTIC FOAM APPLICATIONS

DEEP SEA BUOYANCY

The exploration and production of hydrocarbons from offshore reservoirs accounts for the majority of syntactic foam production globally. The stable, deep sea buoyancy supports equipment within the water column, reducing stresses and the forces required to hold them.

For example, with many developments far beyond the range of saturation diving, much of the work of connecting, adjusting and replacing subsea equipment is carried out by Remotely Operated Vehicles (ROV). Maintaining the craft at neutral buoyancy with syntactic foam allows for greater control and stability of the platform, which must be held stationary and cannot relay on hydrodynamic forces.

CRYOGENIC INSULATION

A combination of high compressive strength and low thermal conductivity make syntactic foams an ideal material for cryogenic insulation. Pipes carrying liquified natural gas operate at approximately 110 K (-160°C). Careful integration of syntactic foams allow the pipe and its contents to be supported whilst remaining isolated from the warmer world outside.

IMPACT PROTECTION

The crush strength of single phase syntactics can be closely controlled. During an impact event, the syntactic will progressively crush, absorbing the impact energy and spreading the impulse over a longer time period. The resultant impact force is significantly reduced, protecting the underlying infrastructure from damage.

TUNED ACOUSTICS

The acoustic performance of a material is governed by its 'lossiness' – its ability to absorb the acoustic energy as it propagates through. More subtly, however, the acoustic impedance of the material must also match the surrounding medium. If the impedance mismatch is too high, the acoustic energy is simply reflected from the surface.

The acoustic properties of a syntactic – and hence its acoustic performance – can be tuned to suit the application by changing the microsphere and macrosphere structures within.

SHOCK ISOLATION

Explosive shock is deliberately disruptive when used to break up rock formations. The shockwaves propagate well beyond the mine site, however, and will disrupt surrounding structures.

Single phase syntactic acts as a low density impedance barrier, reflecting the shock wave away. Localised high stresses will also cause the syntactic to crush, further protecting the environment beyond.

LIGHTWEIGHT CONCRETE

Syntactic macrospheres and microspheres need not require an epoxy binder, but can replace the sand and aggregate within a cement paste to form a light weight concrete. The resulting material can reproduce the strength of concrete at a fraction of the density, reducing the weight of the structure without sacrificing load bearing capability.

COMPOSITE LAMINATES

The moulding process for a three-phase syntactic – the blending of a dry, particulate reinforcement (macrospheres) and a liquid two-phase syntactic – lends itself well to the integration of fibre reinforcements. The liquid resin infuses into the fibre bed, binding the reinforcement together to form a composite laminate. The majority of Matrix's products incorporate a fibre reinforced skin; a carapace to protect the syntactic foam within.

This combination of syntactic foam and fibre reinforcement exists on a continuum, with naked syntactic foam on one end and traditional fibre reinforced laminates on the other. Dependent upon the application, the fibre architecture of the external shell can be tailored to support significant structural loads, with the internal syntactic foam providing support.

Matrix's automated moulding processes can operate across this continuum, adding reinforcement whenever necessary whilst maintaining the low density, buoyant core within.

MATRIX DELIVERING TO THE WORLD

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