"Ferrocement is a thin composite made with a cement-based mortar matrix reinforced with closely spaced layers of small diameter wire mesh. The mesh may be made of metallic or other suitable materials."

'Ferrocement and Laminated Cementitious Composites' by professor Antoine Naaman.

What is FC?

FerroCement, [FC] as the name implies, is a material made from steel and cement. But there are two further essential ingredients namely mortar sand [it must be a fine clean sand and water. The sand, cement and water are mixed in roughly 3:1: 0.4 proportions by weight giving a stiff mortar. This is then applied to the steel which is generally in the form of a mesh like ½" chicken wire or stucco lath.

The difference between FC and RC [reinforced concrete] at the ingredients level is that FC uses smaller or finer raw materials whereas RC uses larger ones. So where FC only uses sand, RC needs sand and stone, and where FC uses wire mesh and lath, RC uses rebar. So, RC is a bulk material whereas FC, while maybe not qualifying as lightweight, is far more sparing in its use of materials.

Both FC and RC are composite materials. But while the ingredients are fundamentally identical [sand is, after all, only ground down stone] they differ widely in their application. There is a section later that deals with the differences and similarities from the ingredients onwards, qualitatively and in some detail.

FC has been used to build boats – the oldest one still afloat being more than 100 years old – and to make table tops. It is used as roof covering and walls in vaults and domes. You can use it to build water tanks, septic tanks, garden ponds, swimming pools. You can create artificial rocks with it, small or large, sculptures or abstract art. FC allows you to create almost anything from formal shapes like a cube or a sphere to the most outrageous form you can imagine. And the greatest thing about it is if you build it well it will last.

Both cement mortar and steel are known quantities in the engineering world. Unfortunately, other structural methods have dominated the construction sector for a long time so there are not many experienced FC engineers around. However, the discussion list on FerroCement.net is an excellent resource with a very friendly and helpful membership.

As a Mechanical Engineer I learnt about steel during my studies as well as through experience. I have picked up a fair amount of knowledge about cement, mortar and concrete through work related associations, interest and private study. I heard about FC boats way back when, but have learnt nearly everything I know about FC via Paul Sarnstrom's website www.FerroCement.net , its links and the discussion group that he hosts.

FC Adding steel to the mortar mix – why bother?.

The best way to get a sense of the quality of FC is to do a simple experiment. The task is to make two small slabs of mortar one with, and the other without, steel mesh. A cool place would be best but if it is winter you don't want to work with cement mortar if temperatures are going to drop below 50^{0}F [11^{0}C].

Simply spread two bits of plastic sheet about 24" square on the ground and spread a thin layer [about ¼" – just enough to embed the mesh you are going to use] of mortar on each. Then take a piece of mesh [a nice flat piece is easiest] about the size of the pool of mortar and press it into one of the two so that it is fairly flat and evenly 'sunk in'. Then apply another thin layer of mortar to both. Cover both with plastic sheeting and keep them moist for a few days [see curing]. When they have cured, strike each one with a hammer so that it breaks. The sample of pure mortar should break into a number of pieces – the FC sample will break but hold together despite visible cracks that will occur. And there you have it! *FC is shatter proof* ! ! !

Well – maybe not quite, as it depends on a whole lot of things, but the pieces of the FC sample remain largely held together by the wire strands.

This is not unlike what is done with large panes of glass although the materials are different. Essentially, two sheets of glass are laminated to each other with a film of tough transparent plastic between them. If the glass is broken, it does not break into a lot of dangerous pieces, but remains stuck to the plastic film.

So, now you have this damaged but unshattered piece of FC, if you hose it off to get rid of the loose stuff, you could apply new mortar, carefully tamping it into all the cavities there may be, cure it again, and a few days later you have a slab once more. Try that with the plain mortar sample ! ! FC you can fix when its broke ! ! !

Here is an extract from an e-mail from an Ferrocement.net list member who was working with Steve Kornher of Flying Concrete [also a member] on a vault to get some hands on experience.

Finally, finally, at long last, I'm gaining a hands-on appreciation for ferrocement. I'm gaining an appreciation for what a tough, forgiving medium it is. Not fragile at all! And if you're working in cool weather, you can even carve it for a period of time.

I learned just how tough, when we needed to modify the curvature of the vault to make it more symmetrical. The single layer of mortar-covered plaster lath had set up for a couple days or so. We took a sledge hammer to it, and only succeeded in punching holes. That is, only after taking some serious power strokes. And these didn't change the shape at all. Then we tried some major leveraging with 2x4's which did the trick. The shell flexed enough to improve the shape. There is a ductility to ferrocement that has to be seen to be believed. [Lootvik]

The next good thing about FC is that because it has all this wire fairly well distributed over its entire area, it can act like a skin, a tent as it were, only better. It is also much more durable than canvas. Because it is typically quite thin ranging from about ½" to a few inches, it is more cost effective than mass systems like brickwork or reinforced concrete – not that it can always be used as a replacement for either.

And then there is its flexibility – and here I am not referring to bendability as demonstrated in the quote above. The way that FC things are made allows almost complete freedom with regard to shape. First a framework is built which is then covered with a wire mesh to which mortar is applied.

So – let's say you want to make a false rock. You take ¼" or $^3/_8$" steel bars as a framework bent and tied together for the shape you want and then cover this with ½" chicken wire or stucco lath, tied to the framework. The covered mesh framework will have the shape of the desired product. Using a stiff and strong mortar mix, about 3:1:0.4, mortar is trowelled onto the mesh with firm strokes. Firm strokes are necessary because you must squeeze the mortar into the mesh so that it oozes through and completely encapsulates the mesh. This is a wasteful process as a fair amount of mortar will fall off the mesh. If any of the mesh remains exposed on the inside it could start rusting and that will ultimately destroy the work piece. A little experimentation with trowel pressure can reduce the amount of waste. If you can get to the inside and have a helper, you could have him/her hold another trowel inside against the area you are working. Some people apply mortar by hand but be sure to wear good rubber gloves if you decide to go that route – cement mortar is very alkaline and will attack the skin on your hands resulting in cracks at the very least. This first layer is more of a key coat than anything else and each trowelful applied should be left undisturbed and unsmoothed. Any attempts at smoothing will simply result in more mortar falling off the mesh. Once the whole work piece has been given an initial coating of mortar and it has reached initial set, a second layer can be applied. This layer will typically close all the gaps in the first layer which is now strong enough to handle a bit of pressure for smoothing the second layer. If you want a textured finish, first smooth this second layer and then use a stipple brush or a bunched up piece of shade net to create the texture on the fresh mortar surface.

If your work piece is relatively small, cover it with a water proof sheet of some sorts and sprinkle it with water to keep it moist for a few days. Be sure to <u>sprinkle</u> and <u>not jet</u> the water onto the mortar or you will wash it away. It is better to overwet than to allow the mortar to dry out. On day 4 you can let it dry out and you will have a grey whatever-it-was that you formed. You can then paint this with very dilute PVA paints using a garden spray bottle. You can run colours into each other and you can spatter colour giving the rock a very natural look. Then you can pick it up and put it where you want it – provided of course, you started out with a small enough 'vision'.

So now we have three noteworthy things about FC. It has good impact resistance, it is relatively easy to repair and it can be formed into elaborate shapes.

How FC does what it Does

To address this topic is to open a Pandora's box. FC applications can be so varied that it is close to impossible. So I will try to explain some essentials briefly and avoid complex stuff as much as possible.

The first simplification I must make is to assume that the mortar that has been used was well mixed, placed and cured. I will also assume that the steel, in whatever form, has been fabricated with adequate cross-linking and ties, is strong enough for the structure and is correctly placed within the mortar volume. By implication you should understand that these are all factors that require consideration.

The first question now is – What does FC do?

An obvious thing but worth stating is that it stays where you put it. It will stay there a long time and very likely outlast you. While it is standing there it will serve whatever purpose you had in mind unless you made some bloopers in your concept and design. If you used it to build a shelter, it will provide that shelter for its lifetime. If the shelter is your home then you have a secure and safe space where you can control the atmosphere in which you live because the FC is an impervious barrier to wind, rain, snow and direct sunlight [except for the high frequency EM waves which even penetrate through concrete]. It is a very effective sound barrier but will also keep sound inside. It is not good thermal insulation compared to materials like EPS and for homes, insulation must be added. It can be made waterproof by using rigorous technique and additives.

FC can cover large surfaces with minimal support and many domes of a vast range of sizes have been built using only FC as the structural element. FC also competes with timber, steel, aluminium, fiberglass and a number of other materials in the boat building and a variety of other sectors.

How it does what it does.

The two basic ingredients of FC are steel and cement mortar. Steel is about ten times stronger than mortar and can handle tensile [stretching] and compressive [crushing] forces equally well. Mortar is a hard and durable material which handles compression well but has virtually no tensile strength. Mortar is also a lot cheaper than steel on both a mass basis and a volume basis.

The most common failure in mortar is cracking, and cracking takes place when there is tension. If there is a steel mesh within the mortar, the steel resists the tension and cracking is restricted, to the extent that failure is prevented if the steel is adequate.

In order for the steel to do this, there must be enough steel oriented in the direction of the tensile forces, and it must be very well dispersed within and bonded to the mortar. The dispersion is achieved by using steel meshes as opposed to rods or bars. The adhesion is a co-incidental and fortunate property of cement based mixtures – they stick to steel. But be careful ! ! The steel surface should be clean, meaning no free rust or oil contamination on the surface. And if you spilled some coffee on your work or the steel, and there was sugar in it, the cement will not cure in that area nor will it bond with the steel. And the 'bond' between the steel and the cement mix is vital – it is the mechanism that gets them to work together.

So, by combining the steel mesh with the mortar, a hard, durable, fairly flexible skin can be created using a relatively small amount of material. This is achieved by combining the tensile strength of the steel with the compressive strength of the mortar, as well as its low cost.

When making large things using FC, it is usually necessary to use more steel mesh and often thicker mortar. This can be achieved by using two or more layers of mesh instead of one. When using two layers, you should try to offset the mesh so that the gap between wires of a ½" mesh becomes ¼". The two layers can be crimped together using short wire ties or they can be spaced apart, depending on what best suits the structure. When things get really large, like a 12' dome or barrel vault, welded mesh is often used as one of the layers of steel together with enough layers of finer mesh to give the required strength.

So, FC does what all composites do – it combines the properties of its components to create a material with specific advantages and applications.

The strengths and weaknesses of the ingredients
[qualitative, a little technical and not essential].

Steel

Steel is probably the most common manufactured material in the world. It is an impure form of iron whose impurities improve its usefulness. Pure iron is a fairly soft material and does not stand up well to fluctuating loads. It also dents fairly easily. Steel, which among other additives has about 3% carbon in it, is harder, tougher and more rigid. So steel is actually an iron alloy but differs greatly from others like cast iron which tends to be brittle.

Steel is also very strong having a tensile strength of 220 Mpa [32 000 psi]. In simple terms that means that a ½" steel bolt will just hold a load of one ton at the limit of its strength. Please note that this is true <u>at the limit</u>. No structural element should ever be used at its limit because failure is imminent ! ! !

There are many kinds of steel that have been developed for specific applications, many with greater hardness to make tools for cutting ordinary steel and others with about 7 times the tensile strength to make cables for deep mine hoists and cableways.

Steel is also elastic. What that means is that if you load it, it stretches or shrinks. For instance a wire holding a weight will be longer under load than when the load is removed. However, the amount of stretch is very small and, depending on the load and the original length of the wire, would measure in the thousandths of an inch. In deep mine hoists this stretch was calculated exactly so that the winch driver, who was sitting in a little room above the shaft, could stop the hoist at exactly the right level down underground. Today a range of automatic detection and instrumentation devices have taken over this function.

If the load exceeds the tensile strength of the wire, the wire will stretch permanently - and then it will break if loaded a little more. A simple demonstration of this can be seen if you take a piece of straight wire and, holding one end between two fingers, bend the other end down a little bit and then let it go. It springs back to its original shape. You can repeat this, increasing the amount you deflect the free end of the wire each time and you will get to a point where the wire does not return to fully straight. You have then exceeded the tensile strength of the wire on the upper section of the curve, which was being stretched. There is a lot more to bending than this, but it serves to demonstrate that the material has an elastic limit beyond which it no longer behaves like a rubber band.

Another great quality that steel has is that it is equally strong in tension and compression. So, whether you stretch or compress it, it will deform by the same amount in either direction.

As the most common metal, steel can be cut, drilled, sanded, wire brushed, ground, welded, bent, polished by most DIY people for a vast variety of applications. It's greatest weakness is that it corrodes – plain old rust. In fact, that is where we get it from in the iron mines, from iron oxides.

So steel needs protection from the elements, moisture being the most important one. In FC work, the steel is completely encapsulated in mortar and if the mortar is 'waterproof' it will protect the steel from corrosion. However, if corrosion does set in, there is big trouble ahead. The volume of rust is greater than the volume of the steel from which it was formed. As a result, rusting areas act like wedges inside the mortar and will crack pieces off the surface. This exposes the steel to the atmosphere and accelerates the corrosion process and the ultimate failure of the FC. If it is localized it can be repaired. If it is spread throughout the work it will require replacement.

A case in point is a 60 km pipeline built to supply water from a coastal town to a mine. The pipes were manufactured using cement mortar and tensioned wire which was then covered with another layer of mortar. The plant that manufactured the pipes was set up about 5 km inland. During the manufacturing process, there was a bottleneck in the steam curing of the outer layer of mortar and as a result, pipes with the wire wrapped around the inner shell were kept in a stock pile until they could get the next layer of mortar. In the coastal environment with regular morning mist [with high chloride content] the wire started rusting - not terribly but you could see it. Within a year of completion, a number of failures occurred. Rust had popped off a section of the outer mortar layer and the remaining wire did not take long to rust away completely. The pressure in the pipeline did the rest. After about 15 years, the entire 60 km pipeline had to be replaced. [return]

Cement.

Cement is a blend of lime and clay which is fired at very high temperature in a kiln, cooled and then ground to a fine powder while adding a small amount of gypsum. Lime is calcium carbonate and gypsum is calcium sulphate – a more common name for the latter is Plaster of Paris and it is generally used as a plaster coat on internal walls in the USA. Portland cement was developed and patented in 1824 by Joseph Aspdin. Prior to its development, lime was the 'mortar cement' of choice but took a long time to harden. Portland Cement set and cured far more rapidly and, under pressure from the increasing pace of life brought on by the industrialisation of the world, displaced lime for this application and also displaced stone – when did you last see a modern monolithic stone column? It's all concrete today !

Cement is a fine grey powder which can cause respiratory problems, and because it is strongly alkaline must be handled with care. Breathing and skin protection are recommended.

When cement comes into contact with water, it reacts chemically to form new compounds. One of these [calcium silicate hydrate - CSH] grows a starburst of hairs called dendrites, from a central point in a cluster and these hairs give the final product its strength. The other important product that is formed is calcium hydroxide and this, together with the gypsum, gives the final product its high alkalinity.

In all chemical reactions, accurately measured amounts of the primary chemicals [reactants] must be mixed in order to obtain the predictable and desired products. This is equally true for the water/cement reaction. And while it may be possible to get a workable paste from the chemically correct proportions of water and cement, things change when we get to the next phase which is making mortar.[return]

Sand

There is little that can be said about sand that most people do not already know. However, for making cement mortar and concrete not any old sand will do.

The sand must be clean. That means it should not contain any organic matter, oils of any kind or foreign chemicals. Typically, building sand is excavated from alluvial deposits [ancient rivers that no longer flow] in valleys. It is then screened and graded before being sold. The most important consideration is that it should have a predominant proportion of inert material like quartz and a low proportion of clay [very fine silty material].

The surfaces of the sand particles should be rough and clean. Fine dusty material adhering to the surface and smooth surfaces are detrimental to the keying in process that must take place during the setting and curing of the mixture.

Sand, being essentially a miniscule rock, is very difficult to crush or to cut, and these are its strengths. As it is inert it will resist chemical attack and because it is hard, it will also last a long time.

For FC work it is important to use Mason's sand which does not contain particles larger than 2mm. If you have a suitable sieve, you can separate the fine and larger particles yourself and this may be the way to go for small jobs if you already have some builder's sand which is used in concrete work [return]

Stone

Having said all those things about sand it is really difficult to say anything about stone except that it should be a good hard material but definitely nothing like slate or sandstone, both of which are on the 'soft' side of the stone scale. Stone for use in concrete should have all the characteristics of the sand described above and has the same properties.

Water

The water that is used should be free of chlorides and sulphates. Chlorides in the mortar or concrete will attack any steel that may be present and sulphates react with the calcium hydroxide creating a new compound that is larger in volume, causing cracking. A rule of thumb is that if the water is potable [fit for human consumption] then it is good for use with cement.[return]

Mortar and concrete

Cement mortar [curing]

Cement mortar is a mixture of sand, cement and water which hardens noticeably a few hours after it was mixed if left undisturbed. The 'hardening' is the result of the growth of CSH dendrites as the cement chemically combines with the water and is usually referred to as the initial set. These dendrites inter- and cross-link with each other on a crystalline level, bonding at points of contact, to give the mechanical grip which holds the ultimate mortar together as a hard material. Unused mortar that has reached the initial set should be dumped. It is not a good idea to mix more mortar than you can use within an hour or so, in fact 10 – 20 minutes is better.

The sand in the mixture gives it bulk [volume] at low cost and the cement paste which hardens during the setting and subsequent curing processes, is the glue which keeps the sand particles in position to form a solid mass. A sand/cement mortar is essentially sand glued together by the dendrites of the CSH crystals. These dendrites also grow into micro-cracks and irregularities on the surfaces of the sand particles to create a bond with the sand. This is the essence of cement technology. return

In a strong mixture, each sand particle is fully enclosed in CSH crystals, in weak mixtures some particles are not fully enclosed. A strong mixture would be 3 sand to 1 cement while a weaker mixture would be 5:1.

Mortar mixes are generally given by volume because it is pretty easy to count shovelsful or bucketsful on the job site. Typically they will range from 5:1:0.6 [sand:cement:water] to 2:1:0.4 [by mass], although ratios outside those limits are sometimes used.

At the mixing stage, the most important thing is to make sure that you do not add too much water. There is no overstressing of the importance of this statement. If there is too much water in the mixture, then the final product will be weak – so weak that you can rub grains of sand off the surface with your finger. A second reason for limiting the amount of water is that all cement based mixtures shrink during the setting and curing processes. The amount of shrinkage increases with the amount of water in the initial mix and more water will result in more and larger cracks.

It is equally important to mix the ingredients thoroughly. The purpose of mixing is to coat every particle of sand with cement/water paste.

That said, the amount of water added to a good mortar mix must be more than the amount required by the cement/water chemical reaction. There are two main reasons for this.

Firstly, that sand particles absorb some water into micro cracks and surface roughness. You can see this if you take a bit of sand and slowly add water while you mix it. The sand becomes damp and a little 'sticky', but there is no free water running off the sand at first. As you add more water, some of it starts to drain off. The better sand types do not absorb a lot of water.

Secondly, if you add only the exact amount of water needed for the chemical reaction, you will have a very unworkable mixture. It will not have the required degree of “slop’ and will tend to ‘tear’ when you try to spread it onto a surface with a trowel.

A good mix will be fairly stiff but will soften if worked a few times. What masons typically do is to take some mortar on their mortar board and then lift it off and slop it down again a few times. The mortar becomes softer as they do this, and then they apply it. So, a good indication of whether you have too much water in your mix is that you can easily apply it without ‘working’ it over a few times. You can recover this mortar by adding some dry sand/cement mix.

A good way to mix mortar is to always keep about 20% of the measured quantity of water out of the mix at first , and then add it bit by bit until the mix has adequate workability. If you are hand mixing, you can ‘see’ it because the mix turns from crumbly to pasty. The same will be seen in a barrel mixer as well as other types. Once pastiness becomes evident in part of the mix, slow down with the water and keep working the mix as you may already have enough water. If the mix remains crumbly rather than pasty, add a little more water and continue mixing until the whole batch is pasty. The transition from crumbly to pasty is quite sudden so add water very cautiously and in small amounts. When you have the correct amount of water added, make sure that you can repeat the quantity for the next batch so that you do not have to go through this process again.

The typical mix proportions given by the cement industry in brochures and leaflets and on their cement bags [sometimes] are good guidelines. As the user you must be careful not to choose the easy way out and make a soupy mixture as you will have poor results.

The cement in mortar and concrete is usually the weakest component. In fact, engineers specify mixtures this way to ensure that they can maintain control over the strength of the final product of a construction process. It would serve no purpose to have very strong cement paste and soft stones in concrete.

The strength of cement paste can range between 7 and 40 MPa compressive stress. Its tensile strength would then be range from 0.35 to 2 MPa, roughly 5% to 10% of the compressive strength.

Common steel like angle iron and flat bar have a strength of about 220 MPa in both compression and tension. Reinforcing steel is designed to have even greater strength.

Concrete

Concrete is essentially mortar with stone added to the mix. The volume of product that you can get this way is much greater for a given quantity of cement, the most expensive ingredient. Just as the cement/water paste must coat each particle of sand, so it must coat each stone. However, the surface area of a stone compared to its volume is far less than the surface area of the same volume of sand, so it requires less cement/water paste.

A heap of stones has a large volume of air space inside – the gaps between the stones where they are not in contact with each other. These voids must be filled, and this is what the mortar does. So, next time you see a concrete column or beam or slab you now know that you are looking at a shaped pile of stones in which the voids are filled with sand with the whole lot being held together by CSH crystals.

Please realize that this is a very simplified and limited description of concrete. The reason I choose not to say more on the subject is because it is a science in its own right and because we do not use concrete, only mortar.

Curing of cement based compounds

A chain is as strong as its weakest link.

In order to ensure good strength in the cement bonding process, CSH dendrite growth must be maximised. When concrete is used in construction, samples are tested for 7- and 28-day strength. Typically concrete will attain between $^1/_3$ and ½ of its design strength after seven days of curing and design strength [or more] at 28 days. What this should tell you is that the dendrites continue to grow for a long period of time. But for dendrites to continue growing moisture is needed. So, to maximise strength, <u>mortar and concrete must be kept moist after initial set</u> and this is referred to as <u>curing</u>.

The chemical reaction between the cement and water to form CSH is fairly rapid. At the same time there is a second product, calcium hydroxide, being formed which is a strong alkali. This process is a little slower.

Once the CSH has formed it begins to grow dendrites and after a few hours they reach a kind of critical mass where the mixture hardens to initial set. By that time the amount of calcium hydroxide formed, together with the gypsum, has increased the alkalinity to the extent that further growth of the dendrites is radically reduced. Any disturbance of the mixture at this stage will have significant negative effects on the strength of the final product. If the mix has not been used by this time, it should be discarded.

Some hours later, <u>provided there is adequate moisture present</u>, dendrite growth gains pace again and the strength of the set mixture increases.

Curing mortar.

Mortar is seldom used for high strength applications. Typically it is used in brickwork where minimum brick strength is of the order of 7 MPa. In that situation, there is little to be gained from a greater mortar strength. The same applies to cement mortar used as a plaster finish on walls. So, in practice, the curing procedure consists of wetting the walls for a few days after the they were built or plastered.

A friend of mine had cast a concrete slab with the help of a labourer. As often happens it took longer than expected and the slab was a little higher than it should have been. It was getting dark and he drove his labourer back home thinking that he could easily chip off the excess when he returned. He very quickly discovered that his chipping hammer was not doing the job and started using a pick. 3 Hours of picking later, at about 10pm, pretty worn out and kicking himself in the butt for his stupidity, he fetched the water hose to ‘blast’ off all the chippings. No sooner had he started jetting the chippings than he realized that the water was washing out the mortar between the stones.

Mortar that has attained initial set has some strength, enough to make it unworkable. But beware, a strong stream of water will wash it away with impunity. Wetting should be done gently.

An application that requires high strength in the mortar is FC boat building. On top of using additives in the mixture to improve early strength development, impermeability and control shrinkage, the mortar is carefully cured using methods such as automatic water sprinkling systems. The obvious expense involved in this additional effort serves to demonstrate its importance.

The same care can be seen on construction sites where concrete is kept enclosed in the formwork and wetted for the duration of the curing period.

The strength of cement based compounds comes from the dendrite bonds, with each other and with the sand and steel [and the stone in concrete and FC]. Dendrite growth is slow and will continue for a long period of time, but it needs moisture. In order to get good results you need to keep your work moist for at least a few days after you have finished it – the longer the better up to about 28 days as after that further strength gain is very small and slow. If the work takes more than one day to complete, keep the previously completed work moist as you continue so that each section completed is kept moist for at least three days. If the work was a concrete slab, it can be kept moist by covering it with plastic builders sheeting. Sometimes wall surfaces or other vertical objects can be covered this way too. Do whatever you can to keep the mortar moist for a few days.[return]

The purpose of steel in concrete.

Steel is paced within concrete to give it the ability to carry tensile loads. If you have ever watched the building process on a construction site where a concrete building is being built, you will have seen the framework of steel rebars that are assembled. These are then enclosed by forms into which the concrete is then poured. Now, a column is going to carry the weight of the part of the building above it so it will be in compression. And if it is going to be in compression then why go to the expense of putting steel in it? *[There will be a separate essay on this website explaining how structural members carry loads.]*

The answer is complex but it suffices to say that there are may factors of loading that influence this. Compression load on a structural member creates tensile stress in the transverse planes. Side loads from wind and differential expansion on the sun and shade sides of the building are two more examples. There are also transmitted loads from floor slabs. The result of all the load factors is that columns are subjected to bending as well as to compression. And when you have bending, there is compression on one side of the structural member and tension on the other.

You can see this very simply by taking a sponge, holding its ends and bending it. One side develops folds and the other stretches a bit. The side with the folds is in compression and the other in tension. You could try the same thing with a sheaf of papers. If you hold one edge of the sheaf down on a desk and lift the other end up, you will see that the sheets slide over each other so that the lifted edge is angled. If the paper had not been free to slide, the sheet sticking out the furthest would have been under the greatest compressive load and each sheet lower down under progressively less load. If you now hold both ends together firmly and bend the sheaf, the papers on the inside of the curve will buckle away from the rest – they are in compression. If a structural element were to deform to this extent it would have failed. So, before the buckling takes place, the top half of the sheaf of paper is already in compression and the lower half is in tension – and you can feel it. The sheaf is quite stiff until the buckling occurs at which point the sheaf is suddenly far more flexible.

The steel framework that is erected before being encased in concrete is designed to be close to the outer surfaces where the tensile load will be greatest, and is usually evenly distributed close to the outside perimeter of a column. A column generally has varying multidirectional loads and must handle bending in any direction equally well.

A beam on the other hand, is primarily designed to carry bending loads. Normally the upper portion of the beam is in compression and the lower part in tension. Consequently, more steel is placed in the lower section of the beam where the tension will occur.

In all cases steel is joined by stirrups and hoops so that when the concrete is loaded, loads are partially transferred from areas of high concentration to areas of low concentration. This sharing of load is achieved by the mechanical lock effect of the transverse steel members as well as the basic adhesion of the cement paste to the steel.

I have pointed out all this because it is probably a part of the common life experience of most people and therefore serves as conceptual reference – something most people have a handle on. So now we make the transition to FC.

The F in FC

Guess what ? Steel does exactly the same in FC as it does in concrete, plus a little more.

Lets take a look at a flat surface like a wall, only this one is made from FC. Let it be a wall from a foundation up to a roof beam and between two columns, firmly attached to all of them. And, for the purpose of illustration, let’s accept that those four elements are rigid and will not budge when we push against the wall.

When we push on the wall, right in the middle where it is weakest, the wall will bend away from us but resist the force we are exerting. If we increase the force, the wall will bend away more and resist more. It behaves just like a spring. The more you try to compress it, the shorter it gets but the more difficult it becomes to compress it more, because its resistance increases as it shortens. Actually a trampoline mat is even more illustrative of what is happening with the wall.

When you jump on a trampoline, it starts deflecting downward the moment your feet make contact with the mat. But the contact is soft at first and rapidly becomes stronger as it slows you down to the point where there is a deep dent in the mat and you are no longer moving downwards. Then you get slung back up again.

In order to see what is happening to the wall you should also look at the springs of the trampoline, because the wall will not show a deep dent – in fact you may have trouble seeing any deflection at all, but it is there. When the trampolinist is at the lowest point, the springs holding the mat to the frame are stretched, very noticeably so. And the same thing has happened to the FC wall, only unnoticeably so. So, other than the point where the force is being applied to the wall, the whole wall is in pure tension. And if it were not for the steels mesh inside there, it may well have failed already [depending on how thick it is and how great the force].

But if the wall were thick then it would have been prohibitively expensive to use mortar so we would have used concrete. And now we are getting to it. The FC wall uses far less material for the strength that it demonstrates. FC work is generally thin walled, say ½" to a few inches thick and it can be impressively strong for such a deceptively thin material.

But FC is so flexible with regard to its forming process that it becomes very easy to make curved things. In fact it was probably the desire to make strong curved things that led to the current upswing in the popularity of FC. Boats and domes and barrel vault houses are just some of the many curved things that have been made using FC. They are relatively formal shapes. Under informal shapes there are artificial rocks, ponds, and sculptures from small to huge.

This is not to say that straight things cannot or are not being made. In fact, in India there is a lot of activity around using FC in low cost housing, for walls, floors and roofs. They make beams using FC, not tremendously long, but enough to span a good sized room, and the beam is a lot lighter than its concrete equivalent so it uses less material. When FC is used this way though a knowledge of stress analysis is essential, so it is not a good place to start.

Bernhard Haussler
hangar@iafrica.com.na