The flexural theory in structural design has directed attention to the tensile stresses in structural members, since most materials are able to resist large compressive forces. This is particularly true for a material such as concrete which has little fibre strength. Concrete, however, can be strengthened by adding materials which have high tensile strength and by placing these materials at critical positions within the member. Steel reinforcing bars and welded wire meshes have been used with concrete for a great many years and reinforced concrete has become a recognized structural material. The reason for employing a non-homogenous material is, primarily, to obtain a balanced design in which compressive and tensile forces are distributed proportionally within the loaded member and to obtain a member which is more compact and sometimes more economical.

Materials like steel, aluminium, cement asbestos and plywood may be shaped to distribute the applied forces and sections of angles, I beams, channels or other forms and are chosen by the designer for specific application.

Timber is the most common structural material in Canada and is probably the one which is most abused by designers. Comparatively, it is a uniform material with wood fibres providing the strength to resist applied forces. It is, usually, not economical to shape timber to distribute the compressive and tensile stresses nor has it been customary to reinforce timber in any way to give it assistance in carrying tensile loads (figure 1). Indeed, it is recommended by the Canadian Institute of Timber Construction that steel reinforcing should not be used with a timber structural member, either plain or laminated. There have been many instances where steel rods have been anchored in timber on the tensile side and there have been steel plates embedded in the lower portion of laminated members, but, in these cases, there has been no joint strength between the steel and timber and in fact, the break in the wood fibres has decreased the initial strength of the timber member. Other methods of reinforcing timber beams consist of strapping steel plates to the sides or top and bottom of the member. This is a sound approach structurally, but is not economical and does not place the steel in the critically stressed portion of the beam just below the neutral axis.

Fibreglass is a material which combines two of the characteristics of both steel and timber. It is fibrous and has a high tensile strength which are attributes desirable for reinforcement material. The strength to weight performance of this material has indicated an advantage over some of the more familiar materials used for reinforcing, since transportation to a construction site is very easy and handling on the site should reduce labour. Desirable compound curvatures can be readily achieved with this moldable material which can be formed as easily in one shape as another without the use of forming tools.

In agricultural, or other structures, the designer is often confronted with the problem of carrying different types of loads even within one member. This can be accomplished in any portion of the structure, with the same basic materials, by simply changing the cross-section and orienting the high strength fibres in the direction of stress. Large tension loads can be efficiently supported by using cloth or uni-directional fibres oriented so as to be aligned with the direction of load (figure 2). An impact resistant area can be created by increasing laminate thickness locally with reinforcements selected for high impact strength and oriented to be equally good in all directions. Furthermore, with many types of resins available, a bond can be obtained between the fibreglass and timber to such a degree that the glass fibres becomes an integral part of the timber and often the resin is stronger than the wood fibres themselves (figure 3).

Fibreglass laminates are essentially a combination of high strength glass fibres bonded together with comparatively low strength resin. The glass fibres are distributed throughout the laminate and provide the strength to the combination. Although individual glass filaments can develop tensile strength between 250,000 and 400,000 pounds per square inch, the mechanical distribution of the filaments in a laminate does not permit the combination to develop this strength. In essence, when fibreglass is used to reinforce timber beams, a laminate is formed, because the resin soaks through the fibreglass and adheres to the timber.

The glass filament used as reinforcement material is a lime-alumina borosilicate E glass of low alkali content which has high chemical stability and moisture resistance. This is desirable in agricultural applications because of the high humidity conditions in most farm buildings and because of the possibility of insect infestation. Sometimes, steel reinforcement is corroded by acids from milk waste or silage but
glass, and the resins used in the combination, will be resistant to acids encountered on the farm.

**TYPES OF MATERIAL**

**Rovings**

Rovings consist of straight bundles of continuous strands resembling a loose untwisted rope. This is used as uni-directional reinforcement and is the best material available for reinforcing timber, provided the strands can be kept reasonably taut and parallel during the application.

**Woven Roving**

This consists of flattened bundles or rovings of fibreglass filaments \( \frac{1}{8} \) to \( \frac{1}{4} \) wide, woven in to a plain square pattern (figure 4). This material has application for reinforcing timber if the fibreglass is soaked through with the resin and if the resin has a good contact with the timber components.

**Cloth**

Cloths and tapes are woven from twisted and plied strands of glass filaments and may be used successfully for reinforcing timber components if properly saturated with resin (figure 5). It is especially good where high stress areas are recognized, but due to a relatively high cost of the material, it is not practical to use for continuous reinforcement.

**Mat**

Mats of fibreglass are available and consist of chopped strands of fibreglass, randomly deposited to form a sheet or layer. This may be used for reinforcing, but does not have the tensile strength of some other types of construction, since the fibres are located in a non-uniform pattern. However, an interesting and practical application of this may be in the use of the Patterson spray gun which consists of a three-way nozzle, wherein resin, chopped strands of fibreglass and a catalyst meet simultaneously and are sprayed on the contact surface.

**Pre-impregnated**

Pre-impregnated reinforcements are reinforcements preloaded with resins (figure 6). It is commonplace to apply pressure and heat to create contact between the pre-impregnated material and the contact surface. However, most of the materials in this category have an affinity for water and the adhering qualities are soon lost as moisture is taken from timber or the surrounding air. This is an especial detriment in farm buildings where high moisture conditions are present.

**Resins**

The resin is an important factor in the combination for reinforcing timber and must be chosen with care. Usually, the thermosetting type, such as, polyesters, epoxies, phenolics and melamine are used for this purpose and cannot be remolded once cured to the solid state. Curing may take place in 30 minutes or less, but in no case, should brittleness be permitted in beam construction.

Research has been carried out at the Ontario Agricultural College, to determine the reinforcing capacities of fibreglass and resin where conjoined with timber in a plain or laminated state. Most of the combinations of fibreglass strands were studied for comparison reasons regardless of the ultimate cost or difficulties of application, since it is to be expected that refinements in production in the plant or in the field will make the method practical in due course. No other comparable work is evident in literature review, though the application of fibreglass reinforced plastics have been applied for many other purposes and the physical and chemical properties of resins and fibreglass are well known. The studies were made by constructing test specimens of white pine and douglas fir with an unsupported length of 24 inches and \( \frac{1}{16} \) inches wide. Five laminations of \( \frac{1}{4} \) inch material were used for laminated beams and similar overall dimensions were used for solid beams. Three samples of each specimen were used in each test and the tests were carried out in pairs, according to direction of grain, since there was a wide variation in this factor in the material used for test. The reinforcing material was placed at the bottom laminated joint, though in some cases where compression failures tended to occur, studies were made with the reinforcement also placed at the top laminated joint (figure 7).

The primary tests were made with the pre-impregnated fibreglass and panite as the bonding material. While the initial contact was very good and it appeared that a complete bond was obtained, overnight setting caused a delamination of the test specimen. This was caused by the moisture in the timber specimen, since the pre-impregnated fibreglass had an affinity for the water. Panite is a water base adhesive which gave up more moisture to the reinforcing material. Application of pre-impregnated fibreglass would be difficult for large scale production, since heat and pressure must be applied for good results.

Epoxy was used as a replacement for Panite and proved to be much more satisfactory, but failed in the brittle qualities which it gained on set (figure 8).
The resin and fibreglass used in reinforcing timber beams are materials which are resistant to rot, insect infestation, and are not effected by acids normally found in and around agricultural structures. They are materials that are readily available and easily applied.

There should be additional research carried out in this field, since the potential is excellent in the farm structures area.

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**GLASSHOUSE DESIGN**

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