THE EFFECTIVENESS OF PLASTIC FORMWORKS IN CONSTRUCTION

By

Jam Isnain Lam

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Alhamdulillah thanks goodness' for Allah who gives me strength to finish my final year project.

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ABSTRAK

Satu kaedah baru dalam industri pembinaan telah ditemui, iaitu kerja-kerja acuan plastik yang mudah digunakan dan kebolehlenturan membrannya yang boleh mengawal ubah bentuk dibawah beban mati yang disebabkan konkrit basah. Kaedah ini digunakan untuk menggantikan kerja-kerja acuan lama yang mempunyai banyak masalah kepada industri pembinaan. Ini menjadi satu kelebihan dalam aplikasi kerja-kerja arkitek, kejuruteraan, dan teknologi pembinaan di dalam asas pembangunan ekonomi. Penglibatan kos yang rendah dan penggunaanya yang boleh digunakan semula beberapa kali telah menjadi satu pilihan dalam aplikasi pratempaan dan tempaan sepenuhnya. Kaedah ini telah dibangunkan untuk asas pembuatan fabrik, dinding, slab, tiang dan rasuk. Kesenangan membran yang membenarkan gelembung-gelembung udara dan lebihan campuran air untuk keluar, telah menghasilkan ketidakcacatan pada konkrit dan juga kandungan simen yang optimum, menyebabkan konkrit menjadi lebih kuat dan tahan lama. Pembinaan struktur bangunan lebih efisien kerana ia mudah direkabentuk, mengurangkan beban mati dan menjimatkan kos material. Pada masa ini kerja-kerja acuan banyak menggunakan kerja-kerja acuan kayu. Ciri-ciri kayu yang sensitif terhadap kelembapan, senang bengkok, meleding dan mengubah bentuk permukaan konkrit, memberi kesan terhadap konkrit. Selain itu, kayu susah hendak dibersihkan, senang rosak, patah, dan apabila ini berlaku, kayu tidak boleh dibaiki dan mestilah menggunakan kayu yang lain. Penggunaan kayu yang berulang kali boleh menyebabkan permukaan konkrit rosak, kerana permukaan kayu yang tidak baik dan senang tercalar. Kegunaan plastik telah banyak digunakan pada masa kini, dan salah satu jenis plastik yang sering digunakan ialah dari jenis polypropylene (PP). Plastik jenis ini senang didapati dalam pasaran.

ABSTRACT

A new construction method replacing rigid formwork panels with flexible textile membrane that deflects under the dead weight of wet concrete, provide numerous advantages and opportunities for architecture, engineering, and construction technology in both advanced and basic building economies. Inexpensive formwork fabrics provide the options of sacrificial or reusable formworks in both precast and cast-in-place applications. A method has been developed for fabric-cast foundation, walls, columns, capitals, slab, and beam. Permeable membranes allow air bubbles and excess mix water to bleed out, producing a flawless, cement-rich finish and stronger and more durable "case hardened" concrete. Structurally efficient variable section members are easily formed, reducing dead weight and material expenses. Most formwork panels these days are faced with plywood. Plywood is sensitive to moisture and can swell, warp and discolour the concrete surface. Plywood is difficult to clean, is easily damaged in use, and can only be repaired at some expense and not without visible traces. For several years now, formwork panels with plastic surface – mainly made of polypropylene (PP) – have also been available on the market. Although these overcome the problems associated with plywood, they are very sensitive to scratching and in many cases, after only relatively few uses, are unable to guarantee a smooth concrete surface.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Plastics formwork uses a flexible textile membrane in place of the rigid formwork panels usually used in concrete construction. When wet concrete is contained by thin formwork membrane, the flexible fabric container naturally deflects into a repertoire of precise tension geometries. This produces naturally efficient structural curves, unprecedented sculptural form, and extraordinary surface finishes. Plastics formworks can be used to form columns, walls, beams, slabs and panels in both precast and in-situ construction. It has significant potential for construction and engineering technology in both advanced and basic building economies. From a sculptural/architectural perspective, the uses of flexible formworks awaken concrete to its fluid origins, introducing a new horizon for architectural form and expression.

1.1 BACKGROUND

Plastics formwork is a special class of lined formwork intended to produce improvements in the strength and durability of the surface of concrete. The bracing and the liner in the formwork are engineered to resist the pressure of plastic (or fresh) concrete, but to allow trapped air and excess water to pass through and be removed during concrete placement and consolidation. The objective in using plastics formwork is to eliminate voids (bug holes) on the surface of the concrete and to increase the strength and durability of the concrete surface immediately behind the formwork. The concept of using the formwork to remove excess water from cast concrete originated in the work of John J. Early in the 1930's. Early manufactured precast architectural facings using dry plaster molds that absorbed water from the concrete and produced a better surface finish on the ornamental castings than he had been able to obtain with coated forms. The earliest types of absorptive from liner consisted of 12-mm-thick panels of pressed board made from ground cane, wood pulp, and similar materials. Even this relatively simple liner eliminated practically all pitting and voids in the concrete surface. Concrete samples that had been cast against absorptive liners and oiled wood were tested by sandblasting. The sample cast against wood showed exposed aggregate while the sample cast against absorptive liners showed "practically no wear with the exception of a new void". Generally the more absorbent the formwork, the lower the wear shown (Johnson, 1941). These early test used a Portland-cement concrete mixture with a 0.6 water-cement ratio (w/c) by mass. Although the 150-mm cubes used in this early testing did show higher unconfined compressive strength in the cubes cast with absorptive

Formwork (as opposed to conventional formwork), it recognized that the absorptive effect of the mold had its major effect in producing a denser, more durable surface with a reduced number of bug holes (Johnson, 1941).

1.2 OBJECTIVES

The focus of this study is to determine the effectiveness using plastics formwork in construction and to study the behaviour of plastics formwork for its possible use in construction.

The purpose of this objective is to adopt plastic formworks as an alternative to replace timber formwork. Nowadays, timber is difficult to obtain and also expensive.

1.3 SCOPE OF STUDY

The scope of this study is to determine the effect of plastic formworks to the environment. Besides that, it is also to know the type of plastic formworks mostly used in construction. The costs of using plastics formwork is important in the production of plastic formworks.

Furthermore, the advantages of using plastic formworks as compare to other formwork are its weight, durability and the smoothness of the concrete surface.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Fibre reinforced polymer (FRP) or call plastics formwork; composites have an extensive history of successful uses in the aerospace, defence, marine, corrosion resistant equipment, and automotive sectors. However, until recently they were largely considered to be of limited value in civil infrastructure beyond use in facades, aesthetic additions, and for architectural purposes. Nonetheless, over the past two decades these materials have made a rapid transition from subjects of academic research to being increasingly considered for use in the renewal of civil infrastructure.

FRP composites, today, are used in a variety of applications, ranging from replacements for steel rebar and woods used conventionally as tensile reinforcement in concrete, jackets for retrofit of columns, and externally bonded reinforcement for the rehabilitation of deteriorating structural system, to use in all composite structures such as building frames. Despite their relative newness, these materials (primarily using E-glass and carbon reinforcing fibres), are being increasingly adopted for specific applications on par with, and even in preference to, conventional construction materials such as steel and concrete. The attractiveness of composites is not merely based on performance attributes such as high specific strength stiffness, and corrosion resistance, but also due to their light weight and ease of installation in the field, tailor able anisotropy, ability for rapid installation often without disruption of traffic, and potential for long-term durability.

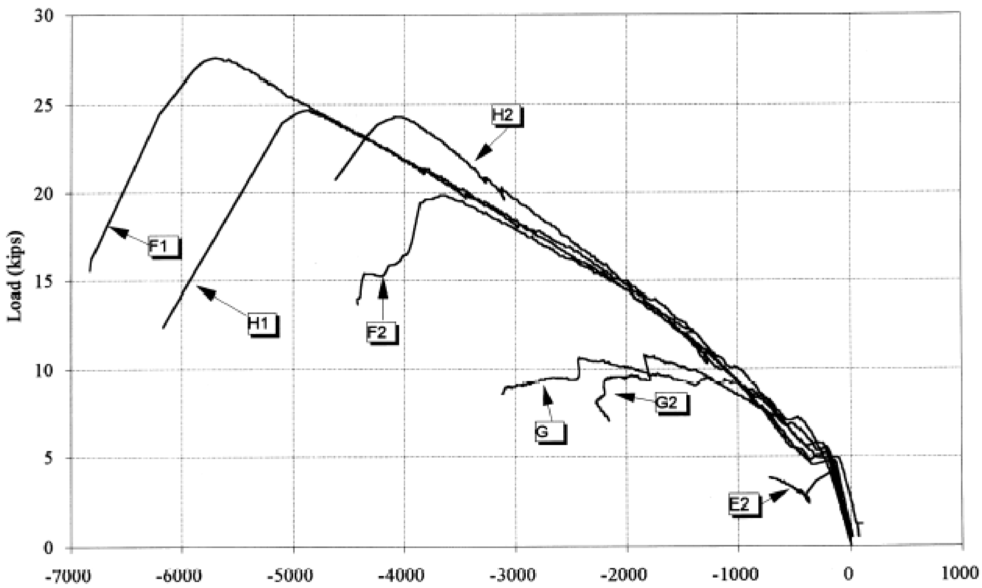
Composites have perhaps found their maximum current use as materials for rapid and cost-effective rehabilitation (retrofit, repair and strengthening) of deteriorating and under-strength structural concrete components. A significant number of tests on columns, walls, beam, girders and slabs have been conducted at scale and full-scale levels to characterize structural response in laboratories, and a large number of field applications also exist worldwide. While the use of FRP in these areas has already found widespread acceptance, progress in the area of new all-composite or hybrid structural components and system has been a bit slower. The response of building systems, structural formwork and profiles has been well characterized in laboratory settings with most of the test being scaled. There are now an increasing number of field applications of these systems, most of which can be classified as demonstration projects. The exception is in the area of building where there has been increased activity over the last few years, driven by needs of lighter weight and more durable systems to offset increasing costs of maintenance of conventional structural concrete in areas of harsh climatic condition, or where there is a need for upgrading of structures to meet new code requirements without access to new construction. In other cases the transition is being accelerated by the need to essentially maintain historical structures. It should be noted, however, that polymer composites are universally applicable in civil infrastructure and cannot be considered as a panacea for deteriorating and other ills facing the world’s built environment.

Despite the increased acceptance of FRP as an addition to the palette of materials available to the civil engineer, further acceptance and widespread use will intrinsically depend on a number of key challenges being addressed. These include aspects related to fire resistance (including the requirements associated with noxious fumes), assurance of durability in harsh changing environments for extended periods of time (75 years or more) with minimal maintenance and inspection, lower manufacturing costs and assurance of high levels of uniformity and repeatability, a greater level of standardisation of products similar to that now existing in the steel industry, and complete development of codes and standards by cognisant authorities worldwide.

Rather than provide a comprehensive review of worldwide activities as related to the application of composites to civil infrastructure renewal, this article attempts to address specific examples that emphasise critical advantages, as well as the transition being made from research and development to field implementation.

2.1 MECHANICAL PROPERTIES

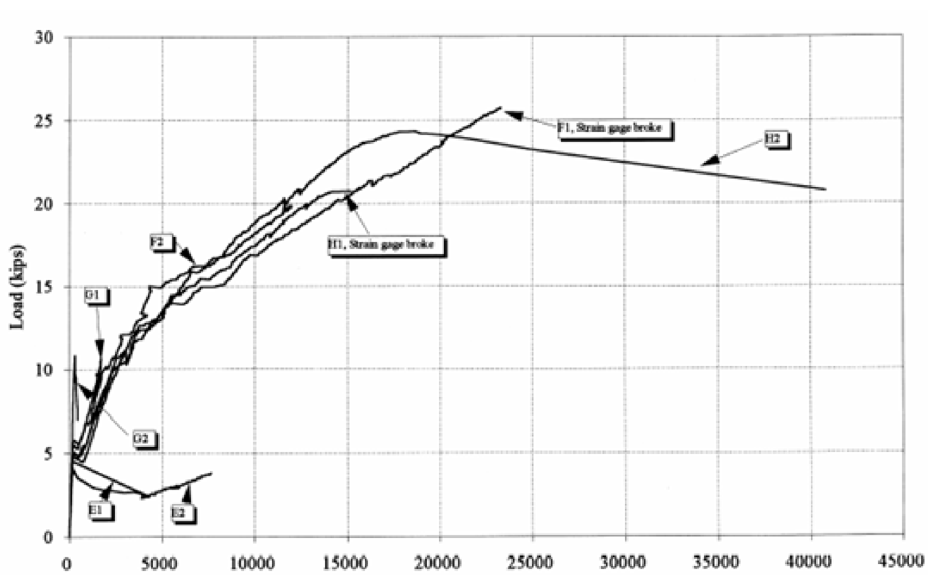
The ultimate strength of FRP is stronger than steel for same diameter. However unlike steel the compression strength is less than the tensile strength. The strength is close to twice that of steel. The load-strain diagrams for FRP show the top and bottom for specimens (refer Figure 1 and Figure 2 below). The stresses in Glass FRP (GFRP) bars are well below ultimate when failure occurs. The modulus of elasticity is twenty-five percent of that of steel. The low modulus of elasticity of FRP may lead to the deflection limit state controlling designs due to it being one quarter that of steel. Lower stiffness produces load deflection that is almost linear. At ultimate load, deflection in GFRP is double that of steel, but due to the higher strength and ductility at failure, deflection of the steel reinforcing is greater (Saadatmanesh, 1994). The specific gravity of FRP materials is a quarter of that of steel, which makes it easier to handle. FRP and concrete have similar coefficients of thermal expansion, which will aid in its use. The bond strength of FRP reinforcing is not as high as steel reinforcing bars, but then again epoxy-coated bars reduce bond strength (Bedard, 1992). The bond strength has been determine to be two-thirds that of steel reinforcement (Brown, 1993). The fatigue of GFRP reinforcing is good up to half their strength.



Top strain

Figure 1: Load vs. top strain for specimens

(Source: Nanni, A. and Bradford, 1993)



Bottom strain

Figure 2: Load vs. bottom strain for specimens

(Source: Nanni, A. and Bradford, 1993)

2.2 MATERIAL PROPERTIES

The use of FRP as reinforcement has the following advantages of lightweight, high tensile strength, corrosion resistance, flexibility, and electromagnetic resistance (Khalifa, 1993). The disadvantages of FRP are low modulus of elasticity, higher cost, low failure strain, anchorage methods, bond to concrete, and ultraviolet light sensitivity. FRP can be made of carbon, aramid, or glass.

Fibres reinforced plastics are often made by the pultrusion process. The fibres are impregnated with a resin and pulled through a dye that forms the geometry of the section. The sections can be hollow tubes, shape or round rods. The round rods are wrapped with additional fibre to form ribs, which aids in the bonding to concrete (Saadatmanesh, 1994). Hooks and bends are difficult to make. It may be necessary to make connections like plumbing or use grids where straight sections will not work (Bedard, 1992). Carbon and aramid FRP can have high fatigue characteristics; three times more than steel, glass fatigue characteristics are generally less than steel. Of the three types of FR, mentioned here, CRFP (Carbon Fibres Reinforced Concrete) has the highest tensile properties. Aramid FRP (AFRP) has the higher strain at failure, but also is most affected by water. Glass FRP (GFRP) is the least and is sand finished for better bonding properties (Erki, 1993). FRP material resists temperature as high as 225^0F. At temperatures in excess of 400^oF, FRP reinforcement loses some of its flexural capacity. High temperature areas could prevent the use of FRP in bridges (Brown, 1993).

2.3 RESULTS OF THE PAST STUDIES

The mechanism of FRP and concrete is to determine the bond strength. The mechanism of FRP and concrete has the ultimate bond comparable to steel with greater slippage however. Also the temperature affects the bond by decreasing it for higher temperature. The FRP rod surface pattern, shear modulus, and surface area to diameter ratio affect the bonding mechanism . Besides that, the axial tension provides an indicator of the cracking width and spacing (Nanni and Bakis, 1994). The cantilever beam is a good indicator of the flexural action in building.

2.4 SUMMARY

There is a need to increase the use of alternative materials for reinforcing concrete structure (Brown, 1993). FRP is a promising material for use as concrete reinforcement. FRP is available as grids, rods, and ropes for prestressing. FRP initial cost is much greater but gets closer to steel once consideration is given to the preventive methods in use to prevent damage to the concrete. Possible cost saving could be found in thinner concrete sections due less cover requirement. However, some section may need to be increase due to tensile splitting of the concrete (Erki, 1993). The use of FRP could be a cost effective long-term solution to the deterioration of concrete due to corrosion of reinforcing steel (Bedard, 1995).

Additional bond needs to be performed to determine development lengths. The manufacturing process needs to be standardized, so that result is universally applicable from one manufacturer to another. The long-term performance of FRP as reinforcing needs to be studied. The durability and reliability need to be predictable (Saadatmanesh, 1994). The ACI current equation for effective moment of inertia, I_e, uses M_{cr} /Ms to the third power whereas going to the fifth power is a more accurate measure of I_e used in the deflection calculations (Brown, 1993). ASTM standards for FRP need to be developed, so that material is consistent and as reliable and predictable in use as steel. FRP will need more extensive testing to determine design parameters that will provide comparable safety factors as used in steel reinforced concrete. More research and work are needed to develop guidelines for the design of structures incorporating FRP materials (Bedard, 1995). Appropriate design procedures need to be developed and confirmed by test data. Acceleration of material testing such as cyclic loading needs to be increase to further studied FRP as reinforcement (Nanni and Bakis, 1994). Nanni also suggests a greater benefit would be to use FRP as prestressing strands.

In 1996, the ACI produced the *State-of-the-Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structure*. The report presents material development, test method, design guidelines, research summaries, recommendations, and research needs. It is recommended concrete sections incorporating FRP reinforcement use compression failure design due to higher ductility, deformability, and lower deflections and crack width. The concrete strength governs the design rather than the reinforcement strength.

CHAPTER 3

METHODOLOGY

INTRODUCTION

This case study is concerned with essentially four different configurations. The concrete was the same basic mix in all configurations. Epoxy-coated reinforcement was used in the control specimens. Non-coated reinforcement was used in the specimens that contained FRP bars and grids and polypropylene-based fibres strands. The properties of material used are presented in the following sections.

1) Kodiak #3 FRP rebar.
2) Duradek I-6000 grid.
3) Non-coated steel reinforcement bar.
4) Epoxy-coated steel reinforcement bar

3.1 FIBRE REINFORCED PLASTIC REINFORCEMENT

Fibreglass reinforced plastics is a composite material. It consists of a plastic resin array with glass fibres to reinforce. The type of fibers controls the reinforcement strength, the orientation of the fibres, the amount of fibres, and the placement of the fibres. A resin binds the reinforcing glass and provides rigidity. The resin material determines the degree of protection from corrosive action, fire, impact and fatigue. The resin also determines the maximum operating temperature in which the reinforcement can be used. Fibre reinforced plastic is manufactured by the process pultrusion. Pultrusion is a manufacturing process for the producing the lengths of reinforced plastic structural shapes. Pulling continuously on the material pulls the raw material through a heated steel die. The reinforcement materials are in rolls of fibreglass mats or balls of fibreglass roving. The reinforcement are encased in a resin bath and pulled through the die. Heat is applied which produces gelatine of the resin that takes on the shapes of the die.

3.2 FRP REBAR

The fibreglass-reinforced plastic rebar used in the beams was obtained from International Grating, Inc. (IGi). The trade name designated is Kodiak. Properties that IGi claim to be advantages of their product are non-magnetic and electrically no conducting. The rebar has ability to resist electrolytic corrosion and attack of acids, salts, and other chemicals that affect steel.

Kodiak rebar is made bye the pultrusion process. The strands are soaked in resin and pulled through a die that removes excessive resin. Around these strands, additional bands of glass fibres are wrapped. This produces the deformed surface similar to that found on steel reinforcement rods. The final procedure is to heat cure the Kodiak rebar and cut it to length, twenty feet for IGi. To obtain hooks and bends in the FRP rebar, they must be made at the plant. The placement in the field is the same as for steel reinforcement except for the use of plastic ties and bent reinforcement areas are not done in the field. The material is lighter than the same size steel reinforcement. The high strength to weight ratio is an advantage that make it easier to handle in the field. IGi presents some of the disadvantages of their product in their literature. The modulus of elasticity of FRP bars being much lower than steel bars affects strength, deflection, and crack width. Whereas low temperature neither does nor seems to be a problem, high temperature (>230$_o$F) produces a loss in strength and flexural modulus. The ultimate tensile stress has a range of 100 to 200 ksi. The manufacturer recommends that 100 ksi be used. Also, they recommend that concrete should be 4,000 psi or greater. Table 1 contains properties of Kodiak FRP #3 rebar as measured or supplied by the manufacturer. Figure 3 show the interior shear ribs of the FRP tubes.

TABLE 1: FRP REINFORCEMENT PROPERTIES

Material	**f_y ksi**	**f_{ult} ksi**	**E ksi**	**Area in^2**	**I In^4**
#3 FRP*	**77**	**100**	**6.700**	**0.11**	**--**
Duragrid**	**--**	**70**	**4.880**	**2.50**	**0.328**

(Source : Weyers and Allen, 1991)

Figure 3: Interior shear ribs of the FRP tubes

(Source : Weyers and Allen, 1991)

3.3 DURADEK FIBREGLASS GRATING

Morrison Molded Fibre Glass Company (MMFG) provided the FRP grating material used as reinforcement in the beams. The trade name that MMFG uses for its proprietary line of fibreglass shapes is EXTREN. EXTREN has the features of high strength, lightweight, corrosion resistant, non-conductive, electro-magnetic transparency, and dimensional stability according to the manufacturer's literature. Three resin systems are available and their properties are summarized in Table 2. The procedure for designing with EXTREN material is similar to designing with other materials. When designing with EXTREN material, the manufacturer recommends that the differences in material properties be considered. There is a low modulus of elasticity compared to steel. This leads to deformations being greater. The material is not homogeneous, thus the direction of strands makes a difference in the properties of the material. A low shear modulus exists which means that shear stresses must be examined carefully. High temperature can affect pultruded fibreglass more than steel. Corrosive resistance is greater than steel thus the plastic material is more useful in harsh environment.

TABLE 2:PROPERTIES OF EXTREN SERIES FIBREGLASS SHAPES

	EXTREN SERIES 500	**ENTREN SERIES 525**	**EXTREN SERIES 625**
Resin	**Isophthalic polyester**	**Isophthalic Polyester with Flame Retardant additive**	**Vinyl Polyester with Flame Retardant Additive**
Standard Color	**Olive Green**	**Haze Gray**	**Beige**
UV Inhibitor	**No**	**Yes**	**Yes**
Purpose	**General use**	**General Use and Flame Retardant**	**Highly Corrosive Environment**

(Source: Sulaimani et. al., 1994)

The grating by MMFG is produced by the pultrusion process and incorporates a number of material improvements. The centre of the grating is packed with dense glass fibres with a continuous glass mat wrapped on the outside. The centre provides for longitudinal strength and stiffness. The glass mat provides for transverse strength. The surface of the grating is coated with a synthetic veil that protects the grating from ultraviolet light and corrosion. The grating is connected by a rod system that is locked mechanically and chemically. The purpose is to provide strength to resist torsion, lateral movement, and to distribute the load throughout the system. It has the advantage of large sections that are light and that can be cut to fit. DURADEK fibreglass grating is a type produced by MMFG. It comes in “T” and “I” sections. It is available in gray (G) or yellow (Y). it consists of a fire retardant vinyl ester (FRVE) resin that also resists corrosion and ultraviolet exposure. It is coated with a skid resistant epoxy. Designation for the grating is GRFVE or YFRVE. The DURADEK series used for study is the I-6000 1 inch, YFRVE. The grating is made similar to the FRP rebar except the strands are formed into I-shape. This I-shape is used to provide the bond strength. The indentations that make the “I” shape provide an irregular surface for the concrete to mold around. This bond provides resistance to loads. The other main difference is that the grating is put together in a grid as spaced when ordered. For this study, the shape was specified to be on six-inch centres with the transverse grid on twelve-inch centres, which correlated to the control beams steel layout.

3.4 POLYPROPYLENE FIBRE

Polypropylene fibres were obtained from a local concrete plant. The manufacturer of the fibres was W.R.Grace. The brand name was Micro fibres. The typical volume mix is one and one-half pounds per cubic yard. The volume mix used for this study was one pound per cubic yard. The addition of polypropylene fibres generally increases the cohesiveness of the mix, which lowers the slump. The air content and unit weight is not significantly affected (Balaguru, 1992).