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CEMENT BASED COMPOSITES FOR THE MINING INDUSTRY

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SYNOPSIS

The background, design and constituents of cement based composite materials are briefly reviewed with particular reference to applications in the mining industry. Applications like insulation systems, drainage channels, corrosion protection linings in pipes, non-combustible materials and fire proofing of combustible materials are looked at. The insulation system offer a totaly non-combustible, non-corrosive and cost effective solution compared with current systems. Drain channels composed of a cement based composite reinforced with polypropylene and alkali resistant glass fibres with much inproved toughness and bending strengths are looked at. Advantages offered by cement based products in the field of corrosion and combustion where it is applied to steel and timber products are discussed.

1 INTRODUCTION

The South African Gold Mining Industry experience major challenges to produce gold profitably while mining low grade ores at ever increasing depths. These challenges must be met in a climate of high inflation rates, political and labour unrest and a low and unpredictable gold price. Due to the nature of narrow reef mining in hard rock and the depths at which it takes place, very little advances in mining methods and techniques are possible. Therefore the potential for developements in the material field will be one of the major areas which could be adressed to meet the challenge. Therefore new material developements will have an effect on:

- Escalating costs where it is caused by availability of materials and labour.
- Design limits of current materials.
- Safety, which is a major contributor to direct and indirect costs.
- Fire hazards.
- Corrosion problems.
- Effectiveness of systems.

In this report developments taking place in cement based composites are looked at. Cement based composite materials where brittle cement matrices are reinforced with fibres became viable materials in the late nineteenth century with the inclusion of asbestos fibres into the matrices. Large scale manufacturing was made possible by the invention of a manufacturing process which was patented at the beginning of the century (Hatschek 1901). The commercial success of this material is probably unparallelled in the entire field of fibre composites. However the use of asbestos fibres is on the decline due to diminishing supplies of cheap asbestos fibres which may be exhausted by the year 2000 (Krenchel & Hejgaard 1975) and the increasing awareness of the hazards to health. But developments of other fibres such as glass fibres, polymer fibres, steel fibres etc. opened up even more applications for cement based composites.

Cement based composite materials provide materials which combine the properties of bonding, compressive strength, durability, non- combustibility, non-corrosiveness, low cost and availability obtained from hydraulic binders and aggregates with the properties of high tensile strengths, high modulus of elasticity and affinity for cement particles etc. provided by different organic and inorganic fibres to produce products with excellent stiffness to weight ratios which is non-combustible, non- corrosive and cost effective.

From the above it is then clear that there should be many possible applications where these materials can be used in products in the mining industry. Grinaker Precast Mining Division already supplies a cement based composite product to the mining industry and is currently busy with research and developement of more of these products.

2 CEMENT BASED COMPOSITES

A cement based composite can be described as a material that consists of a hydraulic binder like OPC, with or without a certain percentage of pulverized fuel ash, hydrated lime or colloidal silica.This binding material is then mixed with different fillers (eg. silica sand, lightweight aggregates, etc.), water and admixtures to produce a cement matrix. The final paste must retain adequate rheological properties and the ability to evenly mix with the fibres.Different processes are then used to place different fibres or combination of fibres with different characteristics in to the matrices. Different composite materials can now be produced for instance flat sheets which can be moulded into different shapes or mould cast structural elements like beams, blocks, slabs, etc.

The processes can take different forms which normally consist of batching and mixing equipment, matrix dosing boxes or spray on systems, fibre placing by hand,mechanical or spray on, mechanical compaction of the wet slurry and fibre additions, dewatering and then final processing to obtain different thicknesses and surface finishes. With mould cast structural elements the slurry is transformed in some cases into foamed cement slurry before it is mixed with aggregates and fibres. Additives are used to assist with mixing in the fibres.

The moulded materials are then cured mainly with LP-steam in insulated tunnels or autoclaved when lightweight materials are produced with foamed slurry. The curing of cement based materials plays a very important part in the process to ensure high quality products with specifically designed properties for different applications.

The variety of materials and processes offers composite materials with many design possibilities.

3 FIBRE REINFORCEMENT

Hydraulic cements used in the construction industry are weak in tension and against impact. Reinforcement by suitable fibres is an obvious method of overcoming these difficulties. In the past two and a half decades extensive research has been carried out on the properties of cementitious composites incorporating various types of fibre, eg. glass, carbon, steelwire and, of course the use of asbestos.

The type of fibre or combination of fibres to be used depends mainly on required material properties and overall cost effectiveness.

3.1 Asbestos cement

Asbestos fibres provide materials with high tensile strengths, high modulus of elasticity and the fibre displays a peculiar affinity for cement particles which makes possible the inclusion of up to 10% by volume of fibre in a continious production process. The fibres are also relatively cheap to produce cost effective products. However asbestos cement products often exhibit brittle failure. Allen * measured the properties of seven types of asbestos cement with various fibre volume fractions of several types of asbestos fibre. The area under the tensile stress/strain curve for high fibre content type V_f 15%, is estimated to be 5.5 KJ/m^3 . Because of this low capacity for energy absorption the overall design possibilities and cost effective use of asbestos fibre is limited.

3.2 Alkali resistant glass fibres

Glass fibres displayed adequate material characteristics for a substitute to asbestos, but the price of glass fibre is unlikely to be low enough in the foreseeable future to allow direct competition with asbestos fibres, although cost effective products compared with similar asbestos products have been produced in the last decade. Glass fibre reinforced cement offer values of up to 120 KJ/m^3 (area under the tensile stress/strain curve, given by Majumdar and Laws** for standard GRC at 28 days) which is already a much improved capacity for energy absorption compared to asbestos products. It is well known that the tougness of GRC is sensitive to age and curing conditions and that it can become brittle after prolonged storage under water. Majumdar** gives tensile stress/strain curves for GRC after storage in various conditions for five years and these curves show that, under air storage, the value is not greatly different from that at 28-days. However, after five years of storage in water at 20°C the value drops to only 3 KJ/m^3. Storage under natural weather conditions results in values between the 28-days value and the one of five years in the water. It must be emphasized that only high zirconia alkali resistant glass fibres specifically designed for alkali resistance is suitable for reinforcing cement based products.

The excellent tensile and elasticity characteristics of asbestos and glass fibre cement composites provide for many important applications of these materials in construction.

3.3 Polyolefin fibres

A last very important fibre to discuss is the use of polyolefin fibrous networks in cement matrices. A method of bonding a fibrous polyolefin material into a cement matrix was discovered in the 1960's (Zonsveld 1970) after fibrillated film fibres had come on the market in the form of strings, ropes and baler twines. Successful products like cladding were made with remarkable impact resistance at fibre percentages as low as 0,5 %. However with thin sheets it is necessary to enable multiple cracking at less than 5 mm spacing which necessitates the use of high percentages of strongly bonded fibres.

To obtain stronger composites it is necessary to incorporate 5-15 % of the polyolefin fibres in the matrix. To achieve this and allow for complex bond requirements a concept of utilizing many layers of fibrillated film opened up to form networks which continuously span the length and width of the sheet material, was developed.

The complexity of the bond requirements as described by D.J. Hannant and J.J. Zonsveld is outlined below:

Location of bond is important because films that are fully keyed by cement reaction products at say, 10mm intervals will not transfer stress back into the matrix as rapidly as films which are fully keyed at 1mm or 1μm intervals. Both situations will entail film breakage before full composite fracture but the crack spacing will be closer for the closely keyed films. The bond must be such that when densification of the matrix occurs at the film interface due to continuing hydration, sufficient slip or flexibility must be available to avoid local fracture of the film at the point where it bends across a crack. Thus the ideal bond is one which will enable the full strength of the film to be utilized at composite failure, produce very closely spaced cracks, yet will allow sufficient flexibility at a crack for failure strains in the composite of at least 1% to be achieved throughout the life of the sheets under conditions of continuing cement hydration.

3.3.1 Choice of polyolefin

Polypropylene, a linear polyolefin obtained by stereospecific polymerization of propylene is an obvious choice of fibre. It has high tensile strengths derived from the high degree of crystallization and orientation of the macromolecules. Processing the fibres by melt extrusion and stretching induces the required molecular orientation and mechanical strength.

Fibrillated films are made by extrusion of the polymer from a die which produces a tubular or flat film which is then slit into tapes and is monoaxially stretched to about eight times its original length. This leaves the film weak in the lateral direction. Fibrillation is the generation of longitudinal splits and can be controlled to a regular pattern by the use of pin systems on rollers over which the stretched tapes are led.(Hannant 1980)

Comparison of the results for polypropylene film fibre cement with those estimated from published stress/strain curves for other fibre cement sheet materials on the basis of energy absorbed per unit volume, shows that polypropylene fibre cement, with a possible total energy absorption in excess of 1000KJ/m^3, can offer a material with considerably higher energy absorption than other fibre cements. (Hibbert & Hannant 1982)

Composites made with this fibre have been tested by natural weathering for over 5 years, with positive results; accelerated ageing has indicated a service life exeeding 30 years.

Other linear polymers such as polyethylene and polyester can be fibrillated but polypropylene is cheaper and offers technical properties like:

- High chemical resistance, particularly to alkalis.
- High strength after stretching .
- High resistance to oxidation when properly stabilized.
- Higher melting point than polyethylene.
- Low density
- Easy fibrillation

Properties that enhance their suitability for reinforcement of hydraulic binders is:

- The wettability of the networks by the water-cement mortar exceeds 0,04N/m, after electrical treatment of the film surface and the use of surfactants.

- Bond with the cement matrix results not only from the slitting operation, but also from the high specific surface of the fibrils and their hairy surfaces.
- The long term resistance to oxidation exceeds 30 years.
- The fibrils have higher tensile strengths (500-600 MPa) and moduli of elasticity (14-16 GPa) than polypropylene films or tapes.
- The bi-directional structure of the networks allows orientation of the reinforcing fibres with the main stress directions (longitudinal and transverse) in the reinforced product.
- The cohesion of the multilayered networks makes for easy handling during production.

Discussion of the applications of cement based composites in the remainder of this paper will mainly be with fibrillated polypropylene fibre reinforcement and in some cases a combination of glass and polypropylene fibres.

4 DESIGN POSSIBILITIES OF PRODUCTS MADE WITH CEMENT BASED COMPOSITES

4.1 Matrix

The matrices used which consist of a hydraulic binder, aggregates, water and admixtures offers a basis to produce non- combustible and non-corrosive products.

Futhermore design of the matrix offers possibilities to design for specific densities, elasticity, strength, surface finish and toughness. The final product can also be designed to cater for specific thermal properties.

Fillers are siliceous or calcareous with an average size of 0,3 - 0,5 mm. Admixtures like superplasticizers are used to assist with pumping of the slurry and to reduce the water content. To obtain stronger matrices colloidal silica or pulverised fuel-ash can be added.

For additional surface and sandwich reinforcing short cut organic or inorganic fibres are used. Colouring can be obtained by means of adding pigments to the slurry and fine lightweight aggregates will contribute to lower densities with subsequent thermal properties.

4.2 Reinforcement

Most of the design possibilities lie with the fibre reinforcement. The amount of fibres incorporated per volume, correct positioning and directional orientation, the type and its final bonding characteristics, cost implications and durability all play an important part in the final product design requirements

The major requirements for the fibre reinforcement can be summarized as follows:

- High fibre content (5% -10% by volume)
- Well bonded fibres with preferably continuous fibres.
- Ductile fibres to avoid fracture due to high local distortion across angular cracks.
- Uniform and closely spaced fibre distribution particularly near surfaces.

When the above requirements are satisfied it is possible to design for material properties as shown in the following example:

A sample which contain 5,7% continuous networks of fibrillated polypropylene film by volume positioned in the direction of stress was used. The material was properly water cured. For the tensile stress/strain test a specimen with a thickness of 6mm and a width of 20mm was used. For the flexural load-deflection test the specimen thickness was also 6mm thick with a length of 135mm and width of 42mm.

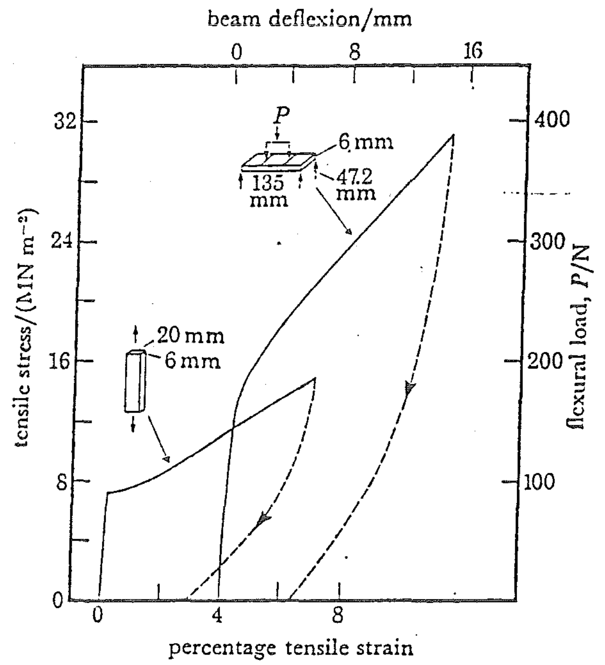

Figure1

Tensile stress/strain curve and load-deflection curve in flexure

100N (Flexural load) ≡ 7,9 MN/m^2 (Flexural stress)

Typical features of the direct tensile stress/strain curve are a linear, stiff uncracked portion up to stresses between 4 and 6MN/m^2 followed by a flat portion to strains of about 7-10% at stress levels depending on the film volume. The load-deflection curve in flexure is relatively stiff and linear up to a load equivalent to bending stresses (modulus of rupture) of about 10MN/m^2 and bending stresses of over 30MN/m^2 can be achieved at large deflections. In tension and in bending crack spacings of less than 5mm are normal. The very large areas under both tensile and flexure curves imply a high degree of toughness and impact resistance.

The above example is an indication of design ranges. The reinforcing effect is already obtained with $V_f\% = 3\%$ with matrices of pure cement or cement plus aggregate and increases gradually up to $V_f\% = 8\text{-}9\ \%$.

The final shape of the products also contribute to structural design strengths. (eg. corrugated roof sheeting). The high specific surface of the networks gives cohesion and plasticity to the cement paste of the wet sheets, thereby facilitating their handling and shaping into various forms.

5 STRUCTURAL AND NON-STRUCTURAL ELEMENTS COMPOSED OF CEMENT BASED COMPOSITES

This type of cement based composite is not necessarily in sheet form but can take basically any form for example; blocks, beams, pipe lagging,pipes etc.

The composite consists of a hydraulic binder like cement which is mixed with aggregates and then reinforced with fibres. The specific type of composite to be discussed in this paper is a lightweight or ultralightweight product if compared to normal fibre reinforced concrete.

The binding material is portland cement with or without added lime. Finely-ground pozzolanic material is normally also added by proportions of up to 25% by weight of the cement and lime. This portland cement paste or mortar is then transformed into a foamed paste by entrapping or generating numerous small bubbles of air or other gas. This can be done by a mechanical or chemical process, or by a combination of both. This foamed paste is then mixed with chopped fibres and different lightweight aggregates.

The final composite is then a combination of the thin sheet type and the element type where the thin sheet type normally acts as a tough and flexible protection skin while the element type forms a lightweight inner to act as a filler and/or insulant or support member with designed yielding characteristics.

6 APPLICATIONS IN THE MINING INDUSTRY

6.1 Insulation system

Most of the deep level gold mines make use of chilled water systems as part of their strategy to cool down working places. The chilled water is produced in underground or surface refrigeration plants from which it is then transported to and from the working places with piping columns. Because of the distances involved between refrigeration plants and working places, which increases as mining progresses, sufficient insulation of the chilled water columns is necessary to prevent excessive thermal losses.

After fatal accidents caused by previous pipe insulation materials, which is now banned by the G.M.E., the mines are desperately searching for insulation systems that will offer:

- Non-combustible materials which will not liberate any toxic fumes during a fire.
- Insulants with thermal conductivity values below 0,05 W/m °C which are protected by effective vapour barriers to prevent the migration of water vapour through the insulation towards the cold pipe where condensation can take place on the pipe surface.
- A protection sleeve to cover the vapour barriered insulant and prevent mechanical damage during transport, installation and in service.
- Durable materials to last at least as long as the pipe.
- Non-corrosive materials.
- A system that should not be labour intensive to provide, install and maintain.
- An overall cost effective solution.

A pipe insulation system which should satisfy all the above requirements for which patents are pending was developed by Grinaker Precast Mining Division. The complete system consists of cement based composites.

The final system will consist of three products which are:

6.1.1 Fire protection sleeve

A sleeve material which is supplied in precast half sections to be used as a fire protection cover around existing combustible insulation materials (eg.UPVC-sleeves and polyurethane insulants.) The sleeve material properties are designed to resist heat transfer during a fire as to prevent any combustion of inside sleeve and insulant.

The composite can be described as a cement based composite reinforced with continuous networks of fibrillated polypropylene films. The matrix itself consist of different proportions of RHPC, siliceous fillers, fine silicon coated expanded perlite, water, admixtures and in some cases pigments. Designs to cater for different heat transfer resistance requirements also incorporates an inner coating of a specially developed thermal insulant which can be described as a cement based composite in element form. (Patents pending on above described product, substance and method).

6.1.2 Protection sleeve and insulant

A sleeve material as described above is supplied in precast half sections and can take the form of an outer and inner sleeve only or a complete half pipe section container. The insulant which is either only covered by the outer and inner sleeve or contained inside the sleeve material is completely vapour barriered. The insulant is designed to maintain a thermal conductivity of below 0,05W/m °C . It can be described as ultra lightweight cement based composite element with a density below 300kg/m^3 and compressive strength of about 0,5MPa. (See description of non-structural cement based composite elements). (Patents pending)

6.1.3 Complete pre-insulated pipe section

Sleeve materials as described above are fitted around a pipe to form a tube-like container the inside is covered with a suitable vapour barrier and the tubes are then filled with the cement based insulant as described above. (Patents pending).

The above described system is an example of a cement based composite reinforced with fibres to form a complete product which offers a cost effective solution especially by eliminating fire hazards and corrosion. Another advantage offered by the materials is that everything is manufactured in precast form which allows for effective quality control systems to ensure a product that provide the required thermal resistance which is properly vapour barriered at all times.

6.2 Drain channel

Most of the underground water used is drained to a lower level where it is collected for treatment prior to being pumped to the surface or being re-used. It is therefore necessary to maintain an effective drainage system in the haulages and cross cuts. This will ensure dry working places, properly drained track systems and a method of retrieving the sludge which contains gold.

Part of the drainage system consists of open drain channels sunk into the footwall on the one side of the haulages and cross cuts. When these channels are constructed in situ, problems with incorrect material usages and methods caused the drains to deteriorate fast. This led to uncontrollable water conditions. Adding to this is the labour intensive and time consuming operation coupled with high transport costs and material wastages. A possible solution to this was a pre-cast drain channel.

Normal reinforced concrete channels were unsuitable for manhandling methods. An asbestos cement channel was then introduced with great success. This product however, proved to be very costly due to a breakage percentage as high as 35% before installation. It was therefore necessary to develop a product suitable for rough handling methods experienced in the underground mining environment.

Grinaker Precast developed a product in conjunction with the mines which was designed for underground conditions and requirements. The original product introduced in 1982 was a cement based composite reinforced with alkali resistant glass fibre. The product proved to be a big improvement and offered a more cost effective system.

Through continued research it was found that unacceptable breakages caused by failure of the brittle matrix still existed although the energy absorption capacity (toughness) was much better than the similar asbestos cement composite.

Further development work undertaken to improve impact resistance and toughness lead to the introduction of polyolefin fibrous networks as reinforcement in the form of continuous layers of networks of fibrillated polypropylene films.

This provided a product with much improved impact resistance due to the strength of the bond between polymer fibres and cement and also much improved toughness provided by a much higher capacity for energy absorption. (See discussion under fibre reinforcement)

To allow for the lateral forces induced by ground movement and trafficking the outside layer was further reinforced with chopped alkali resistant fibre glass.

The final product in use on the mines therefore consists of a composite material which has a high capacity for energy absorption as well as adequate bending and tensile strengths.

6.3 Other applications for cement based composites

6.3.1 Products affected by corrosion

Significant amounts of money are spent on the replacement of products that have deteriorated or failed due to corrosion.Many corrosion prevention and protection methods are available but do not always offer cost effective solutions. The use of cement based composite materials can offer a more cost effective solution and in many cases a superior product.

Examples of applications are:

- Piping: From the findings on a test programme conducted by the Anglo American Research Laboratories, cement linings exhibited excellent corrosion resistance but relatively high mass sometimes rendering them unsuitable for use in underground piping. The mass restriction however can be overcome by making use of thin cement based composite materials. Possible methods to achieve this are currently under investigation.
- Ventilation ducting: Ventilation ducting is used to force or remove air with fans to and from development working places. Galvanized sheeting in tube form is used in most cases and due to the costs involved it should be re-used as much as possible. This is normally not possible due to deterioration caused by corrosion and handling. Tubes are sometimes left behind in worked out areas because of the difficulties involved to reclaim them and the labour implications.A possible solution therefore is to make use of a disposable product which will not constitute a fire hazzard. This could be achieved by making use of a low cost cement based composite ducting material.

  The requirements to be met are:

  - Ducting which can be man-handled in restricted areas like raises.
  - Ducting which will maintain a specified volume and provide unobstructed air flow.
  - Non-combustible and non-corrosive.
  - Disposeable from a cost point of view.
- Explosive containers: Most explosive containers are made out of mild steel. Containers made from cement based composites should be more cost effective in terms of initial cost and lifetime.

6.3.2 Products which constitutes fire hazards

Thin flexible sheeting made of a cement based composite could be used as ventilation curtains and ventilation brattices. This will offer a non-combustible and much stronger material which would be more cost effective.

Fire proofing of timber packs and other timber is done with different spray-on cement base materials. These systems however are normally not as effective when excessive scaling takes place due to shrinkage as the material dries out. The situation can be improved by using suitable fibre reinforcement in the matrices. A properly designed cement based composite with adequate bonding properties to the timber and long term ductility will offer a more effective fire proofing system.

7 CONCLUSION

From this paper it should be clear that cement based composites offer a material with special properties that allow for optimal cost effective solutions to problems in the field of combustion and corrosion. It also provides for specific design possibilities to improve the overall effectiveness of systems both from an operational and cost point of view.

Grinaker Precast Mining Division is committed to offer solutions to the challenge of making deep level mining viable. This will be done through ongoing research and development to supply cost effective products which make use of new improved materials.

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