THE DEVELOPMENT OF A LIGHTWEIGHT HEADBOARD FOR THE SOUTH AFRICAN GOLD MINING INDUSTRY

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CSIR AND COMRO

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SUMMARY

A joint venture was undertaken between COMRO and the CSIR for the development of a light weight headboard for use in the South African Gold Mining Industry.

At present an existing elongate wooden headboard is used as an areal support for the stope hanging wall with a prop load of 80 kN for rock fall conditions. It has proved successful in concept but timber reusability is low due to blast damage. The inherently low cost of the wooden component however, makes the headboard attractive for the mining industry.

A glass fibre reinforced plastic (GRP) headboard has been developed with a 30% mass reduction. Its design eases handling and improves overall stability. It is also anticipated that it has a high reusability rate.

Minimal load shedding and greater resilience makes the GRP headboard less prone to being blasted out, than the wooden headboard.

The cost of the headboard required that it survive at least 30 blasts at the front row of props. This should be achievable through the use of a polymer blast shield. Further tests are required to ascertain the life span of the GRP headboard.

The strength potential of the GRP composite allows for modification to the headboard to handle higher load conditions (200 kN loads).

1. INTRODUCTION

Accidents and fatal injuries in the stope face area have long been recognized as major contributors to the overall number of rock related deaths in the mining industry. One of the critical areas in the stope working area is the area between the stope face and the permanent support. This distance on strike is typically 3,0 m - 4,0 m but in some shallow mines it might be as much as 5,0 m. It is in this area where the main mining activities take place and where personnel congregate.

Studies of falls of ground indicate that temporary support is always required in this area as a stable span cannot be guaranteed. In addition all support units should have a good areal support capability and in areas prone to rock bursts, it will be an advantage if the temporary support units contribute to the overall support resistance in the stope face area and, in addition, have a rapid yield capability.

The overall face support system should integrate with the rest of the mining system with the minimum disruption and be cost effective.

One such face support system currently under investigation by COMRO is the blast-on 80 kN hydraulic prop. The current headboard consists of a steel pan on top of which a 800 mm timber slab is placed. This headboard is installed in the stope face area with the long axis orientated on strike to cover the face parallel fractures. COMRO approached the CSIR to develop a substitute composite headboard to replace this steel and timber headboard.

A typical headboard currently used is shown in Fig. 1.1.

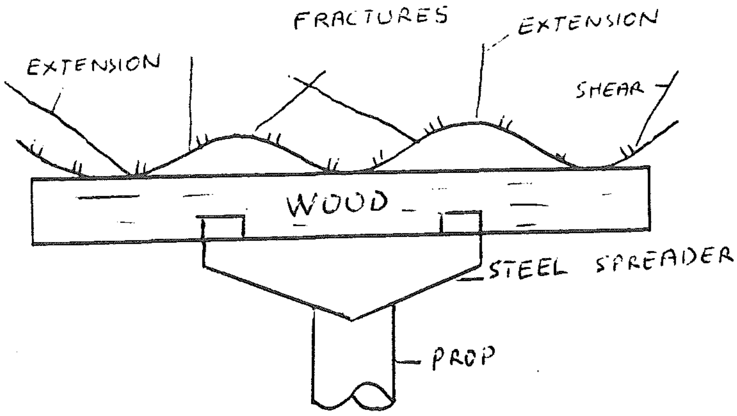

FIGURE 1.1: An existing headboard (rock fall)

2. REQUIREMENTS

For acceptance into the mine environment the headboard must conform to the following specifications:

2.1 The headboard must be of low weight (8 kg or less) with a minimum length of 800 mm.
2.2 Load capacity = 8-10 tons.
2.3 Load introduction into the hanging wall must be distributed as evenly as possible along the headboard length.
2.4 Handling must be improved over the existing headboard.
2.5 The headboard must be cost effective. This implies a cost around R2/blast.
2.6 The prop and headboard must remain intact during blasting.
2.7 The structure must be sufficiently rugged to withstand the blast and rough handling at cost effective levels.
2.8 Overall stability must be improved.
2.9 If combustible, there must be no poisonous fumes (cyanide etc.).
2.10 The headboard must be compatible with the existing 80 kN hydraulic prop.

2.11 Good "visibility" is important as headboards can become lost. This implies bright colouring.

2.12 Ease of stacking and transportation is important.

3. CONCEPT DEVELOPMENT

3.1 Structural Forms

A re-look at the area support concept was required. The major criterion in deciding upon a concept is the requirement for suitable headroom and access to the working area. Support concepts are categorized into three, two and one dimensions.

Three dimensional supports include such structures as inflatable bags, back filling etc. The major disadvantage here is the limited access to the working area. For this reason and others such as cost, the idea was not considered suitable.

Two dimensional support has been considered and tried. Essentially it implies a uniform support over the entire hanging wall. This form of support would be deemed most suitable. The category includes netting, beam networks, umbrellas, platforms etc. Although this route may well be followed in the future it was decided that complexity and cost would not make it a viable alternative at present.

One dimension support includes the existing headboard concept or beam. It is the simplest and least expensive and allows good access to the working area. Its effectiveness was of course considered.

As the majority of fractures run parallel with the stope face it should be sufficient to provide support perpendicular to this direction only. Placing beam headboards in this direction has indeed proved fairly successful.

It was decided that the development of a replacement light weight beam-type headboard would be a suitable first step in solving the area support problem.

3.2 Beam Type Headboards

Several variations and concepts involving the beam principle were considered and tried.

A detailed material discussion is dealt with later. Owing to its high specific strength a fibre reinforced plastic was selected as the base material for the replacement headboard. Combinations with other materials were considered.

3.2.1 Glass fibre reinforced plastic with a wooden core

The apparent problem with the existing saligna headboard is its poor performance in blast and overload conditions.

Covering a wooden core would prove the simplest and cheapest solution. A glass reinforced polymer (GRP) covering would increase bending strength and resistance to blast. The purpose of the core is the absorption of compressive loads.

Load introduction requires the use of a similar load spreader as that used for existing headboards.

The only advantage in using this concept is a gaining in overall strength and ruggedness. Handling and weight problems still remain. The cost of this system compared with its advantages makes it unattractive.

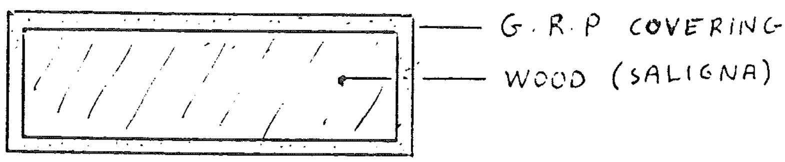

FIGURE 3.1: GRP/Saligna headboard cross section

3.2.2 GRP with lightweight core

The concept here is similar to that of above. A corrugated cardboard core is used in the place of wood.

A laminate of cardboard is made. Unplasticized cardboard sheets are impregnated with resin and bonded together. The cell orientation is chosen in the shear direction for optimum strength.

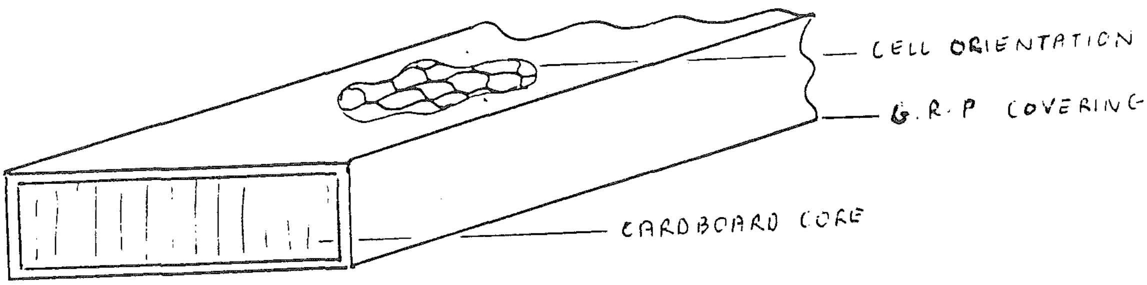

FIGURE 3.2: GRP/cardboard headboard

GRP "spar caps" are bonded at top and bottom of the core. The caps absorb bending loads. A GRP skin is used for handling and blast protection (this would not be sufficient alone).

Once again a steel spreader is required for load introduction.

As the structure was little lighter than that of the GRP/wood headboard and at a higher cost it would not prove viable.

3.3.3 GRP beam

When designing with GRP laminates it is important to eliminate the use of thick sections as this results in high interlamina shear stresses.

Almost invariably, a GRP composite structure will take the form of a box or system of plates (curved or flat).

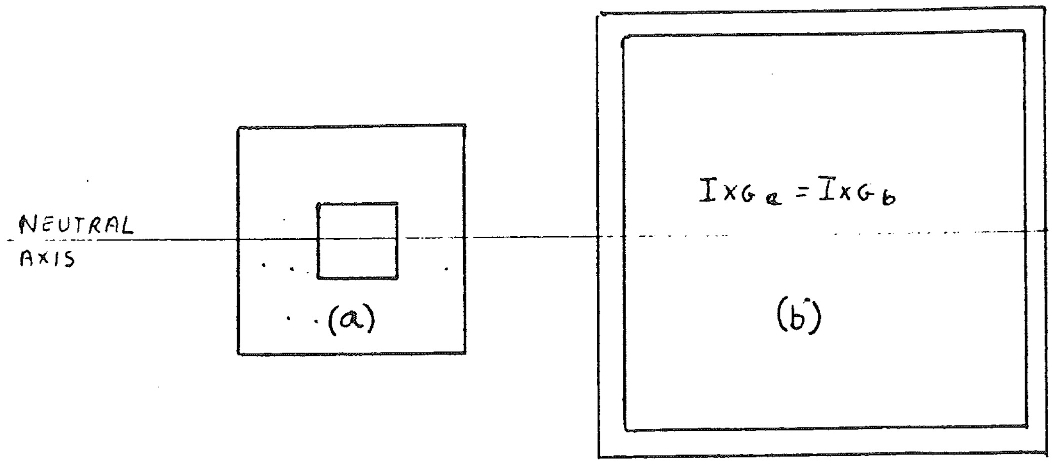

FIGURE 3.3: Hollow box beam principle

The above figure represents the cross sections of two beams. Both beams have the same section moment of inertia IXG. Section (a) is inefficient in material use (material should be placed as far away from the neutral axis as possible) and has large shear stresses in the top and bottom panels. Section (b) is a better configuration provided that it is not subject to buckling failure common with thin walled structures.

The method of prop load introduction dictated the structural concept in most cases. The systems considered were:

a) ball protrusion/socket

b) recess for prop (articulating)

c) pin.

An early prototype headboard is shown in Fig. 3.4. It makes use of a protruding ball that locates in the crown of a typical 80 kN prop.

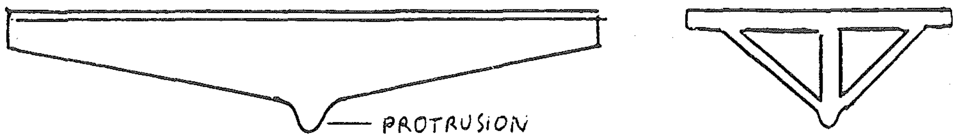

FIGURE 3.4: Triangular box beam headboard

A central web absorbs and distributes the prop load while the side and top panels stabilize the structure.

The reticulating ball allowed for conformance with the hanging wall. This is of course very important.

The problem encountered with this concept was its inherent instability. It was was found that lateral loads due to blasting would topple the headboard and prop. Overcoming this would require a large base to height ratio. This concept may prove useful for a 2-D headboard as shown in Fig. 3.5, but not for a simple beam.

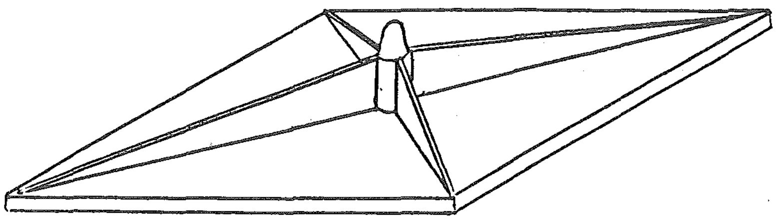

FIGURE 3.5: 2-D headboard with protruding ball

A recess for prop mounting was the most likely solution to the problem. Here the headboard sides would provide tilt stability while allowing pivoting in the plane of the headboard as shown in Fig. 3.6.

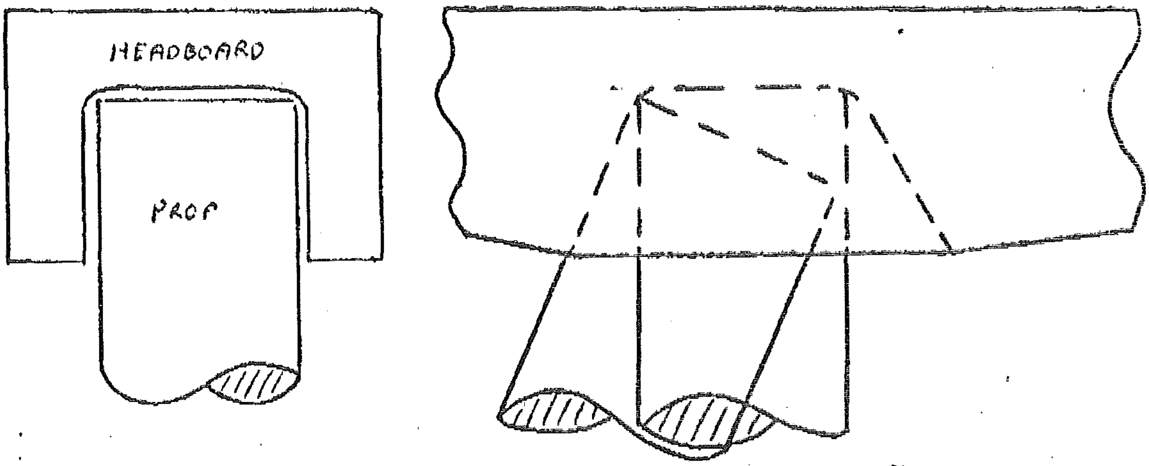

FIGURE 3.6: Beam type headboard with recess for prop mounting

The first prototype headboard with a recess was constructed in 3 stages (Fig. 3.7). The body provided bending strength, the belly-pan provided blast protection and the cup absorbed mounting loads and located the prop.

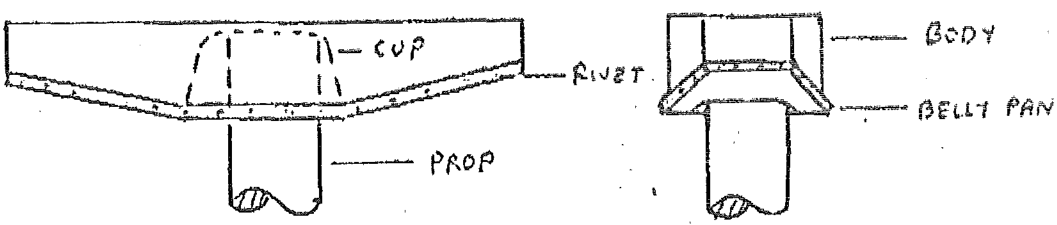

FIGURE 3.7: Three piece headboard

Two problems became evident:

Firstly, the cost of fabricating three separate components and then assembling was too high.

An important structural fault was identified in terms of the headboard's resistance to side forces (Fig. 3.8).

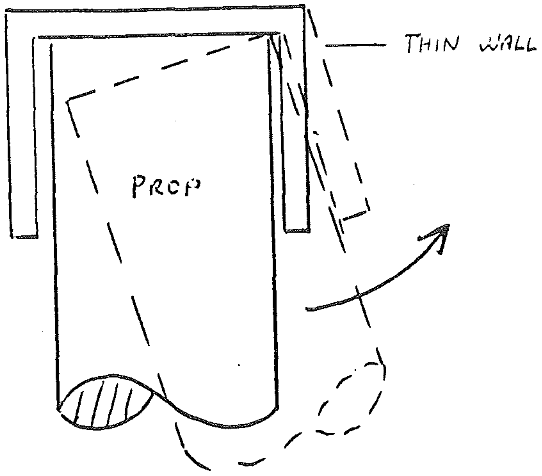

FIGURE 3.8: Side force induced failure

It was found that eccentric loading or blast forces would rip the cup from the headboard. This implied the need for thicker wall sections as in Fig. 3.9.

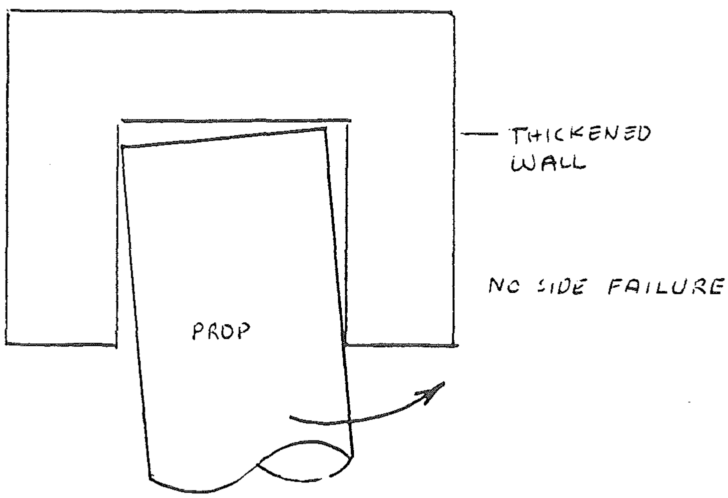

FIGURE 3.9: Thickened wall section

As thicker sections imply greater mass it was necessary to consider a foam core (in this case polyurethane or PVC) (Fig. 3.10).

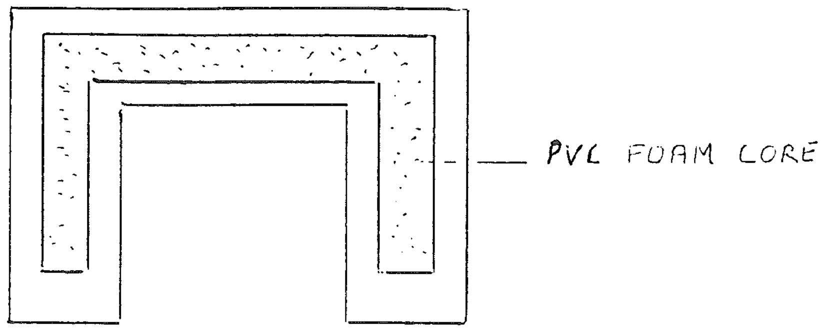

FIGURE 3.10: Foam core for strength

It was found that the belly-pan was of little use and could be done away with. At the same time, the cup could be replaced with a prop locating protrusion (Fig. 3.11). The possibility of a one shot moulding operation was evident.

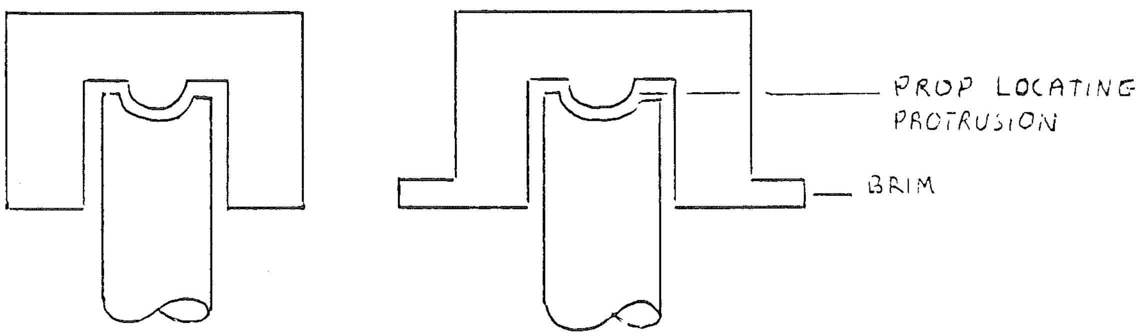

FIGURE 3.11: GRP headboard concept with and without "brim"

Introducing a "brim" allowed for easier manufacture as excess fibre could be folded to one side. This is important for manufacturing processes such as Resin Transfer Moulding. It was found that the brim increased prop strength against eccentric or side loads.

A catamaran concept was tried (Fig. 3.12) that made use of a pivot.

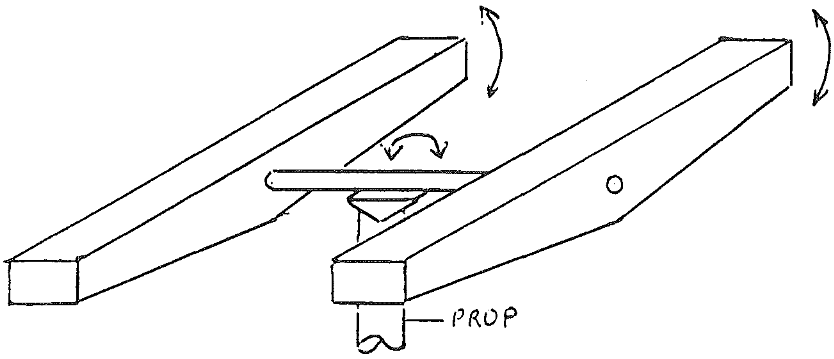

FIGURE 3.12: Catamaran headboard

Two hollow box beams (early GRP headboard prototypes) were placed on either end of a 400 mm solid round bar. The bar was welded onto a spreader for prop location. Each beam was allowed to pivot about its neutral axis as shown.

The advantages are that the structure is inherently stable and can pivot about 2 axes thus providing a more efficient support. It was felt that the cumbersome nature of the headboard would not make it a viable solution at present.

3.3 Material Selection

A fibre reinforced plastic was considered as a suitable headboard material as it exhibits a relatively high specific strength and stiffness. Properties such as excellent corrosion resistance would also prove useful. Special attention was given to blast resistance as the composite material alone would not be sufficient.

3.3.1 Fibre reinforcement

Pure polymers exhibit poor strength, stiffness and creep resistance. For this reason it is often necessary to add some form of reinforcement. This may the form of a powder filler or in this case, a network of fibres. Typical fibre types are glass, kevlar and carbon.

As a rule the direction of the fibre is governed by the direction of principal stresses within a structural component. It is desirable to aim for as high a glass content as possible when designing for strength and stiffness. Some typical glass volume fractions for various processes are:

Hand layup	=	40-50%
Resin transfer moulding	=	60%
Pultrusion	=	60-70%
Filament winding	=	70%

Very important is that fibres are coated with a coupling agent or sizing to allow bonding between the fibre and resin matrix. In the case of glass this would be a silane.

Owing to its relatively low cost (R8-R9/kg) and energy absorbing capabilities E-glass would be most suitable for the headboard. This fibre is locally manufactured (AFI) and is sized for polyester, vinylester and phenolic resin systems.

3.3.2 **Resin matrix systems**

a) *Thermosetting resins*

Polyester resins are best known within the local composites industry owing to their competitive costs (R8/kg) and a suitable range of mechanical properties such as strength and corrosion resistance. Two disadvantages are resin shrinkage and its combustibility. The latter can be reduced through the addition of fire retardants. Fillers (talc etc.) can be added to reduce cost. A more serious problem is water absorption that can result in a reduction in strength with time.

Vinylester resins are chemically similar to polyesters but exhibit excellent corrosion resistance (at R10/kg).

Epoxy resins are mechanically superior to polyester but at a significantly higher cost (R30-R50/kg) making them unsuitable for the task.

Phenolics have advantages in that they are the cheapest of the resin systems (R7/kg) and are locally produced. A major advantage is that they are non-combustible, an obvious criterion for the mining industry. A factor against their use is their brittle nature. This is currently being investigated as new formulations and plasticizers are being developed. Further attention towards their high water absorption is required.

b) *Thermoplastics*

This family of resins (polyethylene, polypropylene, nylon, etc.) is attractive as they exhibit many superior qualities over thermosets, namely:

1) high toughness (10x that of epoxy)

2) no water absorption

3) No shrinkage

4) No shelf life

5) recycling possibility

6) fast processing (cold pressing).

The problem is the high cost associated with the manufacture of thermoplastic composite prepregs. This makes the material unsuitable at present. Further investigation may however prove worthwhile as costs decrease.

Thermoplastics will prove valuable for the headboard in an unreinforced state as is discussed (blast proofing).

c) *Choice material*

Polyester resins proved most viable for the prototype stage owing to factors such as cost and ease of processing. Further development may lead to the use of phenolics.

3.4 Blast Proofing

Adequate blast resistance cannot be obtained using a composite material alone (as was discovered during the prototype stage). For this reason it was necessary to provide some form of covering.

Mine props are currently sheathed in high density polyethylene. This has proved successful and would indicate the type of covering required for the headboard.

Other possibilities include chemically cured rubber and polyurethane. The problem associated here is the fire and toxic fume factor making their suitability in the mine environment questionable.

3.5 Manufacturing Processes

Prototype development involving thermoset polymer composite materials usually involves hand lay-up (bucket and brush) techniques.

Increasing quality and production rates requires processes such as Resin Transfer Moulding. The process is described briefly.

A male and female mould are constructed typically from glass fibre reinforced plastic or steel. The mould surfaces are coated with some suitable release agent and in some cases a gel coat. Heating is sometimes provided for faster injection (reduced resin viscosity) and cure times.

The dry fibre preform is placed in the mould (female side) and the male side clamped down.

Resin, accelerator and catalyst are mixed and injected into the mould cavity, causing the wetting of the dry fibre preform.

After sufficient time for gel, the mould is separated and the component is released.

Final trimming results in a finished component.

Processes such as DMC or SMC (dough and sheet moulding compounds) are not suitable for the headboard applications owing to their low specific strength.

Automatic fibre placement such as filament winding is time consuming and expensive and is thus unsuitable.

4. SOLUTION SPECIFICATION

The final prototype headboard (Fig. 4.1) is based on the beam principle. The structure locates automatically into the top of an existing 80 kN mine prop. The construction material is a glass reinforced polyester with a PVC foam core.

Blast protection is provided through the use of a high density polyethylene coating (vacuum-formed).

The resin transfer moulding technique is the manufacturing method to be used.

Specifications

1) length = 800 mm
2) width = 160 mm
3) weight ≈ 8 kg
4) cost estimated ≈ R120 - R150/headboard
5) prop/headboard interface: ball/socket
6) contact surface: rippled
7) blast protection - high density polyethylene
8) colour - white
9) load capacity (3 point bending) - 100 kN + safety factor

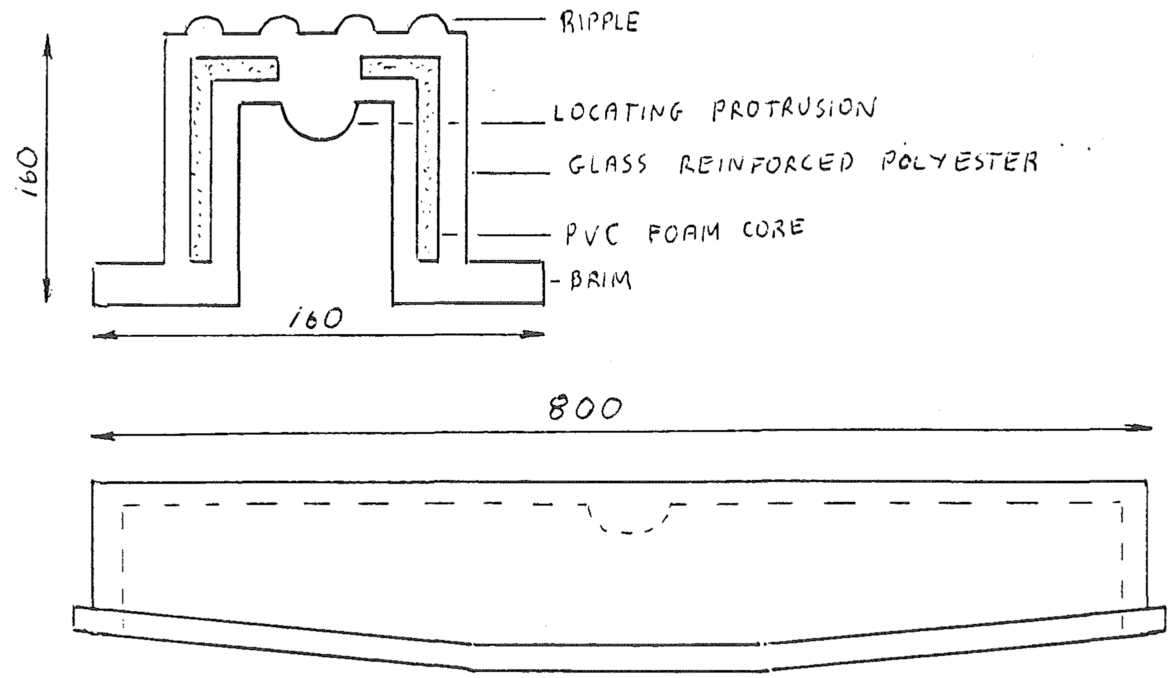

FIGURE 4.1: GRP headboard prototype

5. DISCUSSION OF SOLUTION

Wood is a natural composite material available at a low cost. Replacing it in the mining industry is difficult. The COMRO/CSIR headboard has, to date, proven more successful than its wooden counterpart in many aspects. The problem is the inherent cost (≈R8-9/kg) of a glass fibre reinforced plastic. It is expected that further refinement and modifications to the resin system will reduce the headboard cost significantly.

5.1 Structural Design

Proper use of a GRP can result in strengths equivalent to those of steel, at a significantly lower mass.

It was important to select suitable fibre orientations to withstand bending moments and shear forces in excess of 28 kNm and 140 kN respectively (with safety factor, prop load = 140 kN) with suitable resilience. The advantage of "tailoring" composite properties was clearly evident as these requirements were suitably met (midpoint headboard deflection at 100 kN = 11 mm). This was achieved using suitable quantities of 0°/90° glass fabric (orientation to beam axis) to absorb bending stresses and 45% cloth for shear strength.

The support strength of the GRP headboard was superior to that of the existing headboard. It was found that GRP headboards would withstand 3 ton prop loads (3 point loading) after failure. This implies a significant level of residual strength in the event of headboard failure (i.e. no catastrophic failure).

Of interest is the strength potential of the existing GRP headboard. With little refinement its load capacity will exceed 200 kN making it potentially suitable in rock burst conditions.

Load relaxation was found to be minimal for the GRP headboard (note that wood relaxes up to 50% of its load level after prop installation). Relaxation was reduced further after the initial installation. This was due to the relieving of internal stresses.

The inherent resilience of the headboard will reduce the blast-out rate (as a result of load relaxations). This is an important consideration. The greater resilience implies greater energy absorption as well as better-conformance with the hanging wall. At the same time loads are better distributed along the headboard.

Existing load capacity was attained at a headboard mass around 8-9 kg. This will reduce if safety factors (=2) are reduced along with structural refinement.

Suggested refinement steps include the reduction of ±45° orientated fibre (excessive shear strength), increased tapering and rounding of edges. The latter is important as the existing mould results in resin-rich areas.

Resin costs can be reduced by adding fillers and/or the move to phenolic systems.

It was found that the earlier prototype was easily lost. This was blamed on camouflage colouring (brown). A headboard can be confused with the ore produced after blasting and would then be scraped away. Lighter colours such as yellow or white would be advisable.

5.2 Blast Resistance – Life Prediction Versus Cost

Earlier prototypes were blasted upon without blast protection. Their life span was restricted to 2 or 3 blasts. The later prototype, without protection, was more successful but showed signs of damage that would eventually lead to failure. (Note that wood survives one or two blasts.)

A fabricated (welded) polypropylene covering (4 mm thick) was produced for the final prototype. The welding process resulted in weak seams that failed during installation. The covering that still remained proved successful in protecting the underlying composite. A new covering technique was sought.

A polyurethane covering was applied by spraying but was never tested. Indications from other applications (prop covering) showed it to be unsuitable (apart from the fire hazard).

A local company was approached for the vacuum forming of high density polyethelene over a prototype headboard. Different thickness coverings are to be tested. Although not tested as yet, this covering promises to be the most successful of those tried.

Although it is difficult to say at this stage, it is expected that 20-30 blasts (front row of props) will be achievable. This must still be verified.

It is appropriate at this stage to discuss costing.

The raw material cost for the existing prototype are around R70. With manufacturing costs along with profit margins the overall cost may rise to R120-R150. The headboards viability will depend upon the number of blasts it can withstand.

It is hoped that the overall cost can be reduced by 20-30% during a refinement or commercialization stage. Provided that the prototype headboard does perform as expected.

5.3 Stability and Handling

For the acceptance of the headboard into the mining industry. It is important to ensure ease of handling and suitable stability after installation.

Handling is improved through the addition of the brim as well as a significant weight reduction. The headboard shape allows for stacking thus improving storage and transportation.

Stability is provided through the strengthened hat section profile. The small location protrusion has proved successful in aiding both stability and conformance with unlevel hanging walls.

The GRP headboard is both easier to install (lighter and one component only) and more stable than the wooden headboard. Indications from the test mine are that it should be accepted by the mining industry if it becomes financially viable.

5.4 Fire Resistance

The glass/polyester composite and polyethylene covering is indeed combustible. However, gas emissions are CO_2 and CO (no cyanides or chlorine gas associated with polyurethane and PVC). Combustibility can be reduced through the addition of fire retardants. This will unfortunately increase costs.

Replacing the polyester with a phenolic will reduce combustibility significantly. This will require further development.

It is recommended that fire tests be done to ascertain the degree of combustibility of the prototype headboard and its effect.

5.5 Manufacturing

The resin transfer moulding technique (RTM) will prove the most efficient for the mass production of the headboard.

Refinement of the process such as the use of consolidated preforms as well as modifications to mould design will be required.

At present a low reactivity resin has been used with gel times up to 1 hour. Injection times are presently around 20 minutes. Monitoring of the process (cure sensors etc.) will reduce cure time significantly. Injection times will reduce with mould modifications along with resin flow measurement.

Changing to filled polyesters or phenolics will require special attention as resin viscosity increases significantly. This will require special mould design along with precise rheology control and heating.

6. CONCLUSIONS AND FURTHER WORK

1) The structural properties of the GRP headboard have proved superior to those of the wooden headboard. These include:

   i) higher strength

   ii) greater resilience (reduced likelihood of prop blast-out)

   iii) strength capacity for larger props (with modification)

   iv) low mass (8-9 kg)

   v) more robust

2) Estimated cost at present is R120-R150 but may be reduced by 20-30% after refinement.

3) Blast protection is provided through the use of a high density polyethelene covering. Projected life spans should exce . 20-30 front line blasts.

4) Stability and ease of handling has been improved over the existing headboard.

5) Combustibility may be a problem, but ways of reducing it are being investigated.

6) Mass production will involve resin transfer moulding. Refinement is required to reduce cycle times.

7) A large prototype batch must be evaluated to establish performance and life span.

8) Modifications will allow the headboard to be used with larger props (200 kN).

7. ACKNOWLEDGEMENT

The work described in this paper was carried out as part of COMRO's (Chamber of Mines of South Africa Research Organization) research programme into the development of safer stope support methods, so as to increase mine safety. Permission to publish the paper is gratefully acknowledged.