MANDELA MINING PRECINCT

MINDS FOR MINES

PROJECT CLOSE-OUT REPORT FOR THE PERIOD – 2018 to 2021

Programme: Longevity of Current Mines (LoCM)

Project: Support

Work package: LoCM18WP4 / LoCM19WP3/ LoCM20WP8

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1 EXECUTIVE SUMMARY

During year one of the Longevity of Current Mines (LoCM) programme, a need was identified for a lightweight, easily installed underground support unit. The scope was envisaged as a continuation of work done by Impala Platinum (Implats). Implats identified composite sticks as an alternative to timber support, which is heavy, difficult to handle, and which may face supply constraints in the near future.

Work Package 4 (Support) was initiated and scoped to continue development of the composite pipe stick developed by MechCal (subsequently MOC Technologies) in collaboration with Implats. The initial budgets proposed by MOC Technologies (MOC) could not be accommodated, so the project changed direction to consider other non-timber-based support options. Re-scoping was done, but not executed as MOC subsequently agreed to a scope which would focus on prototype development. A new scope was prepared for the proposed work. A Memorandum of Agreement (MoA) was drafted between MOC and Minerals Council South Africa (MCSA). Further execution of the project was delayed until the approval of the MoA in October 2019.

Work done so far (2018 and early 2019) indicated that the MOC composite pipe stick has the potential to replace timber sticks and may compete with grout-based yielding support when assembled as clusters. Initial testing of the MOC prototype shows impressive load-bearing capacity and yielding characteristics. The response, however, also shows sudden load drops and a lack of consistency in certain batches.

The 2020 work focussed on addressing these shortcomings through numerical simulation and prototype design and testing. The scope was revised to reflect changing timelines and interim progress. MOC, the CSIR, and the Mandela Mining Precinct (MMP) have collectively been involved in collaborative research, which is aimed at determining the elongate material characteristics as input parameters in order to simulate the failure mode with the required improved outcome. Thirty single composite sticks were tested based on the re-evaluated design of the poles derived from previous test results undertaken in February 2020 and December 2020.

The post failure investigations suggested modifications are to be made to the end of the elongate, which various modifications were implemented and tested. The latest test results conducted in December 2020 and verification tests conducted in March 2021, showed positive elongate deformation results, which no buckling effects were experienced over the full length of the elongate; the elongates were designed for 35T load and averaged a consistent 35T load/yield design and early indications are that the composite sticks can be used as a replacement for the cementitious support when installed as cluster packs, but requires further testing to proof this.

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2 INTRODUCTION

2.1 Background

During the Mining Phakisa it was clearly articulated that mining operations are struggling to remain profitable, primarily due to depleting ore resources, rising costs and inefficient production. The Longevity of Current Mines (LoCM) programme is an initiative within the SAMERDI programme to identify and develop processes - to be implemented in the short term - to extend the life of current operations which are based around the drill-and-blast cycle. The support activity was identified as a critical path of the production cycle, requiring further investigation into optimisation for safer operations and improved production output which could result in reserves being mined for longer. Work package 4 (WP4) – Support - was proposed in the 2018/2019 budget.

The project was aimed at delivering a lightweight support unit for use in underground mines. This would enable quicker support installation, resulting in improved shift cycle efficiency, and it is likely to reduce worker fatigue. The support unit would also be manufactured using composite material instead of timber, which can be constrained by shortages. The potential exists for local communities to manufacture the units using purpose-built equipment.

The primary objective for this project was to provide a successfully tested prototype of the composite elongate (pipe stick), which the deformation test results would meet the design criteria.

3 PROJECT DEVELOPMENT

3.1 Evolution of the work package scope and activities

3.1.1 2018/19 Project Deliverables

Year 1 of the Longevity of Current Mines (LoCM) program identified challenges within the current mining cycle. One of the needs identified was for a lightweight, easily installed underground support unit. The original scope for the work package is presented in Table 1.

The scope was conceptualised as a continuation of work done by Impala Platinum. In the year 2000, Impala Platinum (Implats) conducted research into alternative support systems for stope support. Implats, which predominantly uses timber-based support, identified composite sticks as a potential alternative. Three manufactures were approached to develop the composite stick, namely MechCal, Saltus Poles and Xuba Polymer Industries. MechCal was selected as the best option. After Phase 1 (development of the composite stick) was completed, the project was stopped by Impala Platinum due to budgetary constraints.

It was envisaged that the Mandela Mining Precinct would resume the project at Phase 2, which comprised the testing of the already-developed composite stick prototypes. The "Support" work package was initiated and planned as indicted in Table 1. The allocated budget was mainly for independent laboratory and in situ testing of the composite stick, assuming the final prototypes were completed during Phase 1 of the project.

Table 1. Original project scope for the development of a composite pipe stick

No	Milestone	Activities	Milestone Timelines		Milestone Cost (R)
			Start Date	**End Date**	
1	Start-up meeting with OEM	Set up meeting and meet the OEM	08/18	08/18	48 000
2	Obtain and review Implats trial documentation	• Contact OEM • Establish motivations and analyses trial results • Identify applicable environment based on strength, yield ability and other properties • Establish which timber based support is similar to the composite stick for comparative studies	09/18	09/18	70 000
3	Obtain yielding timber elongates with similar characteristics for comparative study	Source the timber based support with similar characteristics to the Composite stick for comparative testing	09/18	09/18	50 000
4	Secure lab testing facility and test both the timber and composite elongates	Conduct load-deformation testing of the composite stick and the timber support	09/18	09/18	154 000
5	Analyse the results and write a report	• Analyse the test results and plot load-deformation graphs • Conduct statistical analysis of the data to obtain mean values for each support unit	09/18	10/18	100 000
6	Modify the composite stick with the OEM (if necessary)	Based on the comparison and applicable environment check whether the composite stick is comparable to the timber support, if not change the composite stick mixture	10/18	10/18	26 900
7	Identify trial site at a yielding underground environment	Identify suitable test site based on support demand and design support spacing and layout of the composite for the trial area	10/18	11/18	50 000
8	Define monitoring objectives and methodology with various stakeholders. This will include risk assessments, roles and responsibility allocation with stakeholders (including MOSH implementation plan adoption) for the successful trial	Meetings with various stakeholders to conduct risk assessment and define monitoring objectives for the overall project	11/18	11/18	100 00
9	Obtain monitoring instrumentation such as closure loggers, closure robots, fog lights and other risk mitigating instrumentation	• Obtain a quotation from the supplier for monitoring equipment • Purchase the monitoring equipment to be used during the trial	12/18	02/19	120 000
10	Conduct trial at a yielding environment	Monitor the performance of the composite stick underground based on the defined monitoring objectives	03/19	05/19	200 000
11	Draft report	• Compile all information into a close out report with recommendations or value proposition for the composite stick • Research into localisation of the composite stick, define the requirements for localisation	05/19	05/19	19 200
12	QA-QC of the report	Circulate report for review	05/19	05/19	26 800

Meetings were held with Implats and with the OEM, which was subsequently became MOC Technologies (MOC). Implats indicated that they had selected the MechCal/MOC pipe stick based on the following potential benefits:

- Lighter than timber.
- Flameproof.
- Potentially cheaper than timber.

- Easy to install.
- Could be produced locally, using local SMMEs in a local industrialisation program.
- The design could be altered to suit different environments (yield ability at depth, etc.).

Implats appreciated that the composite sticks were more expensive than timber poles. The business case for Implats was based on reducing production cost through economies of scale, managing anticipated pressures on the reliability of timber supply and the need for affordable yielding support at depth.

Meetings were held with MOC to discuss further development of the prototype. They supplied a proposal and cost estimate for R3.4m to complete laboratory and underground tests, and to conduct pilot plant testing. The available budget at this stage was only R 0.95m. In light of the shortfall and the possibility that the collaboration would not continue, the project was re-scoped to consider alternative support lightweight systems through the execution of industry surveys and workshops. The proposed scope is presented in Table 2. The changes were communicated to Mandela Mining Precinct management in October 2018.

Table 2. Revised scope for developing alternative support systems

No.	Milestone	Milestone timelines (mm/yy)		HR costs (R)	Total (Excluding VAT*) (R)
		Start	*End*		
1	Draft a close out report on the work completed (testing programme, Impala trials and independent value proposition based on the work from Impala platinum)	26/10	07/11	94 000.00	94 000
2	Develop survey methodology to be applied for industry participation in the survey to identify research focus for year 3 (interaction with the Steering Committee and SATCAP)	26/10	23/11	94 000.00	94 000.00
3	Conduct a survey with Rock Engineers, Department of Minerals Resources, Mine Managers and other stakeholders to identify industry needs to address the FOG risk by ensuring support is installed correctly, timeously at all times	26/11	30/11	100 000.00	100 000.00
4	Analyse feedback from the survey and prepare for a workshop	30/11	14/12	54 000.00	54 000.00
5	Conduct a workshop to identify the project focus for year 3	18/12	18/12	54 000.00	54 000.00
6	Draft a proposal for year 3 project and submit to the Steering Committee	19/12	22/12	54 000.00	54 000.00
Total					**451 200.00**

Before any proposed events reflected in Table 2 could take place, further meetings were held with MOC and they suggested a scope which would focus on prototype development in February 2019 (Appendix A). A Memorandum of Agreement (MoA) was prepared and the scope was amended again (**Table 3**) in April 2019. The MoA was ultimately signed in September 2019.

Table 3. Revised scope for continuing development of the MOC composite pipe stick

No.	Milestone	Milestone timelines		Original costs (R)	Revised cost (R)	Remarks
		Start	*End*			
1	Project Initiation	Aug-18	Oct-18	55,250		55,250
2	Close out report for composite stick submission	Aug-18	Nov-18	223 850.00	20,840	244,690
3	Develop questionnaire and survey methodology to be applied	Nov-18	Jan-19	66 060.00		66,060
4	Conduct survey	Dec-18	Feb-19	90 400.00		90,400
5	Conduct a workshop	Feb-19	Mar-19	110 400.00		110,400
6	Submission of the close out report to Steercom	Feb-19	May-19	180 400.00		180,400
Total				726,360	20,840	747,200

As discussed above, three scopes were ultimately prepared for this project to accommodate changes in research direction. The following sections provides details of milestone delivery against the last approved scope (Table 2).

3.1.1.1 Milestone 1: Project Initiation

The research team started with the first milestone, which was to contact OEMs through start-up meetings to discuss the work package requirements and determine the OEM's ability to participate in the design and manufacture of the set criteria prototype.

The OEM met twice with the team from the Mandela Mining Precinct to discuss the composite sticks. An introductory meeting was held at MOC where basic information was shared and a way forward was agreed upon. A second meeting was held where the specifications of the sticks, manufacturing process and test results were shared. Further to that, laboratory consultants were approached and testing procedures were developed. Quotations were received from the OEM (to manufacture the sticks) as well as from the laboratory consultants (to test the sticks). Subsequent to this, engagements took place between Timrite, MOC and Mandela Mining Precinct researchers. It was agreed that further testing would take place at Timrite's facilities. A non-disclosure agreement was drawn up for Timrite, but this was never signed. The failure to obtain an NDA, together with concerns regarding possible conflicts of interest, resulted in preliminary testing being done at the CSIR's Rope Testing facility.

The milestone deliverables were met and completed to the cost of R55,250.

3.1.1.2 Milestone 2: Close-out report for composite stick submission

The second milestone deliverable was to submit a close out report for composite stick. This close-out report presents the details of the work which transpired up to the point of the second milestone been completed. The work completed amounted to R244,690.00, which concluded the deliverables for milestone 2.

3.1.1.2.1 Technical details of the composite pipe stick

A compression test result on a prototype composite pipe stick is shown in **Figure 1**. The yielding capacity of the unit is aptly demonstrated by the maintenance of 380-500 kN loads up to deformations of 160 mm. The response also shows sudden decreases in load bearing capacity (at 30 and 58 mm deformation). These were associated with failure of the circumferential fibres and resulting splitting down the axis of the unit, as highlighted in **Figure 2**, which also shows that the damage is localised at the end of the unit, and that the yielding mechanism is associated with progressive "unpeeling" of longitudinal strips. This mode of failure causes preferential failure at the ends of the unit, and effectively inhibits the undesirable buckling failure mode. It was noted during meetings with MOC that it would be necessary to test units of lengths representative of typical mining heights, to confirm that buckling does not occur.

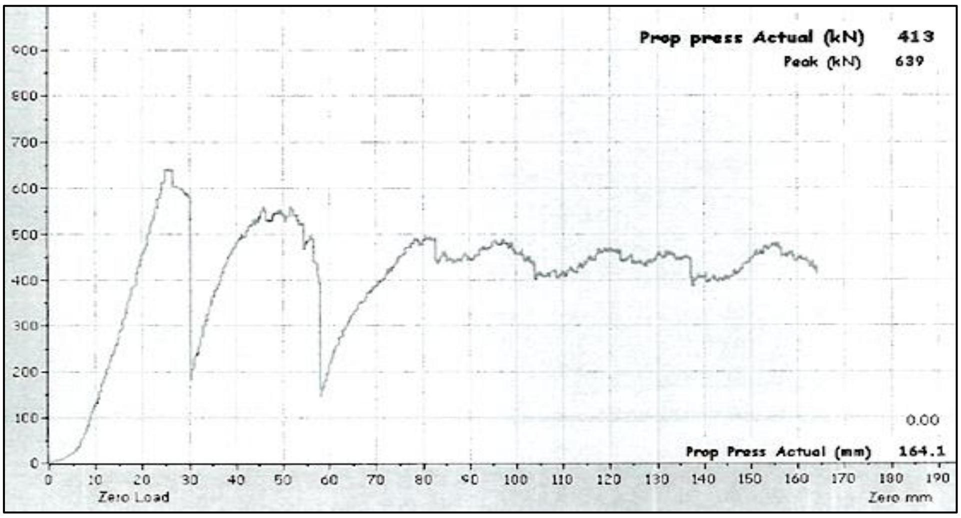


Figure 1. Load-deformation response of a short (400 mm long) MOC composite pipe stick

Figure 2. Localised failure at the end of the pipe stick, showing breakage of circumferential fibres

MOC has tested a number of "engineered" units at Timrite. The results from one of these sets of tests are shown in **Figure 3**. These results show reduced load drops following the initial failure of the unit. It must be noted, however, that these tests were not observed by the research team and the results cannot be confirmed until such tests have been observed or conducted by Mandela Mining Precinct researchers.

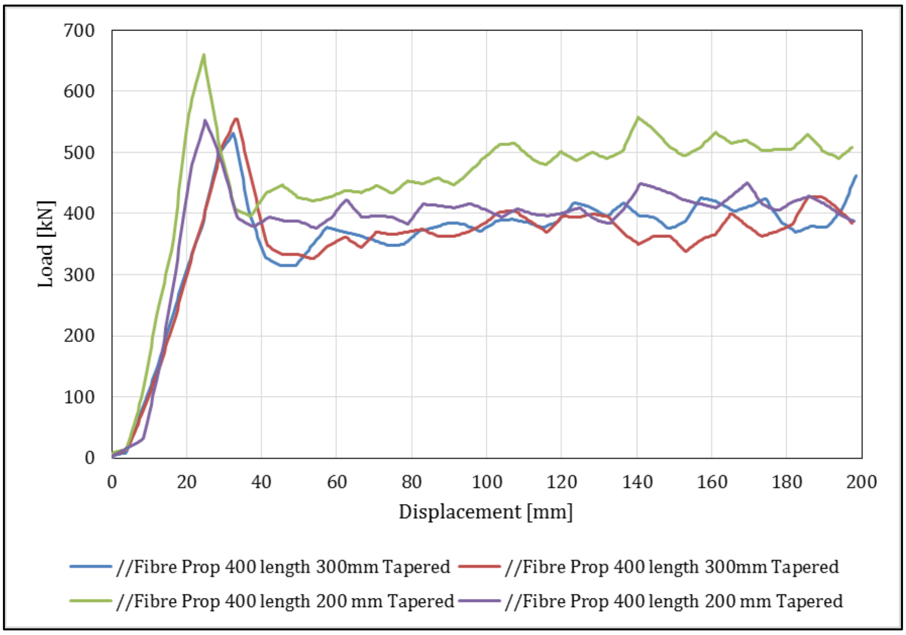


Figure 3. Test results for "engineered" composite pipe sticks

3.1.1.3 Milestone 3 to 5: Develop questionnaire and survey methodology to be applied; Conduct Survey; Conduct a Workshop

The last-approved scope included the development of a survey questionnaire, to conduct a survey and to conduct workshops that would inform strategies for the development and uptake of novel support systems. This work was initiated, but was placed on hold as a result of an agreement being reached with the composite stick manufacturer regarding the further development of their product. The project was then re-scoped (**Table 3**) to focus on funding development of the MOC product.

Only the costs associated to the researcher's time and rates were declared for payments from CSIR, which these payments were made prior to March 2019. The milestone 4.3 amount declared was R66,060.00 and milestone 4.4 amount declared was R90,400.00. Milestone 4.5 was cancelled and no amount was declared or payment being made.

In anticipation of the tests to be conducted in Milestone 3, the current state of the composite pipe stick (CPS) development was evaluated, and is described in the next section. This information provides some background and details on the current status of the technology.

3.1.1.4 Milestone 3.6: Submission of Final Close-out Report

The project was scoped to include the development of a survey questionnaire, and to conduct workshops that would inform strategies for the development and uptake of novel support systems. In the interim, agreement was reached with the composite stick manufacturer (MOC Technologies) regarding the further development of their product. The milestone 5 was cancelled as it was found not applicable as the project progressed and due to the delay which resulted from finalising the Memorandum of Agreement. The project was then re-scoped to focus on funding development of the MOC product.

The first two deliverables for the project are project initiation and completion of the close-out report. These have been achieved, but further progress has been stalled by delays in finalising the memorandum of agreement (MoA) between MOC and Minerals Council South Africa (MCSA). The MoA was signed in August 2019 which concluded the deliverables of the work package deliverables for the budget 2018/2019. The close out report was completed and are herewith being submitted as the final close-out report, which this final milestone deliverable amounts to R44 400.00

3.1.1.4.1 Recommendations

The composite pipe stick has the potential to provide support and yielding capacity comparable with yielding timber units. The units weigh approximately one quarter of equivalent timber support, and can be manufactured locally. It is possible that local mining communities can manufacture the units. Projected unit costs are not yet comparable with individual timber support units, but, when the units are combined into clusters, the cost of these is competitive with equivalent grout-based options.

The phase 3 deliverables are set out in the signed MoA. This work package deliverable resides under the Budget 2019/2020. The manufacturing of 1.6m composite sticks are to be tested and the deformation results are to be documented. This follows further cluster testing of composite sticks, which would result in a final report been submitted to TSC for approval, which is scheduled for completion in March 2020.

3.1.2 2019/20 Project Deliverables

The 2019/20 Business plan was presented to the LoCM Technical Steering Committee in which the 2019WP3 – Support project scope and deliverables were presented and approved. Due to Covid-19, the project plan was impacted with budget cuts been implemented, which narrowed the scope to single composite pipe stick testing and verification of test results compared to the design, with a final report being submitted. The cluster stick testing was deferred to 2020/2021 budget. Table 4 provides the 2019/20 project deliverables details and the original budget timelines, which also was impacted by the Covid-19 lockdown.

Table 4: 2019/20 MOCTECH Support project deliverables

Objective		Milestone No	Milestones	Start Date	End Date
		2019/20 Milestone Deliverables			
3.2	Support systems MOCTECH Individual Composite Pipe stick Tests	3.2.3	Mobilisation	Oct 19	Oct 19
		3.2.4	Model failure modes	Nov 19	Nov 19
		3.2.5	Manufacture 25 x 40mm poles	Dec 19	Jan 20
		3.2.6	Test 25 x 40mm poles and select best design	Jan 20	Jan 20

3.1.2.1 MILESTONE 3: Mobilisation

The project mobilisation was done in October 2019. A project plan was rescheduled as a result of the contract changes and the Covid-19 impacting MOC resources.

3.1.2.2 MILESTONE 4 Model failure modes

The failure mode determines the post-yield behaviour of the unit (Roberts et al., 1987). Where buckling occurs, the load-bearing capacity of the unit is completely eliminated. Buckling is typical of un-turned timber units, particularly when they have dried out or have been damaged by blasting. The likelihood of buckling increases as the length-to-diameter ratio of the unit increases (Roberts, 1995). Other failure mechanisms allow the unit to sustain significant, sometimes increasing, load levels with increasing deformation: steel jackets encourage a “wrinkling” failure mode; steel wedges cause the timber to splay continuously; and “pencil” profiles result in the timber “brushing”. All of these mechanisms avoid buckling by engineering the failure process and localising it to the end(s) of (or within) the support unit.

The failure mode simulations done prior to November 2019 gave unsatisfactory results. It was discovered that assumptions were made to the composite pipe stick material characteristic parameters and required testing to confirm these parameters, which these tests were conducted during November 2019 to February 2020. The failure mode simulation results, based on the new material parameters, indicated more consistent failure, which indicated that the failure mechanism should be introduced at the composite pipe stick end. Further testing was delayed in March 2020 due to the Covid-19 lockdown implementation. The project work could only re-start in August 2020.

3.1.2.3 MILESTONE 5 & 6 Manufacture & Test poles and select best design

The test samples were manufactured for testing. Previous tests conducted had no adjustments made to the pipe stick ends, which showed a sharp increase in load bearing to a peak load of

$\sim$ 650 kN and then a sudden load drop, which recovers to $\sim$ 40 T constant yield.

Various failure modes have been introduced at the end of the composite pipe sticks, which are:

- Vertical cuts - wide spaced vertical cuts were made 30 mm into the pipe stick;
- Internal Crown/Wedge - cut 4 internal inverted wedges;
- External Crown/Wedge - cut 4 & 6 external "flat topped" wedges;
- Sharp Wedge/Crown – cut 30mm deep sharp wedges or crowns;
- Chamfer – cut a 15mm chamfer around the circumference of the end of the pipe stick.

3.1.2.3.1 Test Results

This section is covered in section 3.1.3.1.5 in this report.

3.1.2.4 Conclusions

The initial pipe stick profile design of cuts and wedges did not provide the effective design modification to reduce or eliminate the sudden drop in load bearing capacity of the sticks. Material characteristics testing was required to determine the parameter input into the simulation model to provide improved outcome, which resulted in improved consistency in deformation of the pipe stick with no sudden load bearing capacity drop. The introduction of 6 crown wedges, sharp wedge/crown and chamfer illustrated most effective results. This proofs the tested process undertaken was successful in determining the failure mode that eliminates the sudden drop in load bearing capacity of the sticks. The modified chamfer profile showed the most favourable outcome, where no sudden drop in load bearing capacity occurred as previously experienced.

3.1.2.5 Recommendations

The single pipe stick units deformation results is similar for the 400mm length compared to the 1.6m lengths. The failure mode is successful with the chamfer profile being the most effective consistent deformation. It is recommended to use this failure mode application to the cluster tests for further testing.

3.1.3 2020/21 Project Deliverables

The 2020/21 project work plan consisted of two parts, the first part is for CSIR research team to deliver milestones 1 to 6 (CSIR) and MOCTECH to deliver milestones 7 to 10 (Table 6). This project are funded by Department of Science and Innovation (DSI). These two projects are interlinked, sharing test result outcomes to determine and finalise design specifications.

3.1.3.1 CSIR project deliverables are:

Table 5: CSIR Project Deliverables

Milestone No	Milestone	Deliverable	Start	End	Value (ex. VAT)
8.1	Determine performance criteria	Documented performance criteria for the composite pipe stick	Sept 20	Sept 20	R86 577.78
8.2	Provide testing facilities	Testing facilities made available for compression testing	Sept 20	Nov 20	R175 660.11
8.3	Observe selected tests	Logs confirming observation of critical tests	Sept 20	Nov 20	R30 755.56
8.4	Evaluation of FE modelling	Report on FE modelling	Sept 20	Dec 20	R31 866.67
8.5	Advise and assist with design selection	Report indicating the design modification process	Sept 20	Dec 20	R52 444.44
8.6	Final report	Report comparing the performance of the composite unit against design criteria.	Dec 20	Jan 20	R74 044.44
TOTAL					**R455 000.00**

3.1.3.1.1 MILESTONE 1 – Determine performance criteria

This milestone describes the performance characteristics required of the composite pipe stick. General characteristics of elongate support units are discussed. The specifications stipulated by Implats are outlined, and considerations for other applications are discussed.

3.1.3.1.1.1 Mine support elongates

Elongates are used as in-stope support in various applications and in many different types of ground conditions. The required support resistance is dependent on ground conditions and the expected mechanism of rockmass failure. As with any distributed support system, the forces that the individual units can sustain, the deformation range over which they can operate, and the spacing of the units determine the support resistance offered across the excavation. “Support resistance” is the individual load-carrying capacity of each unit divided by the area over which it acts.

This section aims to describe the general characteristics of elongate support units and how these are used in the design of support systems for specific conditions and applications. The response of a typical yielding elongate (in terms of axial load and compression) is shown in Figure 11. The terms used to describe the performance of elongate support units are discussed below. Many of the definitions are adapted from Daehnke et al. (1998).

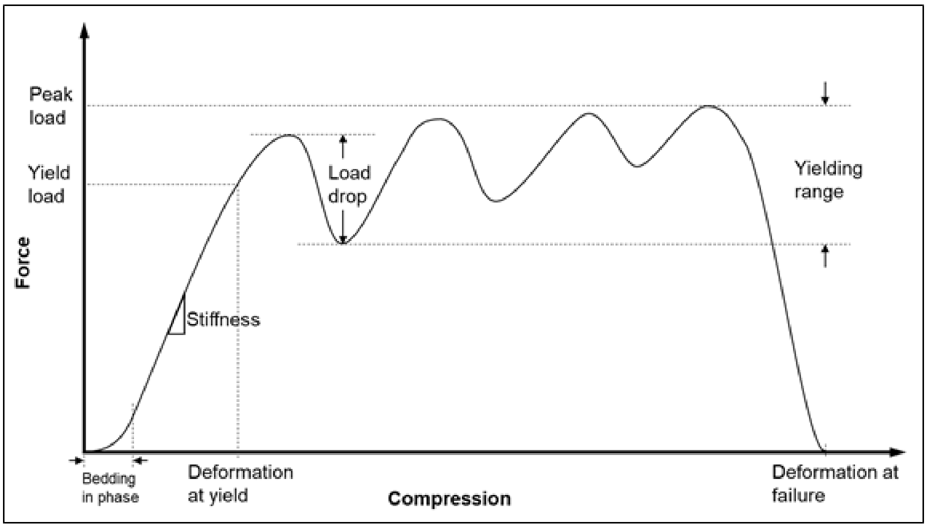


Figure 4. Typical load-deformation response for a yielding elongate

3.1.3.1.1.1.1 Stiffness

The initial response of the unit prior to the first incidence of yielding or failure is characterised by the term 'stiffness'. This refers to the slope of the load-displacement response: nominal stiffness can be calculated by dividing the load at first yield by the corresponding displacement. Depending on the unit construction, this portion of the response may be "elastic" – i.e., the displacement is recoverable if the load is removed or it may contain inelastic components which result in permanent deformations in the unit. Many units are characterised by a "bedding in" phase where very low apparent stiffness increases to a near-constant value which is maintained up to the yield point. Timber units tend to exhibit low initial stiffness and are therefore often pre-stressed to provide support resistance as soon as they are installed.

3.1.3.1.1.1.2 Yield load

The load at which the first deviation from a linear relationship between compression and load is observed. This deviation will be a decrease in the apparent stiffness: it is thus differentiated from the "bedding in" phase, where the stiffness increases with increasing load.

3.1.3.1.1.1.3 Deformation range

The compression range over which the unit is capable of offering significant support resistance. This is the compression range from the start of the response up to the deformation at failure (or the deformation at which the unit no longer provides sufficient resistance to satisfy its design requirements).

3.1.3.1.1.1.4 Strength/peak load

The greatest load sustained by the unit, usually expressed in kN. For unturned timber units, this follows the yield load, and is followed by a consistent decrease in load. For yielding units, the peak load can be observed at any point after the initial yielding of the unit.

3.1.3.1.1.1.5 Yielding range

The range of maximum and minimum loads recorded following the yield point and preceding final failure of the unit. Yielding units will typically be loaded only as far as they are expected to resist deformation. For example, the maximum closure may dictate that the unit is only required to provide support resistance over 200 mm of deformation.

3.1.3.1.1.1.6 Energy absorbing capacity

The ability of the unit to absorb energy, and hence resist loading induced by high closure rates and seismic events. It is the product of the load and compression over the entire range of the unit's response. This is simply the "area under the curve" of the load-compression response.

3.1.3.1.1.1.7 Failure

The value of compression beyond which the unit cannot supply significant support resistance. As noted above, yielding units are rarely loaded all the way to failure.

3.1.3.1.1.1.8 Failure mode

The failure mode determines the post-yield behaviour of the unit (Roberts et al., 1987). Where buckling occurs, the load-bearing capacity of the unit is completely eliminated. Buckling is typical of un-turned timber units, particularly when they have dried out or have been damaged by blasting. The likelihood of buckling increases as the length-to-diameter ratio of the unit increases (Roberts, 1995). Other failure mechanisms allow the unit to sustain significant, sometimes increasing, load levels with increasing deformation: steel jackets encourage a "wrinkling" failure mode; steel wedges cause the timber to splay continuously; and "pencil" profiles result in the timber "brushing". All of these mechanisms avoid buckling by engineering the failure process and localising it to the end(s) of (or within) the support unit.

3.1.3.1.1.2 Impala specifications

Impala Platinum initiated a project to explore alternatives to traditional timber support units. At the time, there were threats of timber shortages, with the likelihood that timber supply constraints would become even more severe in the future. The majority of the material in this discussion was obtained from the Rhinos (2012) report. Table 6 lists the elongate requirements for different depth ranges. A cost comparison indicated that there was little value in attempting to replace standard timber elongates used at shallow and intermediate depths, however, initial estimates showed that plastic or composite units could compete with yielding timber elongates (Strocam, Wedgeprop and Nimrite) when economies of scale were accounted for.

Table 6. Support requirements for different depth ranges at Impala Platinum (Rhinos, 2012)

Description	Shallow conditions	Intermediate conditions	Deep conditions
Depth range below surface	30 m to 600 m	600 m to 850 m	850 to 1,300 m (and beyond)
Required support units diameter	160-180 mm	200-220 mm	171, 180 or 200 mm
Support type	Mine pole	Terramac	Strocam, Wedgeprop or NimRite props
Approximate monthly consumption	30 000	70 000	30 000

With the depth of operations increasing, support requirements will ultimately increase to the point where timber elongates alone are no longer sufficient. Backfill or grout-based systems (such as grout packs) are considered necessary at these depths. These systems require significant capital investment (building grout plants and ranges) and the unit costs are also relatively high. A cost comparison is presented in Figure 5. Implats considered the possibility of using clusters of elongates instead of grout-based systems.

Implats embarked on a research project to develop a support system that would perform at least as well as yielding timber elongates in single unit application, and at least as well as a grout packs in cluster applications. Three different manufacturers participated, providing units of different materials (glass fibre, composites and plastics) and various manufacturing methods (moulding, pultrusion and extrusion).

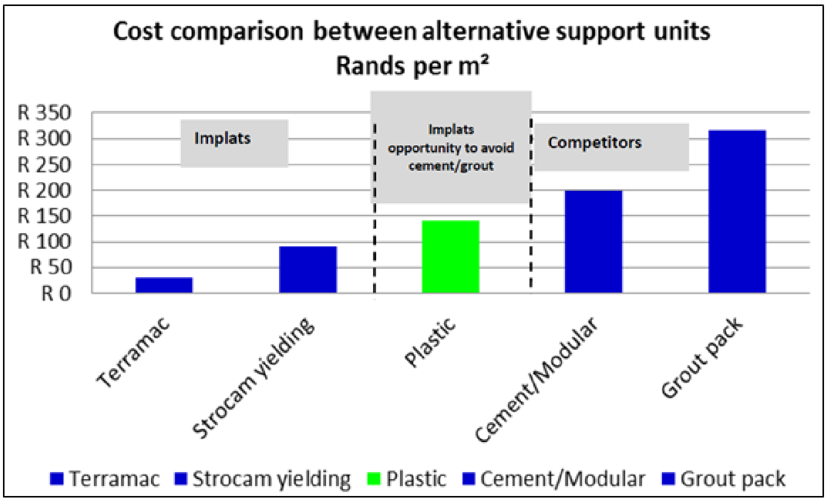


Figure 5. Cost comparison (R/square metre) of alternative support systems (Rhinos, 2012)

A series of specifications were developed for the units. The support performance requirements are listed below.

1. Peak load – more than 400 kN (in compression).
2. After reaching the peak load there must not be a sudden drop of load by more than 40%, for instance, if the peak load is 700 kN the drop from peak should not be more than 40% = 280 kN, to stabilise at around 420 kN.

3. Yielding range – minimum 350 kN, average 400 kN ±1&2 standard deviations.
4. Loading rate to be 30 mm/min or slower.
5. Yield (deformation) – 500 mm at yield load.
6. Pre-stressing – the unit must be of such a shape that a Jackpot pre-stressing device of existing product range can be put on one end of the unit and hydraulically pre-stressed up to 15 MPa, using the existing pump. [This equates to roughly 200 kN pre-stress.]

Implats' specifications also indicated that the unit should be resistant to blasting, i.e., that it should not be blasted out, and that it must retain at least 75% of its yielding capacity after blasting, when placed 2 m from the face. Implats further specified that the unit would operate in mining heights of 1 to 1.5 m.

3.1.3.1.1.3 Timber-based yielding elongate performance

Nimrite props are composed of a machined timber component which is fitted into a steel tube. The yielding mechanism involves localised failure of the step features show in Figure 6. Localising the failure mechanism prevents buckling, and ensures a consistent response. The load-displacement response of the Nimrite timber-based unit is shown in Figure 7. The unit yields (on average) at 240 kN and subsequently sustains loads from 255 to 580 kN. The stiffness of the unit is approximately 15 kN/mm. Load drops are present, but these are lower than 5% of current load. The final 20 mm of the response is ignored, as it appears that other failure mechanisms appear at this point.

The load-bearing capacity of the unit generally increases from the yield point to the end of the test. This is not necessarily a positive behavioural characteristic, as high loads may lead to punching of the unit into the surrounding rockmass, weakening the hangingwall and encouraging falls of ground (Daehnke et al., 2001). At 600 kN load, a 19 MPa localised stress is applied, which can be damaging in weak, blocky or friable ground. The operating deformation range will be capped to prevent punching (e.g., 300 mm deformation in ground that can sustain a 400 kN "point load" (12.7 MPa)).

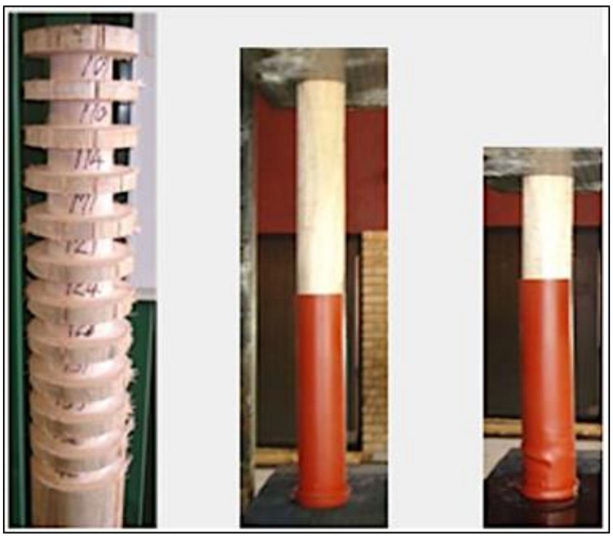


Figure 6. Nimrite timber-based elongate subjected to compressive loading (Timrite, 2019)

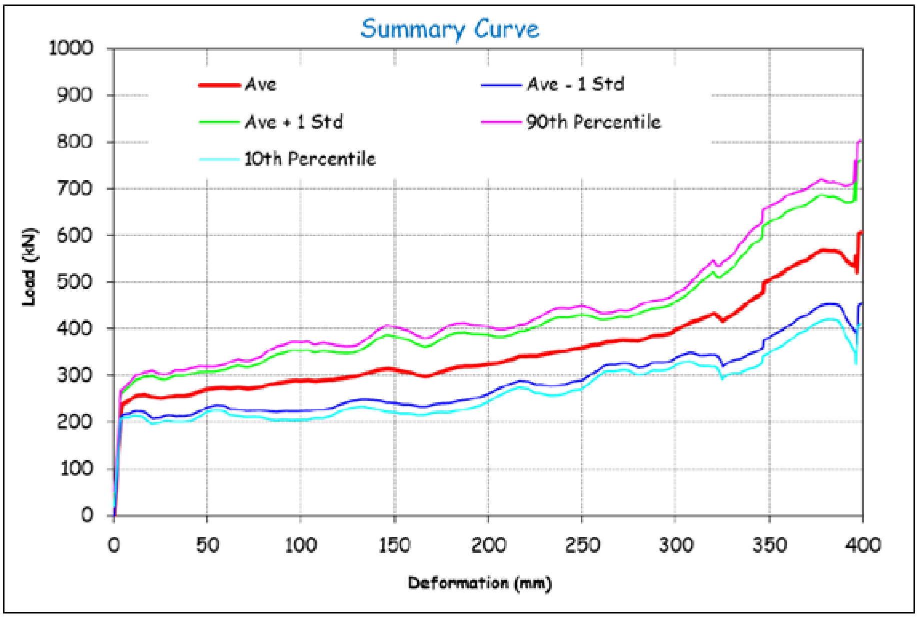


Figure 7. Load-displacement characteristics of 200 mm Nimrite poles (Timrite, 2019)

For design purposes, the 90% confidence line (10th percentile in Figure 7) should be used.

Stiffness:	15 kN/mm
Yield load:	210 kN
Yielding range:	200 – 430 kN
Maximum load drop:	43 kN (13%)
Deformation range:	380 mm

In the absence of other criteria, for example, those dictated by specific rockmass conditions or support requirements, the stiffness exhibited by the Nimrite unit will be used as a criterion for the composite elongate performance. Note, however, that this value is adopted as it is the only guiding information at this point. It should be modified if other information comes to light.

3.1.3.1.1.4 Cementitious pack performance

Cementitious packs are not used as "in-stope" support, that is, they are not used throughout the stope. They are used in specific areas (e.g. adjacent to gullies) and may be installed regularly in lines to supplement in-stope support. They could also be used to replace pillar support in mechanised stopes (Roberts et al., 2005). These units supply significantly greater support resistance than elongates, and are, in general, used at depth ranges that require yielding characteristics. Grout-based support requires building grout plants and distribution ranges or transport systems to supply the stopes with grout. As noted above, the capital required is significant, and operating costs are high.

Grave (2006) provides a thorough exploration of the performance characteristics of grout-based support systems. The most commonly used grout pack (in the platinum industry) is the ring steel support (RSS) pack. A pack is constructed by attaching a bag to the hangingwall, hanging steel rings at regular spacing from the bag, and pumping the bag full of grout. A grout pack constructed on surface as part of the testing program is shown in Figure 8. Dilation of the pack induced by rockmass closure causes lateral dilation, which loads the steel rings, confining the grout and generating support resistance.

Figure 8. RSS grout pack constructed in a frame on surface (Grave, 2006)

Over the course of the project, the "yield pack" – currently distributed by Norsenet – was developed. This is an RSS pack with an extra set of larger-diameter rings hung from the bag. As the smaller rings fail, the larger rings take up load, maintaining the unit's load-bearing capacity and extending the deformation range. The performance of the standard RSS grout pack and yield pack are compared in Figure 9. RSS packs retain load for 100-200 mm and then show step drops in load as each steel ring fails. For the yield pack, load drops are followed by increases in capacity, as described above, resulting in a yielding characteristic.

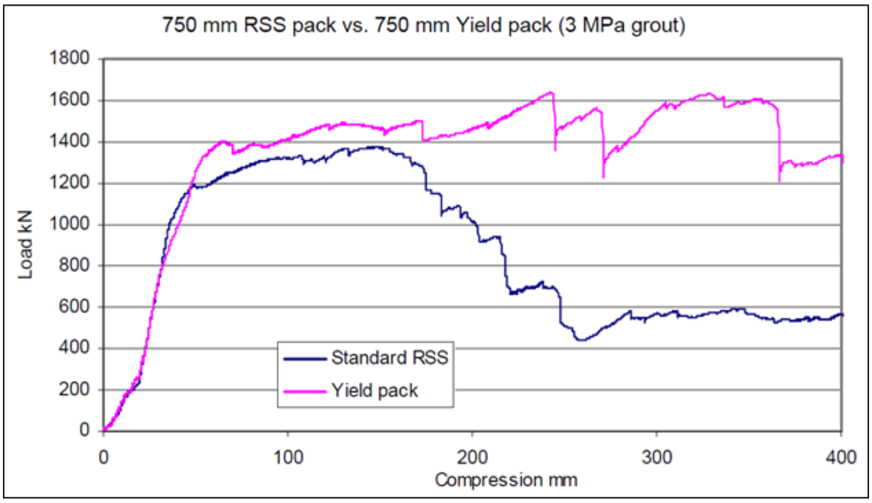


Figure 9. Load-displacement response of 750 mm diameter RSS grout pack and yield pack (Grave, 2006)

The performance of grout packs (and other cementitious support) is highly dependent on the strength of the grout, and on the size (width-to-height ratio) of the unit. Figure 10 shows how the strength of cementitious units varies with the w/h ratio of the unit. Strengths reside within a band between the Taupack and RSS pack response. A similar trend is observed for unit stiffness Figure 11.

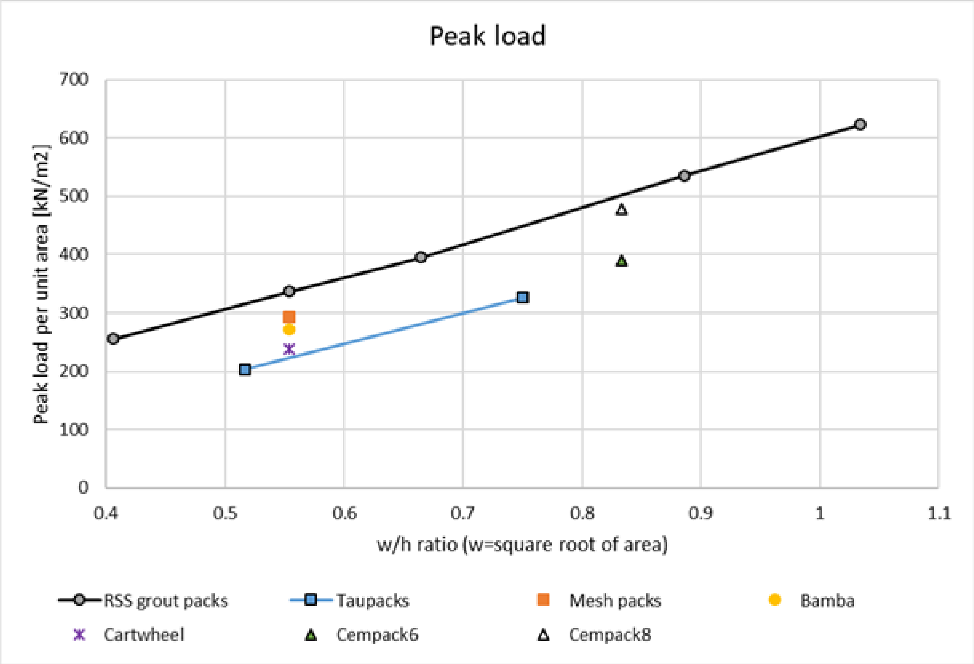


Figure 10. Peak load for cementitious support packs for various width-to-height ratios (after Grave, 2006)

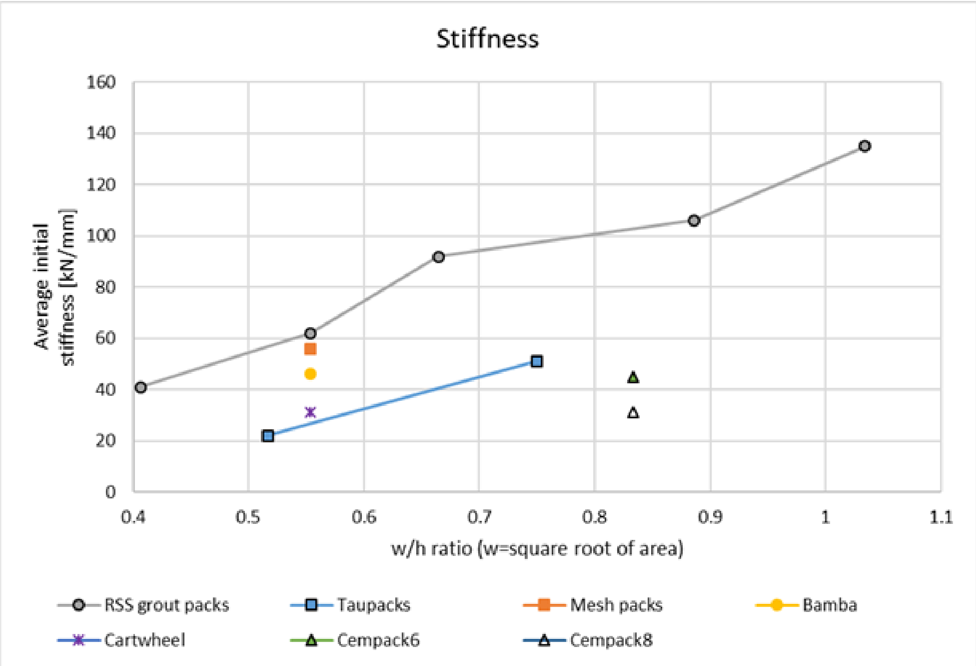


Figure 11. Average initial stiffness for cementitious support packs for various width-to-height ratios (after Grave, 2006)

It is worth noting that the only systems to provide a consistent yielding performance (i.e., no significant drop in load) over 400 mm of compression were the Cempacks and the yield packs. It is reasonable to assume that future support requirements (high closure with the possibility of seismic loading) for cementitious packs will dictate that they yield reliably up to at least 400 mm deformation.

Support requirements of yielding units for any given application will depend on the other components of the support system. If grout packs are used to prevent back-break failures, then they, together with in-stope pillars, will generally be required to supply 1.1 MPa support across the stope (Roberts et al., 2005). If they are used as gully support, their design must be considered in concert with rock reinforcement design in the gullies, and should be based on rockmass conditions and fallout thickness (Roberts, 1995; Daehnke et al., 2001).

Providing a single specification for a cluster composite unit “to compete with grout packs” is not possible. The number of units in the cluster will increase its strength and stiffness, just as increasing the w/h ratio of a cementitious pack will increase strength and stiffness. The choice of which support system to use will be driven by cost more than unit performance. It is necessary, however, to assess the number of units required to obtain performance equivalent to a given cementitious system. This will indicate the general feasibility of using elongates to provide high strength support resistance.

Table 7 shows how many units would be required to attain the strength and stiffness of each cementitious unit. The strength is calculated assuming the strength of the elongate unit is 400 kN, as dictated by the Implats specification. The number of units required to attain equivalent stiffness is calculated according to the stiffness of the 200 mm diameter Nimrite prop (15 kN/mm). Both calculations assume linear relationships between strength and stiffness, and the number of units (i.e., two units are twice as strong, and stiff, as a single unit).

Table 7. Number of elongate units required to attain the strength and stiffness of cementitious support units

Support unit	Size (diameter or square edge length) [mm]	Strength [kN]	Number of elongate units required for equivalent strength (400 kN strength)	Stiffness [kN/mm]	Number of elongate units required for equivalent stiffness (15 kN/mm stiffness)
Grout pack	1400	7200	18	135	9
	1200	5484	14	106	8
	900	3324	9	92	7
	750	2550	7	62	5
	550	1656	5	41	3
Taupack	900	2750	7	51	4
	620	1705	5	22	2
Mesh pack	750	2220	6	56	4
Bamba pack	750	2050	6	46	4
Cartwheel pack	750	1810	5	31	3
Cempack (6 mesh)	1000	4313	11	45	3
Cempack (8 mesh)	1000	3522	9	31	3

3.1.3.1.1.5 Milestone conclusions and recommendations

The performance criteria provided by Implats will be used to guide the development of the composite elongate. In addition, the initial stiffness exhibited by competing yielding elongates is used as a criterion in the absence of other guiding principles.

The performance criteria are as listed below.

1. Peak load of at least 400 kN.
2. After reaching the peak load there must not be a sudden drop of load of more than 40%, i.e., if the peak load is 700 kN, the drop from peak should not be more than 40% = 280 kN, to stabilise at around 420 kN.
3. Post peak load-bearing capacity should not decrease to less than 350 kN, with an average of 400 kN±1&2 standard deviations.
4. The deformation range should be at least 500 mm.
5. Pre-stressing – the unit must be of such a shape that a Jackpot pre-stressing device of existing product range can be put on one end of the unit and hydraulically pre-stressed up to 15 MPa, using the existing pump. [This equates to roughly 200 kN pre-stress.]
6. Initial stiffness should be at least 15 kN/mm.
7. Length of up to 1.5 m.

A unit that meets these performance requirements will satisfy the requirement of a high-strength system (equivalent to cementitious units) in terms of strength, stiffness and yielding characteristics when combined in clusters. Table 7 shows the number of units in a cluster that would be required to attain the performance of various cementitious units.

Other performance criteria (e.g., fire safety, blast resistance and the effect of composites on processing) will be discussed and evaluated within other parts of Work Package 3 (Composite Elongate Support Development).

It is recommended that these criteria be used to assess the suitability of the composite elongate. The desired application will also affect these criteria, and they should be amended if the application varies significantly from those described within this report.

3.1.3.1.2 MILESTONE 2 – Provide testing facilities

The testing work for the full suite of composite sticks was conducted at the CSIR's Mechanical Testing Facility at Cottesloe. The facility carried out a wide variety of mechanical tests in accordance with the SABS, BS and other standards. For the purpose of this project, single and cluster composite elongates were subjected to compression tests using the Amsler compression press, which has a load capacity of 1 000 kN (**Figure 12)**.

Figure 12. Amsler 1000 kN compression testing machine

The compression testing was done during the course of 2020 and 2021. Test certificates issued are listed in **Table 8**:

Table 8: Issued test certificates for compression testing

Test Date	Certificate Number	Test of mine prop composite sticks
11 Dec 2021	T28666	1600 mm x 160 mm x 10 mm
11 Dec 2021	T28667	1600 mm x 170 mm x 10 mm
11 Dec 2021	T28668	400 mm x 170 mm x 10 mm – stack of nine
11 Dec 2021	T28681	400 mm x 170 mm x 10 mm – stack of nine
11 Dec 2021	T28682	400 mm x 160 mm x 10 mm – stack of three

3.1.3.1.3 MILESTONE 3 – Observe selected tests

The CSIR researchers were present to observe selected tests as outlined in the project proposal. The purpose of observing the tests was to ensure the following:

a) The test device is calibrated prior to any test work or as suggested by the testing standard;
b) Measure dimension of each sample and confirm that each sample is identical;
c) Photograph and number each test sample prior to test work;
d) Record photographs of each test sample, before and after test work; and
e) Verify all the test results.

The researchers successfully observed the tests carried out in December 2020 and March 2021 with the following results.

TEST - T28666

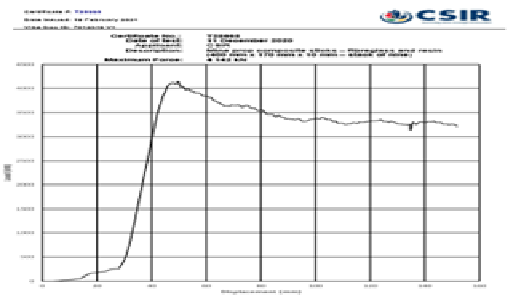
Test No.	Maximum load carried (kN)	Test Comment	Compressed Composite stick
1	482	The composite sticks deformed	
2	397		
3	335		
Mean	404.7		
Standard deviation	73.8		

TEST - T28667

Test No.	Maximum load carried (kN)	Test Comment	Compressed Composite stick
1	508	The composite sticks deformed	
2	482		
Mean	495		
Standard deviation	18.4		

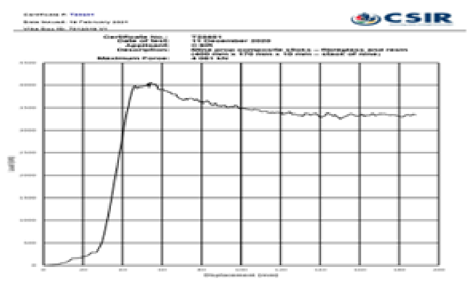
TEST - T28668

Figure 2. Mine prop composite sticks – fibreglass and resin (400 mm x 170 mm x 10 mm – stack of nine) after the test



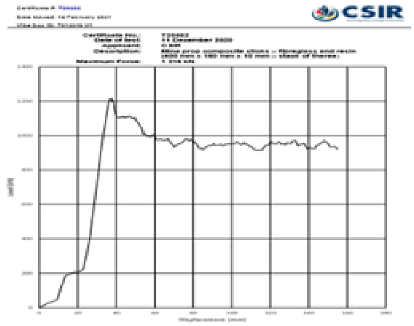
TEST - T28681

Figure 2. Mine prop composite sticks – fibreglass and resin (400 mm x 170 mm x 10 mm – stack of nine) after the test



<u>TEST - T28682</u>

Figure 2. Mine prop composite sticks – fibreglass and resin (400 mm x 160 mm x 10 mm – stack of three) after the test



3.1.3.1.4 MILESTONE 4 – Evaluation of FE modelling

MOCTech indicated that the numerical modelling results - to be used to guide the design process - did not make sense, and that it would be necessary to conduct material tests on fibre samples to properly calibrate the models.

CSIR conducted additional set of compressibility tests during the week of 19th of October 2019 at Cottesloe. Twenty-two standard 400 mm long samples all with a modified end were tested. Six different versions were considered. The aim of the tests was to build on the results from previous modified end tests (2019) to achieve the desired failure mechanism and pole yields. From the material property test results, further simulation was conducted by MOCTech using these latest material property parameters as input parameters into the simulation models, from which new numerical models were developed and tested, resulting in the introducing of failure mechanisms on one side of the pipe sticks.

3.1.3.1.5 MILESTONE 5 – Advise and assist with design selection

3.1.3.1.5.1 Forced failure testing

Initial testing of the 400 mm long composite sticks showed that the elongates could maintain a yielding capacity of between 380-500 kN and up to 160 mm of deformation. However, the load-deformation plots revealed a sudden decrease in load bearing capacity of the elongates at ~30 and 58 mm deformation. The sudden decrease in the load bearing capacity was associated with failure of the circumferential fibres, which resulted in splitting down the axis of the unit.
It was observed that the damage was concentrated at the end of the elongate and that the yielding mechanism was associated with progressive unpeeling of the longitudinal strips. This mode of failure caused preferential failure at the ends of the unit and could effectively cause the undesirable buckling failure mode. This prompted further research work to focus on the following:

1) Testing 1.6 m (stope width size) long elongates to determine whether buckling occurs along the units and;
2) To develop a mode of failure for the sticks so to control the sudden decrease in load bearing capacity that is associated with the failure of circumferential fibres.

3.1.3.1.5.2 **Methodology**

In February 2020, two 400 mm ten-stick clusters were tested, with results that were similar in form to the individual composite stick tests. That is, they showed the sudden decrease in load bearing capacity. Additionally, tests were also conducted on elongates with modified, crown-profile ends (Figure 20). These results showed that the sticks failed progressively, with much lower load drops than those seen in the un-profiled results (Figure 21).

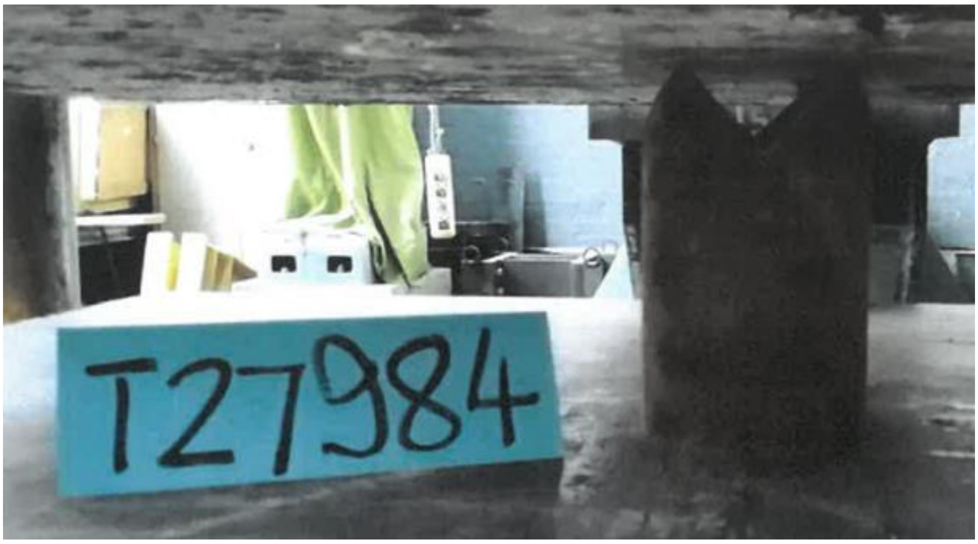


Figure 13 Modified 400 mm long samples, tested in February 2020

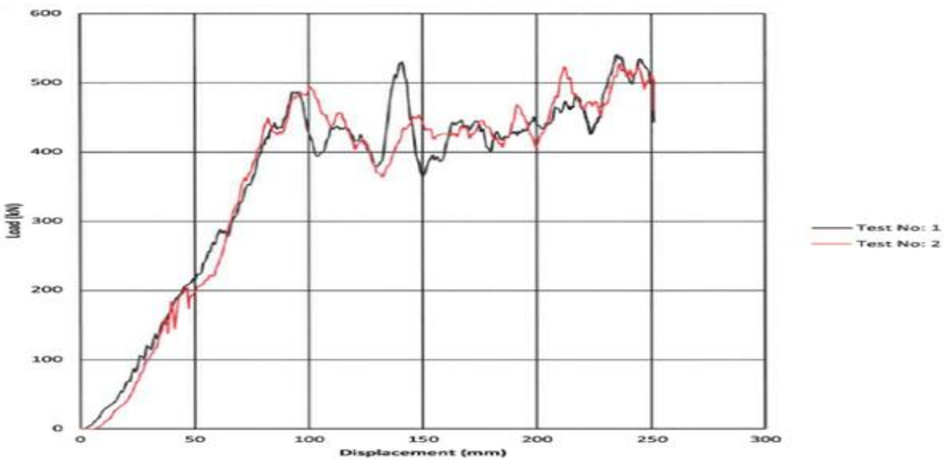


Figure 14. Test results for the modified 400 mm long samples

An additional set of compressibility tests were conducted in October 2020 at the CSIR mechanical testing facility, at Cottesloe. Twenty-two standard 400 mm long samples all with a modified end were tested. Seven different versions were considered (including the original design). The aim of the tests was to build on the results from previous modified end tests (February 2020) to achieve the desired failure mechanism and pole yields. Based numerical modelling results and the previous two rounds of tests; additional end modifications were tested. The additional material tests on fibre samples to properly calibrate the models assisted with realising believable analysis results.

Figure 15 *Modified Pole ends. (Cardboard 170mm diameter and laminates were 10mm thick)*

Table 5 provides details of the various modifications made to the pipe sticks.

Table 9 *End Modification descriptions*

Modification	Cut depth (from end of stick)	Number of sticks tested
No cuts	-	6
Vertical cuts	30 mm	6
Internal wedge/crown	30 mm	4
External wedge/crown	30 mm	4
External wedge/crown	30 mm	6
Chamfer	15 mm	6
Sharp wedge/crown (Feb 2020 tests)	30 mm	6

3.1.3.1.5.3 Testing Results

The following graphs highlight the consistency in the mechanism and the eventual design that presents the best mechanism to continue the testing and developments.

3.1.3.1.5.3.1 No Cuts at end of pipe stick

The 'no-cut' stick design is characterised by a planar horizontal cut. No mode of failure was induced at the ends of the sticks. Figure 16 above shows a sharp increase in the load bearing capacity of the stick with a peak load of ~650 kN. A sudden drop in load and recovery to the ~ 40 T constant yield follows this peak load stage. The drop in load ranges from ~560 kN to ~150 kN (the lowest recorded drop) amongst the elongates. It is not clear why the drop is not consistent between the stick considering the fact that they are identical in make. The behaviour observed from these test does not fit the conditions of the performance criteria therefore this design was excluded.

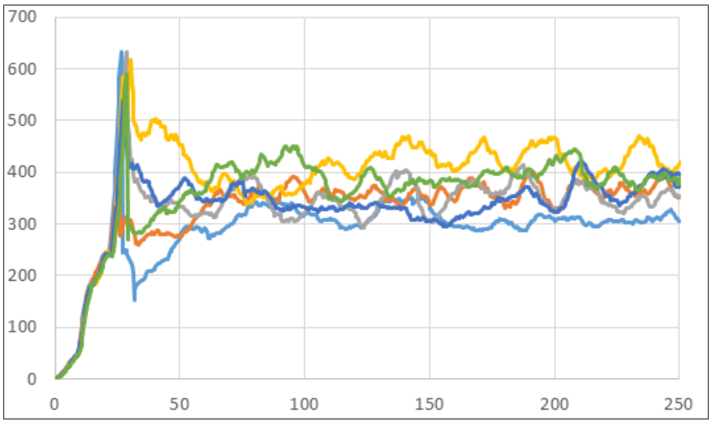


Figure 16: No cuts 400mm samples

3.1.3.1.5.3.2 Vertical Cuts

In this design, wide spaced vertical cuts were made 30 mm into the pipe sticks (from one end of the stick). The results indicated in **Figure 17** above show similar results to the "No cuts" design resulting in significant over shoot (to ~650 kN) and sudden drop in load (down to ~200 kN) followed by the recovery to the 400 kN constant yield. According to the performance criteria, the sudden drop in load should not be more than 40% of the peak load. In this case, the sudden drop load was more than 40% of the peak load resulting in the exclusion of the design.

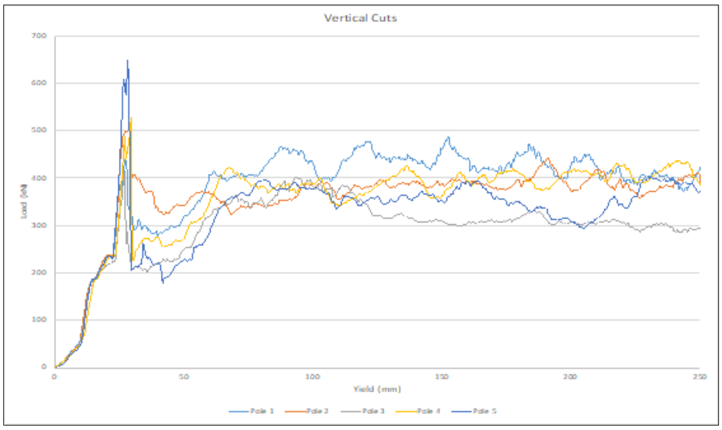


Figure 17: Vertical cuts 30mm deep

3.1.3.1.5.3.3 Internal Crown/Wedge – 4 cuts

The modification to the end of the pole was to cut 4 internal inverted wedges. The depth of the cut on the modified end was 30 mm. The results indicated in **Figure 18** above show consistent results with less over shoot and off-loading earlier than in the "No cuts" design. The results also show that a lower peak load (~200 kN) is achieved with this design, which does not meet the performance criteria of at least 400 kN. This design was excluded.

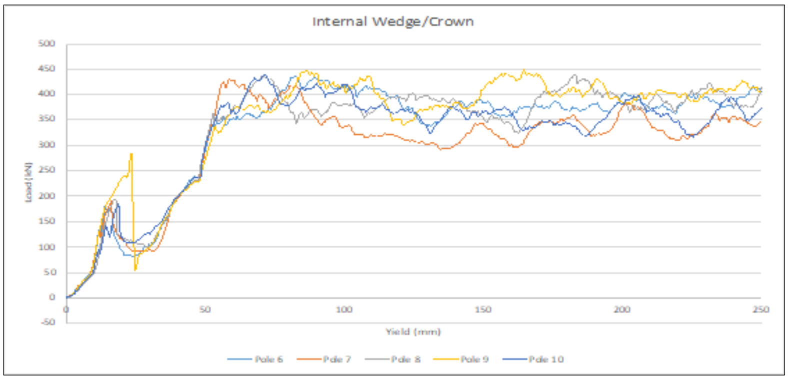


Figure 18: Internal 4 cuts 30mm deep

3.1.3.1.5.3.4 External Crown/Wedge – 4 cuts

The modification to the end of the pole was to cut 4 external "flat topped" wedges. The depth of the modified end was 30 mm. The results indicated in Figure 19 above show consistent results with later off-loading than the internal crown tests. The peak load of this design ranges between 300 kN and 400 kN and therefore does not meet the required minimum load of at least 400 kN. This design was excluded.

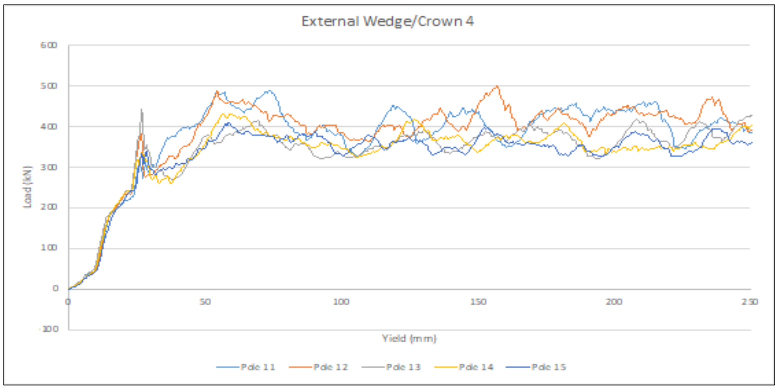


Figure 19: External Crown 4 cuts 30mm deep

3.1.3.1.5.3.5 External Crown/Wedge – 6 cuts

This modification to the end of the pole was to cut 6 external "flat topped" wedges. The depth of the modified end was 30mm. The effect of reducing the cross section in the material under load is evident in these results. The results indicated in Figure 20 above show consistent results with less off-loading after failure. The gradient/slop changes with the lower cross-section under load. Consistent yielding post initial failure is still present at or near the desired 400 kN load.

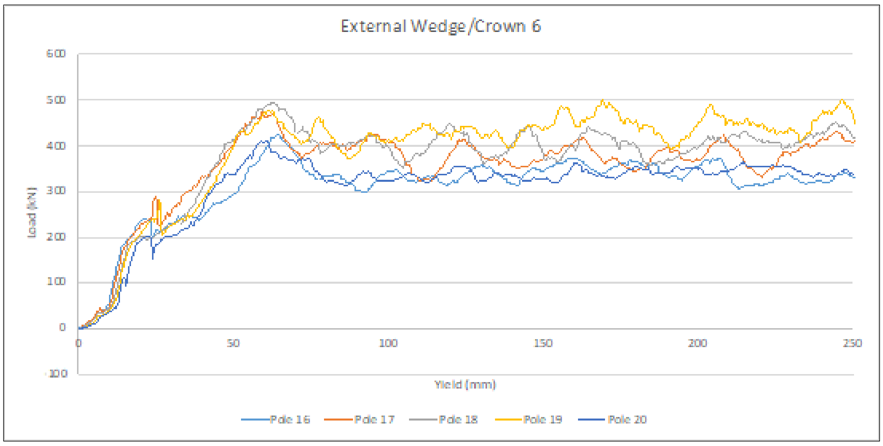


Figure 20: External crown 6 cuts 30mm deep

3.1.3.1.5.3.6 Sharp Wedge/Crown

This modification to the end of the pole was to cut into sharp wedges or crowns. The depth of the modified end was 30mm. The results indicated in Figure 21 show that the modification resulted in no significant sudden drop in the load bearing capacity of the stick. The peak load is achieved at ~450 kN and the post peak load bearing capacity ranges between ~380 kN and 520 kN.

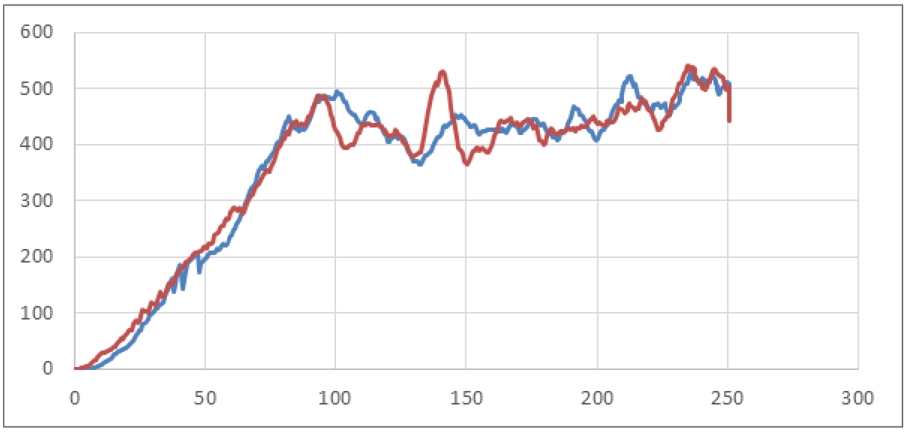


Figure 21: Sharp/Wedge cuts 30mm deep

3.1.3.1.5.3.7 Chamfer

The modification involved cutting a 15 mm Chamfer around the circumference of the stick. The results indicated in Figure 22 show that the modification resulted in a steeper desired gradient/slope with no sudden drop in load bearing capacity. The results show that the peak load of 400 kN is achieved and the post peak load bearing capacity ranging between ~380 kN and ~450 kN is maintained. The variation of the post peak load bearing capacity is less than that observed in the Sharp Wedge/Crown testing.

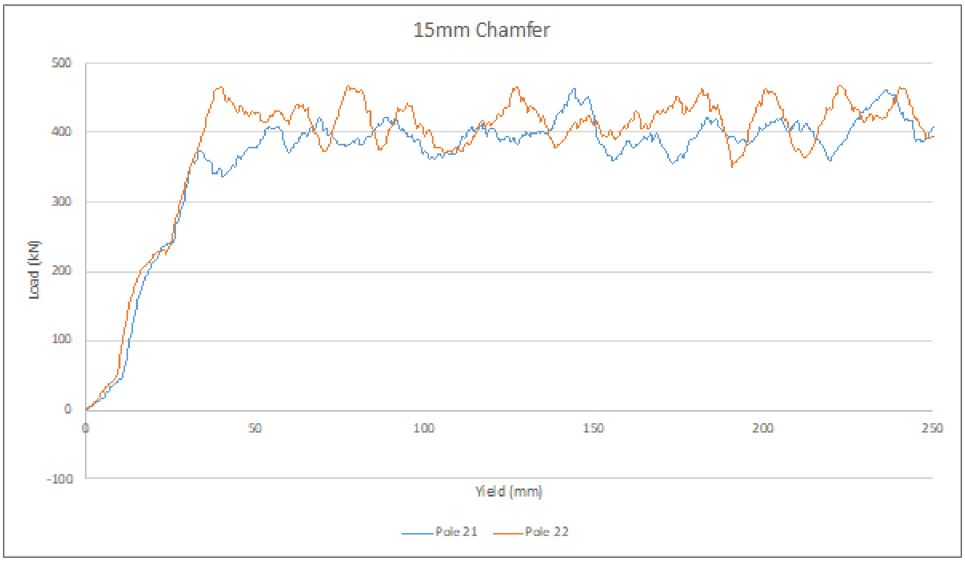


Figure 22: Chamfer 15mm deep

3.1.3.1.5.4 Milestone Conclusions

The initial pipe stick profile design of cuts and wedges did not provide the effective design modification to reduce or eliminate the sudden drop in load bearing capacity of the sticks. Material characteristics testing was required to determine the parameter input into the simulation model to provide improved outcome, which resulted in improved consistency in deformation of the pipe stick with no sudden load bearing capacity drop. The introduction of 6 crown wedges, sharp wedge / crown and chamfer illustrated most effective results. This proofs the tested process undertaken was successful in determining the failure mode that eliminates the sudden drop in load bearing capacity of the sticks. The modified chamfer profile showed the most favourable outcome, where no sudden drop in load bearing capacity occurred as previously experienced.

3.1.3.1.5.5 Milestone Recommendations

The single pipe stick units deformation results is similar for the 400mm length compared to the 1.6m lengths. The failure mode is successful with the chamfer profile being the most effective consistent deformation. It is recommended to use this failure mode application to the cluster tests for further testing.

3.1.3.2 MOCTECH deliverables are:

Table 10: MOCTECH Project Deliverables for CLUSTER STICKS

WP#	Description	Milestone	Milestone Deliverable	Start Date	End Date	Value (excl VAT)
8	Optimising the development of alternate elongate support	8.7	Manufacture 30 x 1.6m poles	Feb 20	Feb 20	R183 652.53
		8.8	Test 30 x 1.6m samples	Feb 20	Feb 20	R4 452.80
		8.9	Define Engineering	Feb 20	Feb 20	R6 730.51
		8.10	Project management and close out report	Mar 20	Mar 20	R105 164.16
TOTAL						**R300 000.00**

This section details the completion of milestone 7 to 10 (MOCTECH) of the LoCM20WP8 project.

The aim of this project is to develop a lightweight alternative to pack support.

3.1.3.3 MILESTONE 8.7 – Manufacture 30 x 1.6m poles

Tests that were conducted in February 2020 and December 2020 indicated that the composite sticks do not buckle at different lengths. It was also observed that the length of the sticks do not affect their performance and load bearing capacity. Therefore, due to time constraints, 400 mm samples were used as an alternative to the original 1.6 m sticks.

Two three- and nine-stick clusters were tested in December 2020. An additional fifty sticks were manufactured for the March tests from which twenty of these were tested as two ten-stick clusters (**Figure 11**). All the sticks manufactured had the modified Chamfer design on one end of the stick. A semi-automated process was used to manufacture the sticks due to the variability of the performance observed when manual manufacturing was done.

Figure 23: Short sticks used for the cluster tests

3.1.3.4 MILESTONE 8.8 - Test 30 x 1.6m poles

The primary aim of testing the single sticks as clusters was to determine whether the clusters satisfy the requirements of a high strength support system (equivalent to cementitious units) in terms of strength, stiffness and yielding characteristics. The secondary aim was to build on the results from previous modified end tests by determining the performance of the sticks when tested as clusters. The testing of a cluster unit is shown in **Figure 12.**

Figure 24: Testing of a cluster unit

December testing

The performance of the three and nine stick clusters are shown in **Error! Reference source not found.** and **Error! Reference source not found.** below. Analysis of the average load-deformation profile reveals that between 0 mm and ~10 mm deformation, the three stick clusters show an initial stiffness of approximately 10KN/mm. This is followed by a more rapid increase in load between 10 mm and 16 mm. During this interval, the load increases from 50 kN to ~200 kN. Between 16 mm and 23 mm deformation, the load slowly increases from 200 kN to ~230 kN before rapidly increasing to a peak load of ~1200 kN. Post peak loading capacity ranges between ~980 kN and 1220 kN. The step-like increase in load observed in the three stick clusters between 0 mm and 23 mm deformation is as prominent in the results of the three-stick cluster (**Figure 13**) and the nine-stick cluster (**Figure 14**). The nine-stick cluster achieves a peak load of ~4040 kN and subsequently sustains loads from 3250 to 4040 kN. Load drops are present, but these are less than 40% of the peak load. The performance of the nine-stick cluster provides performance that is equivalent to the nine elongate grout pack.

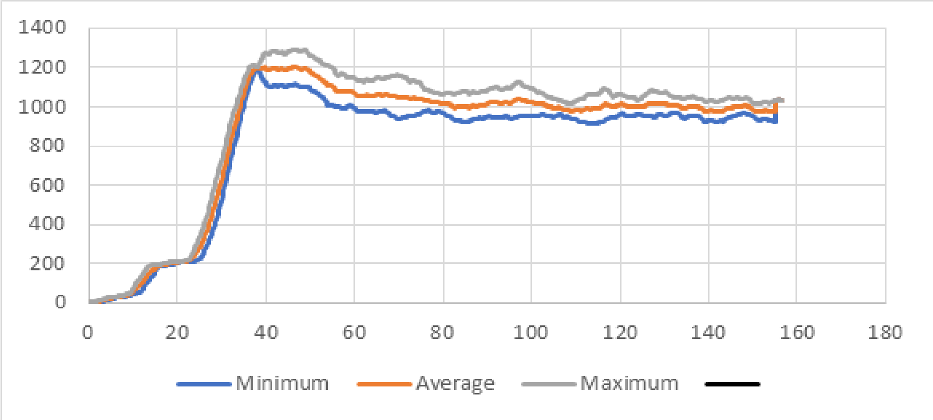


Figure 25: Load-deformation response of 400 mm H x 160 mm ID x 10 mm thickness – 3 stick cluster

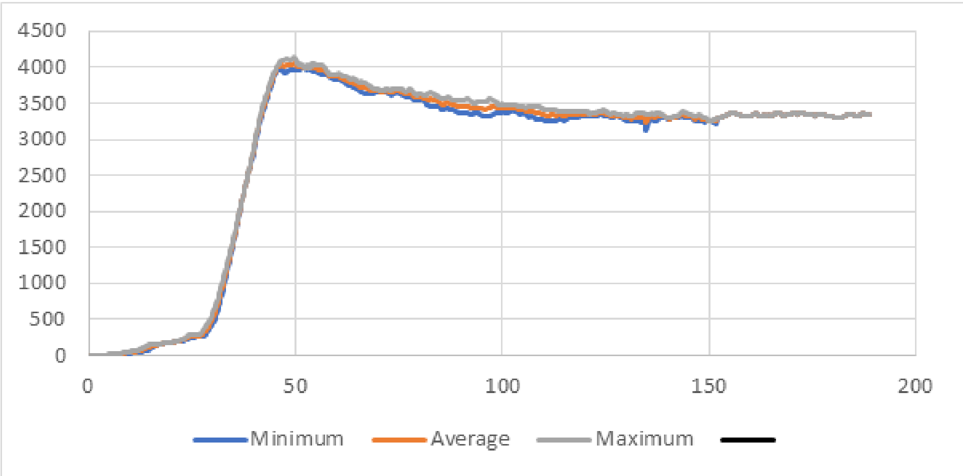


Figure 26: Load-deformation response of 400 mm H x 170 mm ID x 10 mm thickness – 9 stick cluster

3.1.3.5 MILESTONE 8.9 – Define Engineering

The aim of milestone 8.9 is to compare the performance of the composite unit against design criteria.

3.1.3.5.1 Comparison of 160 mm and 170 mm single and cluster sets

The results indicated in **Figure 27** and **Figure 28** show that there is no significant difference between the performance of the long and short sticks of similar diameter (at least under laboratory testing conditions). **Figure 15** shows that the short sticks have a slightly higher peak load (~400 kN) compared to the long sticks (~370 kN). This higher load is maintained between 40 mm and ~108 mm deformation, after which the load bearing capacity for the sticks are the same. **Figure 16** shows that the long sticks achieve a slightly higher yield load (~480 kN) compared to the short sticks (~450 kN). From ~80 mm deformation, the load bearing capacity of the sticks are the same.

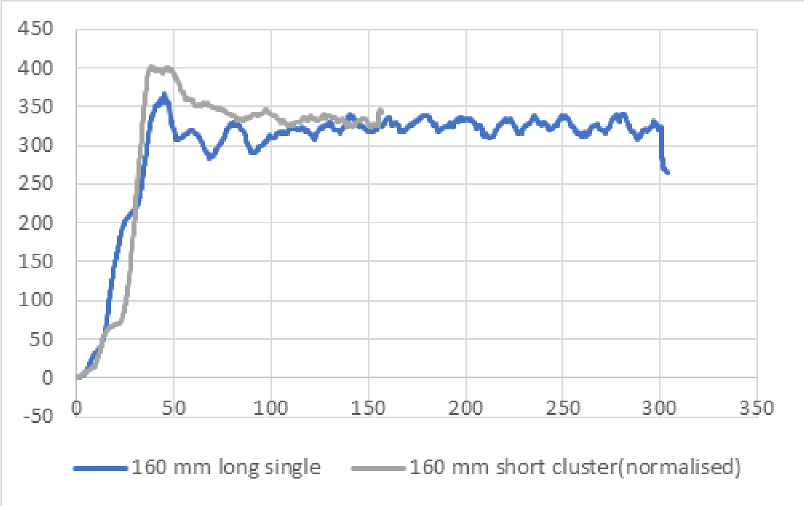


Figure 27: Comparison of the short (400 mm) and long (1.6 m) sticks with the same diameter: 160 mm

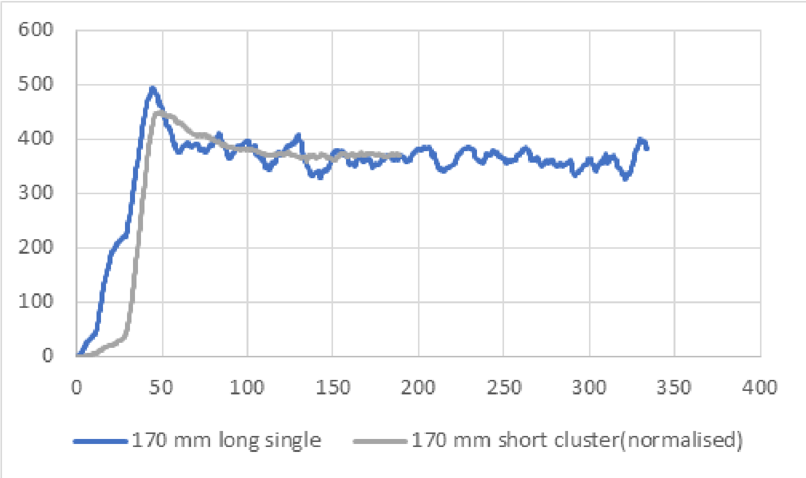


Figure 28: Comparison of the performance short (400 mm) and long (1.6 m) sticks with the same diameter: 170

3.1.3.5.2 March testing

The performance of the ten-stick clusters are shown in **Figure 17**. Analysis of the average load-deformation profile reveals an initial stiffness, which is indicative of grout pack behaviour. This is similar to the behaviour observed in the results for the three- and nine-stick clusters. The units reach the peak load of ~3550 kN at approximately 50 mm deformation and can sustain loads from 3412 kN to ~3800 kN. Load drops are present, but these are less than 40% of the peak load. The performance of the ten-stick clusters are equivalent to the nine elongate grout pack.

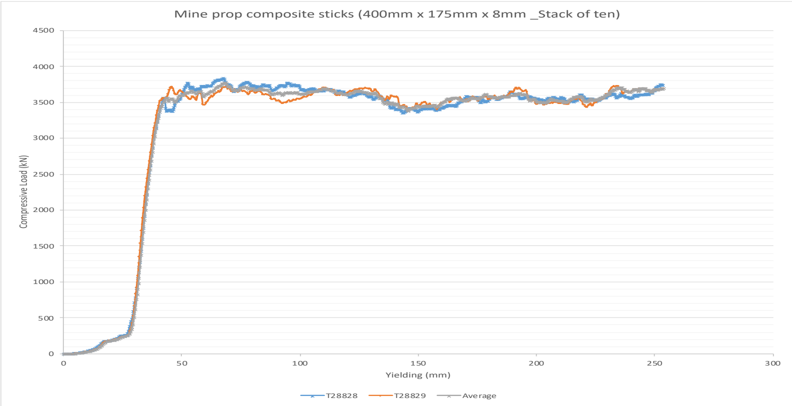


Figure 29: Load-deformation response of 400 mm x 175 mm x 8 mm – ten stick cluster

3.1.3.5.3 Milestone Conclusion – Cluster Sticks

The composite sticks can be used as a replacement for the cementitious support when installed as cluster packs.

3.1.3.6 MILESTONE 8.10 - Project Close-out

The composite pipe stick support project was initiated in 2018 and has been concluded in 2021. Various problems have been experienced in determining the design criteria and numerous efforts been made to achieve the results which are aligned to the criteria.

3.1.3.6.1 Project Conclusions

The following conclusions are applicable to these milestones:

- The design modification process undertaken was successful in determining the failure mode that the chamfer failure profile eliminates the sudden drop in load bearing capacity of the sticks.
- The 170 mm and 175 mm diameter single short sticks meet the performance criteria;
- The 160 mm diameter single short sticks do not meet the performance criteria;
- The results show that there is no difference in the results obtained when testing the long (1.6 m) and the short (400 mm) sticks, for props of similar diameter;
- The long units do not show and evidence of buckling;
- The composite sticks can be used as a replacement for the cementitious support when installed as cluster packs.

3.1.3.6.2 Project Recommendations

The test work conducted during the project indicates that the composite sticks can be used as an alternative for sticks and grout packs. It is therefore recommended that:

- A project should be scoped to test the performance of the composite sticks in an underground environment.
- A cost benefit analysis and feasibility study should be conducted to determine the financial benefits or disadvantages of using the composite stick as an alternative underground support.
- Further work needs to be done to determine the suitability of the composite stick to dynamic conditions

3.1.3.6.3 REFERENCES

APPENDIX A: - The MOCTECH composite design and scope of work report

APPENDIX B: – Terms of Conditions with MOC

3.2 APPENDICES / SUPPORTING DOCUMENTS

3.2.1 Appendix A – Proposal from MOC

MOC TECHNOLOGIES

Composite design Poles

Reference Number: MEC_Q2019-IMP-14

Date: February 2019

Version: 3

Nelson Mandela Mining Precinct/CSIR Our Ref: MEC_Q2019-IMP-14

Your Ref: Attention: Nondumiso Nkosi Email: NNkosi2@csir.co.za Tel: 12 March 2019

Research and investigation of substitute Mine Props

Dear Nondumiso, We thank you for the opportunity to submit this quotation and trust that it meets your requirements. Please do not hesitate to contact us should you have any queries or need additional information.

1 **SCOPE OF WORK**

The underlying technology has been completed by MOC and is the platform for the continued work for the development of alternate supports for the mining sector. High success was achieved during a few tests in the last part of 2018 and is the basis for continued work. After a meeting held on the 9th January 2019 the following was decided as the next phase of development/Testing.

Planned activities for single mine poles:

1. Model the possible failure modes for the composite stick to understand the current behaviour and identify methods of inducing failure. (160 hours FEA)

2. Manufacture 25, 40mm long composite sticks to test the failure modes (5 of each failure method) (120 hours, 25 poles)

3. Test the 25 composite sticks (8 hours)

4. Select the best design (2 hours)

5. Manufacture 30 x 1.6mm long composite sticks (130 hours, 30 poles)

6. Test the 30 composite sticks, possibly test at Groundwork or UP and Timrite (see Groundwork for the quotation) (8 hours)

7 Test the composite stick (40mm) for FST and moisture (we can reuse the sticks here) (8 hours) 8. Close out report for underground testing (24 hours)

Planned activities for cluster stick:

9. Manufacture 3 types of composite clusters one with 5 poles, the next with 7 poles and the last one with 9 poles (8 hours) (285 hours, 63 poles)

10. Test the clusters (8 hours) 11. Define the engineering of the pack (8 hours)

2 DELIVERY

A memo shall be generated and be subject to approval by all stakeholders before proceeding. In conclusion, the options shall be listed and the next phase of the project shall be planned taking into account the knowledge gained during the above test phase/investigation.

3 EXCLUSIONS

Anything not specifically mentioned in the scope of work or the deliverables is not incorporated in this quotation.

4 PRICE

DESCRIPTION	COST
Single mine poles	R438 080.00
Cluster Pack	R277 268.00
TOTAL (Excl VAT)	R715 348.00

Engineering Costs per hour: R820/hour

Technician Cost per Hour/fabrication: R450/hour

Cost of material and consumables R40kg poles average is 15kg

5 SCHEDULE

The work defined in the scope, preceding, can commence as soon as a purchase order is received. It will be completed according to an agreed project plan, but is a 4 to 6 month delivery.

6 VALIDITY

This quotation is valid for a period of 21 days.

7 TERMS AND CONDITIONS

This quotation is subject to our standard terms and conditions, which are available on request.

By awarding a contract to, or placing a purchase order on, MOC, the terms and conditions are agreed to and accepted by Nelson Mandela mining precinct

8 Indemnity for consequential losses of damages

MOC shall have no liability in contract or legally for any loss of profit, loss of business, increased costs of operation or any consequential losses or damages no matter howsoever arising.

9 GUARANTEES/ warrantee

MOC's liability from all sources shall be limited to the provision of corrective services only for the services, as supplied, in terms of the contract, to correct errors and omissions of MOC's own making only.

10 TERMS OF PAYMENT

The following payment terms apply to the complete contracts:

Milestone progress payments will be agreed to by project team and will be accompanied by a completion certificate per task

11 COMMUNICATION

All correspondence regarding any contractual matters shall be addressed to:

MOC (Pty) Ltd

Attention: Gavin Ratner Tel: +27 83 3520306

3.2.2 Appendix B – Terms of Conditions with MOC

MANDELA MINING PRECINCT
MINDS FOR MINES

Corner Carlow & Rustenburg Road
PO Box 91230, Auckland Park, 2006

+27 11 358 0003

enquiries@MandelaMiningPrecinct.org.za

Mr Gavin Ratner
6 Director Road
1619 Kempton Park – Spartan Ext 21
Gauteng South Africa

4 March 2019

Dear Gavin
The terms and conditions (T&Cs) for the composite pipestick test work are detailed as follows:

Terms and Conditions

1. Agree and sign the Memorandum of Agreement.
2. Agree and sign the Terms and Conditions.
3. Test work can commence following the acceptance and final signatures of the Memorandum of Agreement and the Terms and Conditions.
4. Model different failure modes.
5. Manufacture 25 x 40mm long samples of the composite pipestick.
6. Design 5 different modes of inducing failure for the 25 x 400mm composite pipestick. Each failure mode will be tested on 5 identical samples.
7. MMP researchers to view all test samples and verify test results.
8. Record test results for each sample (25 off) as follows:
    a. Finalise and confirm the test site and facilities;
    b. Measure dimensions of each sample and confirm that each sample is identical;
    c. Photograph and number each test sample prior to test work;
    d. Calibrate test device to confirm the integrity of the device, prior to any test work;
    e. Design and finalise the test criteria, with MMP researchers;
    f. Complete the testing of the 25 x 400mm samples in the presence of MMP researchers;
    g. Record all test results and failure details for each failure mode. MMP researchers must verify all the test results;
    h. Record photographs of each test sample, before and after test work;
    i. Compare results of all failure modes and record the decision for further test work. Further test work will be based on the failure mode which recorded the best strength results according to the test criteria;

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9. Manufacture 30 x 1.6m long composite pipesticks, for further test work. These 30 samples will be based on the failure mode which recorded the best strength results according to the test criteria, as follows:
    a. Finalise and confirm the test site and facilities;
    b. Measure dimensions of each sample and confirm that each sample is identical;
    c. Photograph and number each test sample prior to test work;
    d. Calibrate test device to confirm the integrity of the device, prior to any test work;
    e. Design and finalise the test criteria, with MMP researchers;
    f. Complete the testing of the 30 x 1.6m samples in the presence of MMP researchers;
    g. Record all test results and failure details for each 1.6m sample. MMP researchers must verify all the test results;
    h. Record photographs of each test sample, before and after test work;
10. Test the composite pipestick (40mm sample) in terms of reactions to:
    a. Moisture and fire, smoke and toxicity (FST). The test samples used in previous test work can be re-used for these tests
    b. Determine test criteria for these tests
    c. All test work to be completed with MMP researchers present
11. Compile a close out report describing all test work, results, findings, conclusions and recommendations for further work.
12. Manufacture 63 x 1.6m length composite pipesticks for cluster test work. Three types of clusters will be tested as follows:
    a. 5 composite pipestick cluster x 3;
    b. 7 composite pipestick cluster x 3;
    c. 9 composite pipestick cluster x 3;
    d. Finalise and confirm the test site and facilities;
    e. Measure dimensions and shape of each sample and confirm that each cluster is relevant for comparison with a pack type of support;
    f. Photograph and number each test cluster prior to test work;
    g. Calibrate test device to confirm the integrity of the device, prior to any test work;
    h. Design and finalise the test criteria, with MMP researchers;
    i. Complete the testing of the cluster samples in the presence of MMP researchers;
    j. Record all test results and failure details for each cluster sample. MMP researchers must verify all the test results;
    k. Record photographs of each cluster sample, before and after test work;

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13. Define the engineering criteria and parameters for the cluster, with MMP researchers.
14. Document a final report of all findings and test work.
15. Describe how this project will be used within your company to develop human capital.
16. A risk register (what are the risks during the development of the support prototype, and how will these be managed).

Payment Terms and Milestones

Payment will be structured according to the completion of defined milestones as follows:

Milestones Completed	Rand	Comment
Individual composite pipestick tests		
3	71,535	Mobilisation
4	58,533	Model failure modes
5	71,400	Manufacture 25 x 40mm poles
6	4,340	Test 25 x 40mm poles and select best design
7	1,640	MMP verify test results and select best design with MOC Tech.
9	83,900	Manufacture 30 x 1.6m poles
9	4,340	Test 30 x 1.6m samples
10	5,080	Test 40mm sample for moisture and FST
11	122,180	Project management and close out report
Sub Total	**422,948**	
Cluster Composite Pipestick tests		
12	179,000	Manufacture 63 x 1.6m poles
12	4,340	Test clusters
13	6,560	Define Engineering
14	102,500	Project management and close out report
Sub Total	**292,400**	
Total	**715,348**	

Yours sincerely

N Singh
Co-Director- Mandela Mining Precinct Precinct

A Macfarlane
Co-Director- Mandela Mining

Page **3** of **4**

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