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Evaluation of Composite and Standard Liner Plates on Hydraulic Face Shovels Operating in Platinum Mines

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The article details the results of research determining whether the use of composite liner plates, specifically chromium-carbide overlay (CCO) liner plates could be recommended as an alternative to abrasion-resistant (AR) plates to extend the production cycle of hydraulic face shovels operating in platinum mines.

Research indicates that only 53% of the RH340 face shovels operating in a platinum mine sustain 3 500 hours in production. To comparatively study the performance of the two materials, two RH340 face shovel components were repaired, using the respective materials, after which performance was monitored, documented, and supported by regular field service inspections.

To support the veracity of the observations, both materials were compared in a literature review, substantiated by metallurgical testing, comparative wear analysis and field service analysis of the production performance.

The evaluation indicated that CCO is more expensive, has lengthier delivery times, and weighs less than AR plates. On average, the AR plates maintain 3 283 hours in production, while the CCO maintained 4 803 hours in production.

The outcome of this study applies to components operating specifically in platinum mines in the Limpopo Province, since the wear rate of a material is influenced by geological content.

An alternative liner plate could potentially increase component productivity, maintaining high-efficiency production outputs. The study recommends CCO as an alternative to standard liner plates, however, since this conclusion is based on a single installation, additional research into optimising the placement and orientation of the CCO plates is recommended.

Keywords: abrasion-resistant (AR), chromium-carbide overlay (CCO), ground engaging tools (GET), wear packages, liner plates, face shovel

Evaluering van Saamgestelde- en Standaardslytvaste plate op Laaibakke van Hidrouliese Voorlaaiers in Platinummyne: Die artikel gee ʼn uiteensetting van die resultate van navorsing wat gedoen is om te bepaal of die gebruik van chroom-karbied (CK) oorlegde voeringplate as ʼn alternatief vir slytvaste (SV) plate aanbeveel kan word ter verlenging van die produksiesiklus van hidrouliese voorlaaiers in platinummyne.

Navorsing toon dat slegs 53% van die RH340 voorlaaiers wat in die myn gebruik word ʼn diensperiode van 3 500 uur in produksie haal alvorens meganiese herstelwerk genoodsaak word. ʼn Alternatiewe voeringplaat met langer diensperiodes kan die produktiwiteit van die meganiese voorlaaierkomponente verhoog terwyl produksie-uitsette en hoë vlakke van doeltreffendheid gehandhaaf word.

Die slytvastheid van saamgestelde CK- en standaard SV-plate is vergelyk deur twee RH340 voorlaaierbakke toe te rus met die onderskeie materiale, waarna die werkverrigting van die twee tipes plate onder normale produksietoestande gemonitor en gedokumenteer is tydens gereelde velddiensinspeksies.

Die geldigheid van die navorsing is eerstens ondersteun deur ʼn vergelykende literatuuroorsig van beide materiale. Tweedens is ʼn reeks metallurgiese toetse uitgevoer op die twee materiale nà vergelykbare periodes in produksie, insluitend ʼn vergelykende slytanalise.

Die evaluering het aangedui dat saamgestelde CK-slytplate duurder is en dat die wagperiode van bestelling tot aflewering langer is, maar dat die CK-slytplaat minder weeg as die SV-slytplate. Die SV-slytplaat in hierdie studie het 3 283 ure in produksie voltooi, en die CK-slytplaat 4 803 ure.

Die bevindinge van hierdie studie is van toepassing op komponente wat in platinummyne gebruik word, aangesien die slytasietempo van laaibakvoerings beïnvloed word deur die geologiese eienskappe van die las wat dit moet skuif.

Die studieresultate ondersteun die aanbeveling van CK as ’n alternatief tot SV voerings. Verdere navorsing behoort gedoen te word om die plasing en oriëntasie van die CK-plate te optimaliseer.

Sleutelwoorde: Slytvaste (SV) plate, Chroomkarbied slytplate (CK-slytplate), Grondverskuiwingstoerusting (GVT), Slytpakket, Voeringplate, Voorlaaier

Introduction

One of the industries contributing to the South African economy is the platinum mining industry. Njini (2020) indicates that the South African platinum mining industry contributed 8% of the GDP in South Africa in 2019 and produces 75% of the world’s platinum, with each employee in the mining industry supporting at least 10 dependants (Njini, 2020).

A face shovel, also referred to as an attachment or component on an earthmoving machine with ground engaging tools (GET), is a popular implement used on a platinum mine. One of the production risks in the mining industry is the downtime or breakdown of any attachment or component caused by premature wear or material failure.

The typical production cycle of an RH340 face shovel wear package, i.e. lining, is approximately 2 500 hours in a platinum mine, before it is necessary to replace and/or repair the wear package liners. The mining industry is reliant on increased production hours and encourages repair and manufacturing contractors to produce products that will reach a minimum production life of 3 500 hours in platinum mines (Borox Wear Parts (Pty) Ltd, 2020).

Preliminary research indicated that the primary cause for premature repair and relining on the wear package or linings on the face shovels operating in platinum mines, is due to excessive wear, or structural failure.

Liner plates are defined as abrasion-resistant liner plates that are used in applications where friction between two or more parts of materials or minerals creates extensive degradation by continuously rubbing or abrasively contacting the surface, and are regarded as expendable items preventing excessive wear or damage to expensive equipment (Precision Grinding, 2016).

RH340 face shovel components considered during the study period managed an average of 3 283 production hours. The components removed from production because of premature failures caused by excessive wear managed an average of 1 791 production hours (Borox Wear Parts (Pty) Ltd, 2020).

Figure 1 illustrates a component marked for repair and relining after completing its production cycle in a platinum mine, having been removed from production due to excessive wear (Borox Wear Parts (Pty) Ltd, 2020).

FIGURE 1: RH340 3G component (JCB-Gearvest (Pty) Ltd, 2018)

Borox found that 38% of the components investigated, lined with standard wear packages, were as a result of premature failure due to excessive wear (Borox Wear Parts (Pty) Ltd, 2020).

Specification wear steels such as abrasion-resistant (AR) plates and liner plates have been used in high-wear areas such as sorting and crushing plants and are commonly used for special applications in the mining industry (Borox International AB, 2020).

However, mining industries, especially the industries closely related to the wear and tear of mining equipment due to abrasion, are familiar with AR plates which have been used extensively in the past to extend a component’s wear life. With this in mind, the purpose of this article is to determine whether there is a possible substitute to standard AR liner plates that could be considered as a suitable alternative to be used in the wear packages to extend the component’s hours in production.

Barnes et al. (2014) state that overlays for the mitigation of wear and corrosion are a cost-effective alternative to manufacturing large scale components entirely from high-performance materials, and that specifically chrome-based weld overlays have played a primary role in mining and processing applications, particularly where component lifetime jeopardises production reliability (Barnes, Borle, Dewar, Andreiuk, & Mendez, 2014).

Chromium-carbide overlay (CCO), a specific variety of composite liner plate, has successfully been used in other high-wear scenarios or areas in the mining industry where high wear and moderate impact are found (Waldun, 2020). CCO material is ideal for applications where conventional liner plates are not sufficient to withstand the severe working conditions where materials with high abrasion resistance and impact properties are required (CS Wear Resistant Material Co., Ltd, 2020).

The suitability of the CCO will be determined by evaluating the performance of CCO as a liner plate in comparison to standard liner plates in similar and comparable operating conditions, using the criteria below.

The liner plates on a component must have a proportional relationship between the material's wear and impact absorption capabilities being able to withstand sharp impacts – typically sustained during production – long enough for the liners to reach their maximum wear life, i.e. the alternative liner plate must have a proportional relationship between the material toughness and hardness.

This article details the results obtained in a comparative material investigation which researched whether CCO material specification can be considered as a suitable or viable alternative to AR plates in the platinum mining industry and whether further research and investment into the performance thereof is recommended.

The use of all material or sources researched and used in the completion of the proposed research has been authorised by both JCB-Gearvest (Pty) Ltd and Borox Wear Parts (Pty) Ltd and will remain the property of the respective companies. The conclusions, inferences, and certain deductions that have been made concerning the sources used, will form the basis of the research.

Ethical consideration will ensure that any material, data, information, sources, or results obtained during the conducted research, or this study, will not be mispresented to unfairly advantage or disadvantage either one of the liner plate options, or to unfairly support any conclusion or recommendations made, any malpractice, misrepresentation, and dishonesty that may reflect badly on the profession and will affect the veracity of the proposed study.

Methodology

The research approach was a mixed methodology, whereby quantitative as well as qualitative methods were used to evaluate the performance of both material options during production, which observations were further supported by an analysis of the material options in laboratory conditions. The research methodology was chosen to prevent the formation of a biased conclusion.

The word "production" – for the purposes of this study – means the continuous operational use of the RH340 face shovel for its designed purpose in a platinum mine, and "production hours" will have a corresponding meaning.

Both components studied in this article operated in the same Limpopo platinum mine in South Africa and operated under similar loads, geological content and conditions.

This ensured the reliability of the outcome of the study and prevented preconceived ideas and biased conclusions from influencing the data obtained or the interpretation thereof.

Preliminary literature review

A preliminary literature review was conducted to gain insight from existing products and research as well as their conclusions and experiences gained from previous projects. This gave insight into possible challenges that could have been expected and how to overcome or mitigate the impact thereof.

Physical production performance comparison

JCB-Gearvest (Pty) Ltd was contracted to repair and reline two components with excessive wear and structural deterioration that were removed from production. Both components had substantially the same wear patterns but with different Scope of Works (SOW). Both components operated in the same platinum mine under similar conditions and in the same area in Limpopo South Africa.

The SOW, cost-estimation, material, and mass specifications of both components were evaluated before the repair and realigning process commenced and after both components were removed from production, to evaluate the relationship between the initial and postproduction cost of the repair and the production performance.

The first component was relined with a standard AR plate package and the second was relined with a CCO liner plate package in the high-wear and high-wear medium impact areas on the front jaw of the face shovel.

The wear packages of both repaired and relined components were set under continuous observation by JCB-Gearvest field service management teams to evaluate the performance and obtain a visual comparison of the wear and impact patterns of the respective wear packages.

Independent metallurgical laboratory testing

To ensure the veracity of the research and to support the observations made from the performance evaluation of the material during production and further support conclusions drawn, both materials were independently tested according to the standards and specifications detailed in Table I, for comparative analysis and material compliance to standard specification.

The chemical analysis of the AR plates was done, to determine whether the decreased performance or the inconsistency of the AR plate wear package performance could be attributed to the cookie effect or to any deviations from the material and mechanical property specification of that specific grade of material.

Jadco indicates that this inconsistency can also be attributed to the cookie effect. This effect is typically suspected when a liner plate initially performs very well, maintaining integrity during the first phases of production, but then rapidly starts to wear in a matter of weeks. The cookie effect occurs when materials do not have the correct alloying elements in the correct ratios, preventing the material from being hardened throughout the entire thickness. The result is a material that is effectively only surface hardened, leaving the centre of the material with material properties closer to that of mild steel, hence the apt label of the "cookie" effect (Jadco, 2019).

TABLE I: Material testing specifications

#	Material test	Specification	TH400	Overlay
1.	Brinell Hardness Testing	ISO 6506-1	✓	✓
2.	Notching and Impact Testing	ISO 148-1	✓	
3.	Tensile Testing	ISO 6892-1	✓	
4.	Spectrometric Analysis	ISO 6507-1	✓	✓
5.	Micro Examination		✓	✓

Results and discussion

Literature review

The literature review investigated various modes of failure and whether the configuration of the excavators, such as backhoe of face shovel configurations, could affect the amount of wear sustained by a component.

Typically, a face shovel component will sustain more wear during the production cycle. Aggregates Business found that the breakout force delivered by a face shovel configuration is larger than the breakout force of a backhoe configuration (Aggregates Business, 2012).

To extend the production cycle of an earthmoving component, the components are fitted with AR plate wear packages. AR plates are regular steel plates that have higher toughness and hardness material properties, that last approximately four times longer when compared to a standard high-strength structural steel plate (AZoM, 2018).

An AR plate is a high-carbon steel plate which is harder because of the addition of carbon during the formation of the steel, however, the addition of carbon reduces the strength of the plate, and subsequently its brittleness. and is used in environments where wear and tear abrasions are the main cause of failure. It is not used for structural applications (AZoM, 2018).

Liner plates are a modern solution for the production and regeneration of high-wear and erosion-resistant industrial installations (Klimpel, Gorka, & Czuprynski, 2006).

Abrasion, broadly classified as a wear mechanism, contributes to 60% of the total wear losses in the mining, lifting and excavation industries. In this instance the wear process is described as impact abrasion where the abrasion involves the removal of material from a solid surface when loaded against particles that are of equal or greater hardness (Chintha, 2019).

By analysing the hardness, microstructure, and wear surface morphology of wear-resistant Hardox400 and NM400 wear-resistant steels, it was established that the wear mechanisms of the steels manifested primarily as abrasive wear and fatigue wear (Pei, et al., 2020). Fatigue wear, pitting and impact wear are wear mechanisms that are found in operations where components are exposed to sliding, rolling and impact respectively. The exposure results in sudden surface destruction due to sub-surface cracks propagated by stress cycling. Abrasive wear and sustained wear sliding are as a result of scratching by hard particles trapped by or protuberances projecting from the mating surface (Varenberg, 2013).

A CCO liner plate is an extra-hard clad plate with additives giving it high abrasion and wear resistance in high-stress areas with low to medium impact absorption conditions. CCO is cost-effective and is recommended for applications where resistance to wear and particle erosion are needed. CCO requires a low level of maintenance and is easy to install (ASGCO, 2020).

All welding alloy plate products can be thermally processed without affecting the wear resistance of the plates in the heat-affected zones, subsequently stopping preferential wear, typically seen in quenched and tempered plates (Welding Alloys Group, 2020).

The challenge is to design an overlay combination that has welding crack resistance with a good combination of properties; however, a balance is required considering that a higher content and greater sizes of carbides in the overlay would give greater wear resistance but would also lead to a higher crack tendency, higher cost and often lower resistance. Optimised overlay specifications should contain a reasonable amount of primary hard phases that provide wear resistance, while hard particles need to be optimised to prevent breakage during abrasion wear (Jing, Rangasayee, Minghao, & Leijun, 2020).

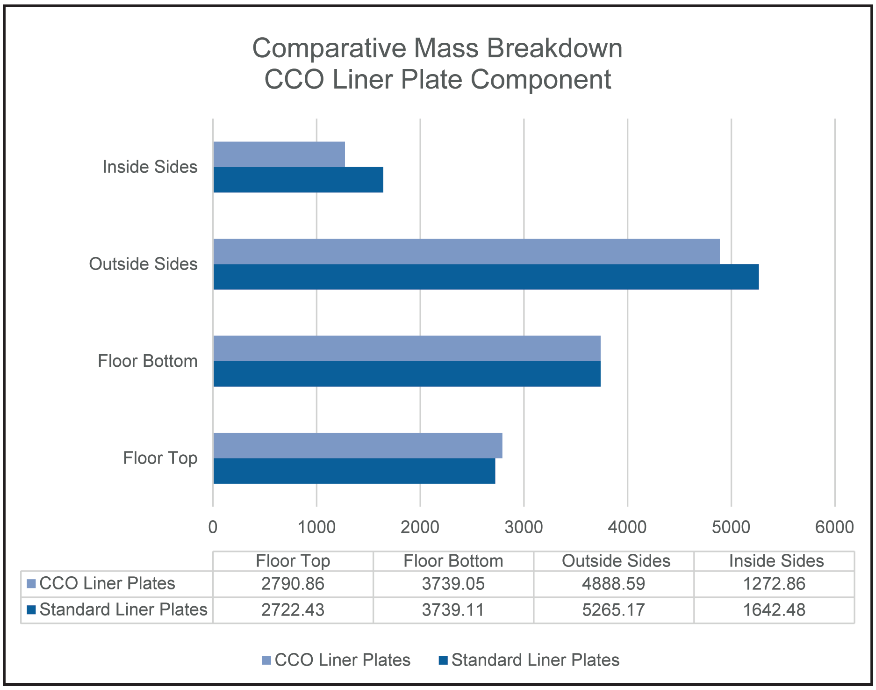
Because the overlay plates have such a high hardness and resulting stiffness, it is not recommended that the end-users attempt to form or bend the plates themselves. Pre-forming is best done in a workshop, with the forming of the plates perpendicular to the weld direction of the overlay deposit (Welding Alloys Group, 2020).

In contrast to standard liner plates, where the orientation of the material has an indiscernible effect on the material's wear capability, CCO liner plates must be aligned according to the direction of the wear. Products that have been welded with stringer bead techniques, and that are used in high-speed particle applications, must be fitted with the welding direction of the overlay perpendicular to the flow of abrasive material. For oscillated weld beads, preferential wear can be seen in the bead overlap areas if the overlay plates are installed with the weld direction parallel to the flow of the material (Welding Alloys Group, 2020).

Material mass analysis

On the same component, the mass of the current combined, CCO liner plates and standard liner plate package design, used to reline the RH340 front jaw composite liner plate component will be 677.83 kg lighter than a component relined with a standard liner plate package as illustrated in Figure 2.

This equates to the front jaw being approximately 5.34% lighter when relined with CCO liner plates but will have little to no effect on the carrying or load capacity of the component. For calculations and analysis purposes the value was simplified to 600 kg saving on mass.



	Floor Top	Floor Bottom	Outside Sides	Inside Sides
CCO Liner Plates	2790.86	3739.05	4888.59	1272.86
Standard Liner Plates	2722.43	3739.11	5265.17	1642.48

FIGURE 2: Comparative mass breakdown CCO liner plate component (JCB-Gearvest (Pty) Ltd, 2018)

Figure 3, illustrates the components during the gouging process, where the old wear package is removed, and the components are prepared for the fitment of the new wear packages. This also shows the extent of the wear sustained by the component during production.

Where the wear packages have been excessively worn, the structure of the component, especially on the sidewalls, has been exposed. The structure of a component is significantly more expensive and time consuming to repair.

If a CCO-lined component could potentially maintain a minimum of 3 500 hours, it results in an additional 55 146 tonnes of material being moved in the lifespan of a component.

FIGURE 3: Stripping and gouging components before repair: (a) Component relined with AR-Plates (b) Component relined with CCO (JCB-Gearvest (Pty) Ltd, 2018)

In optimal conditions, the potential additional 55 146 tonnes of material gained when using a component relined using CCO liner plates can result in a 10.106% increase in productivity output per component in production.

Material supply

Repaired components must typically be delivered within 16 weeks from the date the component was delivered to the warehouse. It can take up to 12 weeks to repair a component from the date the wear packages and material have been delivered.

Quality incidents, material and consumable delivery delays and power outages all contribute to time lost. To ensure that the component is repaired in good time, it is critical that the material ordered be delivered timeously, and is manufactured to a high-quality standard according to the approved drawings.

Cut to size (CTS) operations for standard material such as S355J, 400 and 500-grade liner plates, used in the repair and relining of the face shovels, typically take between three to four working days, irrespective of the size of the order; bending or forming operations take up to seven working days.

Quality incidents occur when there is a deviation in the quality control process (QPS), the orders are placed on the breakdown, resulting in a five working day delay for the production team.

CTS standard composite liner plates that have standards sizes and overlay ratio specifications can typically be delivered within —three to five working days. CCO parts that require profile cutting, forming, shaping, and bending, and that have a unique overlay ratio specification, have a twelve working day delivery lead time to twenty working days.

If the integrity of the CCO parts were compromised during manufacturing of the part, it can influence the performance of the parts resulting in increased chipping or delamination during the component's production cycle.

This accorded with what was seen during production and is supported by the metallurgical analysis and report of the CCO liner plate.

Figure 4 shows the fitment process of the respective wear packages onto the components. The CCO liner plates are marked in blue and are unique to the component.

Research showed that the delivery of the CCO liner plates exceeded the initial lead time delay of 20%, with a total of 40% when compared to the delivery lead time of standard AR plates, however, the 40% material lead time delay is related to the repair and remanufacturing of delaminated parts which could be avoided with a more efficient CCO wear package specification and design in future repairs.

The type of composite liner plates, CCO liner plates, used in the relining of the component in this article had a material specification of 40% base material with a 60% overlay deposit for the 25 mm plate, and a 43% to 57% overlay deposit for the 30 mm plate – this deviates from the standard composite liner plate overlay ratios discussed in the paragraph below, that show that the thickness of the overlay deposit must not exceed the thickness of the base material since a thicker overlay and base material ratio is more likely to delaminate during forming and bending processes.

Standard composite liner plates very rarely delaminate during the manufacturing of the sheets. The standard sheets, researched in the literature review, are available in overlay concentrations not exceeding a 50:50 base material overlay ratio.

The study indicates that the welding procedures, specifying standard carbon steel consumables like ER70S or ER100 used to weld standard material S355J, 400 and 500-grade materials, are not applicable when welding the composite

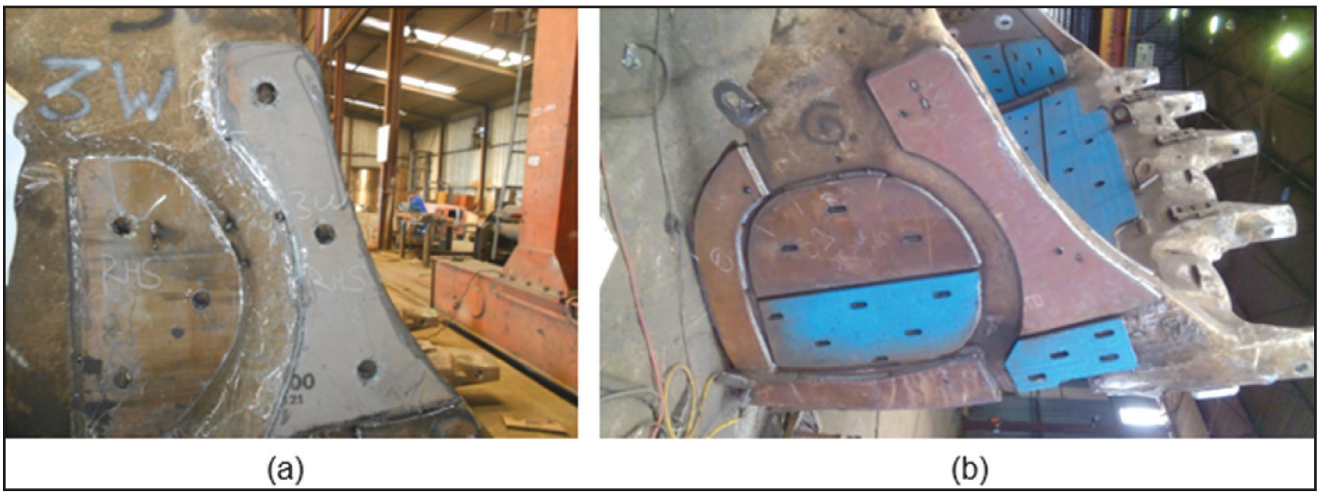


FIGURE 4: Fitment of wear packages (a) AR-plates wear package (b) CCO wear package (JCB-Gearvest (Pty) Ltd, 2018)

liner plates. The standard carbon welding procedures can only be used to weld the mild steel base.

In typical scenarios, this does not present a problem, but because the CCO liner plate specifications deviated from the standard composite liner plate overlay ratios, the mild steel base became too thin to adequately weld the parts onto the structure of the face shovel without the overlay deposit contaminating the welding consumables. The recommended welding consumables, i.e. 307 stainless steel welding consumables, must be used to weld the CCO parts. Figure 5 depicts the completed repair of the CCO wear package component.

Production performance analysis

The observations made during the field service inspections of both the component relined with the composite liner plate material and the standard liner plate material were critical to understanding the behaviour of each wear package during production.

These inspections identified areas where additional wear or impact protection was needed to protect the structure.

FIGURE 5: RH340 face shovel CCO liner plate repair completed (JCB-Gearvest (Pty) Ltd, 2020)

The evaluation revealed that both components sustained critical wear having been taken out of production due to wear being identified as the primary cause of failure at different production cycle stages.

The component relined with standard liner plates sustained significant damage and was temporarily taken out of production due to a breakdown on the font jaw's floor, illustrated in Figure 6. The welding on the remaining vertical liners appeared to have failed, thereby pulling the liners away from the floor section and exposing the floor structure plate to damage and wear.

Had this breakdown not been repaired it would have resulted in the catastrophic failure of the front jaw, resulting in the component being taken out of production and identified for premature repair and relining. The breakdown took approximately five hours to repair, during which the mine lost a potential 7 499.85 tonnes of production, 1 499.97 t/h.

The data analysis of the field service reports shows that the component repaired with CCO liner plates, illustrated in Figure 7, performed progressively worse as the overlay on the composite liner plates started to delaminate and chip; however, they sustained no critical breakdowns.

Initially performing well and showing no signs of excessive wear or having sustained damage due to impact, once the liner plates started to chip, the damage spread at a significant rate to the rest of the composite liner plate part. The observation was only made on composite liner plates placed in medium impact and high-wear zones.

The floor liner plate, illustrated in Figure 8, which is manufactured entirely from composite liner plate, performed remarkably well, showing no signs of damage or significant wear during the field service observations.

At the time the liner plates, with the CCO material specification, were designed for the component's wear package, we were not aware that the orientation of the

FIGURE 6: Standard wear package damage (LHS), repair (RHS) (JCB-Gearvest (Pty) Ltd, 2019)

liner plates would have such a significant effect on the performance, however, during the literature review it became evident that the CCO is most effective when the weld bead, or CCO deposit, is installed perpendicularly to the direction the wear or abrasion is sustained. Therefore, there is a potential for variation in wear package performance until the design of the CCO wear package has been optimised and the optimal orientation and placements of the CCO liner plates have been developed and confirmed. The geological content in which a component is operating has a direct effect on the wear mechanism and rate of wear on the component wear package, and as such the optimised CCO wear package design will be location-specific.

The orientation of the overlay deposit on the the design of the CCO floor plate was perpendicular to the direction of the wear, however, this was not the case with the worse performing sidewall liners. It became evident that the orientation and placement of the CCO wear package must be further improved upon and researched.

The field service analysis indicated that comparatively, the composite liner plates showed less wear, especially when comparing the floor liners of the front jaws. However, once the composite liner plates on the inside and outside walls of the front jaw were compromised, they gave extraordinarily little, if any, protection against wear.

Research into the production lifecycle of a component revealed that, on average, an RH340 face shovel relined with standard liner plates will maintain up to 3 283 hours in production (Borox Wear Parts (Pty) Ltd, 2020). This is 6.2% below the desired minimum number of hours, resulting in an approximate 217 hour loss in production.

A component which has a 1 499.97t/h production rate, shows that the 217-hour loss in production per component could potentially equate to an approximate 325 493.49 tonne loss of production across the lifespan of the component. The total number of production hours achieved by specifically the floor liners was 2 194 hours in production, 37.30% lower than the minimum desired production hours.

Figure 9 illustrates the relationship between the average, minimum and maximum hours sustained in production by components fitted with standard wear packages in comparison to the prescribed minimum number of hours and the number of operation hours sustained by the component fitted with the CCO wear package.

FIGURE 7: CCO wear package field service evaluation (JCB-Gearvest (Pty) Ltd, 2019)

FIGURE 8: CCO wear package field service evaluation inside floor (JCB-Gearvest (Pty) Ltd, 2019)

The component with CCO liner plates in the high-wear zones, and certain high-wear, medium impact zones managed 4 803 hours (Figure 9, Orange – T1) in production, which is 37% more than the desired minimum number of hours and 46.30% more than the average RH340 face shovel component.

Borox found that at a minimum an RH340 component repaired with standard liner plates, with wear having been identified as the primary cause for failure, managed only 1 728 hours (Figure 9, Yellow – T5) in production (Borox Wear Parts (Pty) Ltd, 2020). This is approximately 50.62% less than the desired 3 500 hours (Figure 9, Red – T3) in production.

On Average, an RH340 face shovel component repaired using standard liner plates also managed an average of 3 283 hours (Figure 9, Green – T4) and a maximum of 4 328 hours (Figure 9, Blue – T2) in production (Borox Wear Parts (Pty) Ltd, 2020). Approximately 9.37% longer than the desired minimum in production.

This results in 2 600 hours, nearly 250% discrepancy between the minimum and the maximum number of hours maintained by an RH340 face shovel, repaired using standard liner plates and having been removed from production due to wear being identified as the cause of failure.

Taking this into account, the composite liner plate component only managed 10.98% more production hours than the highest performing standard liner plate component but did manage approximately 276.35% more than the worst component repaired using standard liner plates.

The expectation was that, should the composite liner plates be able to sustain the wear for an extended period, the repair and relining need on the components will be reduced as the liner plates will have sufficiently protected the structural material from sustaining damage.

Therefore, once the components completed their production cycle, they were identified for repair and relining. The new preliminary SOW's were analysed to ascertain whether the composite liner plates warranted additional protection to the structure plate.

The second SOW found that both components required a complete front jaw inside floor, inside walls, outside wall repair and relining, with the bottom floor requiring an extensive relining.

Upon completing 1 728 hours in production, the standard liner plate RH340 face shovel front jaw necessitated an estimated mass of 10 650.95 kg preliminary repair (JCB-Gearvest (Pty) Ltd, 2019), 32.60% less than the estimated material required for the second repair of the CCO component.

RH340 face shovel, relined with CCO, found an estimated 14 122.67 kg material needed to repair the component, after completing 4 803 hours in production (JCB-Gearvest (Pty) Ltd, 2019).

Despite requiring less material to repair the standard liner front jaw components, the preliminary SOW revealed that

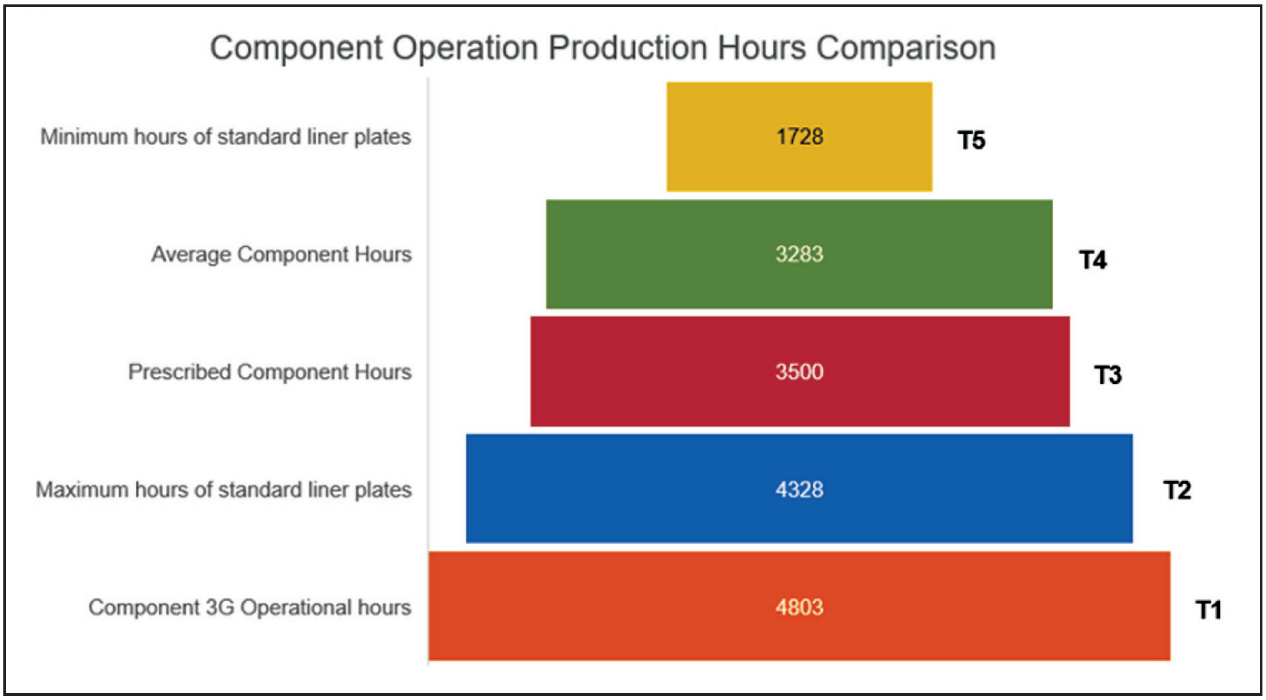


FIGURE 9: Component operation production hours comparison (Borox Wear Parts (Pty) Ltd, 2020)

the component required nearly 2 484.79 kg in structural repairs, due to damage sustained to the floor structure during production. The component relined with CCO plates required 809.62 kg of structural repair, 2% more than required in the initial repair.

Material analysis

The analysis of the laboratory results and how they compare to what was observed during production and what was researched is critical to support the outcome of the research.

The material testing included an analysis of the mechanical properties of both the CCO and AR plates. An analysis of the chemical composition of the AR plates was done including a technical report of the comparative wear capabilities of both samples provided.

The chemical analysis of both the 20 mm and 30 mm AR plate samples, Sample A and Sample B, revealed that neither samples' chemical composition matched the specified standard, and with differential compliance, neither of the samples' original material certificates corresponded to the results of the chemical analysis.

Figure 10 (Sample A) and Figure 11 (Sample B) illustrate the discrepancy between the element concentration specified in the material certificates and element concentration obtained during the laboratory testing.

Series 1 (Blue) represents the element concentration results obtained during laboratory testing and Series 2 (Red) represents the element concentration specified on the material certificates.

The comparison indicated the carbon concentration obtained in the laboratory testing in Sample A was approximately 68.75% higher than that specified on the material certificate.

The higher hardness of the material noted in the laboratory results, detailed in Table II, could be attributed to the increased levels of carbon present in the material.

The laboratory results revealed that Sample A's UTS was 29.55% higher than the UTS specified in the material certificates.

Sample B's chemical analysis and element concentration are approximately similar, with a much lower discrepancy between the materials testing laboratory results obtained and the analysis specified in the material certificates.

Although the hardness specified on the material certificate and the hardness obtained during the laboratory testing, detailed in Table III below, do not correspond, each hardness falls within the specification range with a 4.1% discrepancy between the material certificate result and the lab test results.

It is necessary to confirm a material's compliance to the set specification of that material grade since a deviation in the chemical concentration of critical elements in the material composition could attribute to the material's or wear package's improved or decreased performance.

The technical note investigating the wear properties of abrasion-resistant steels and overlay coating material

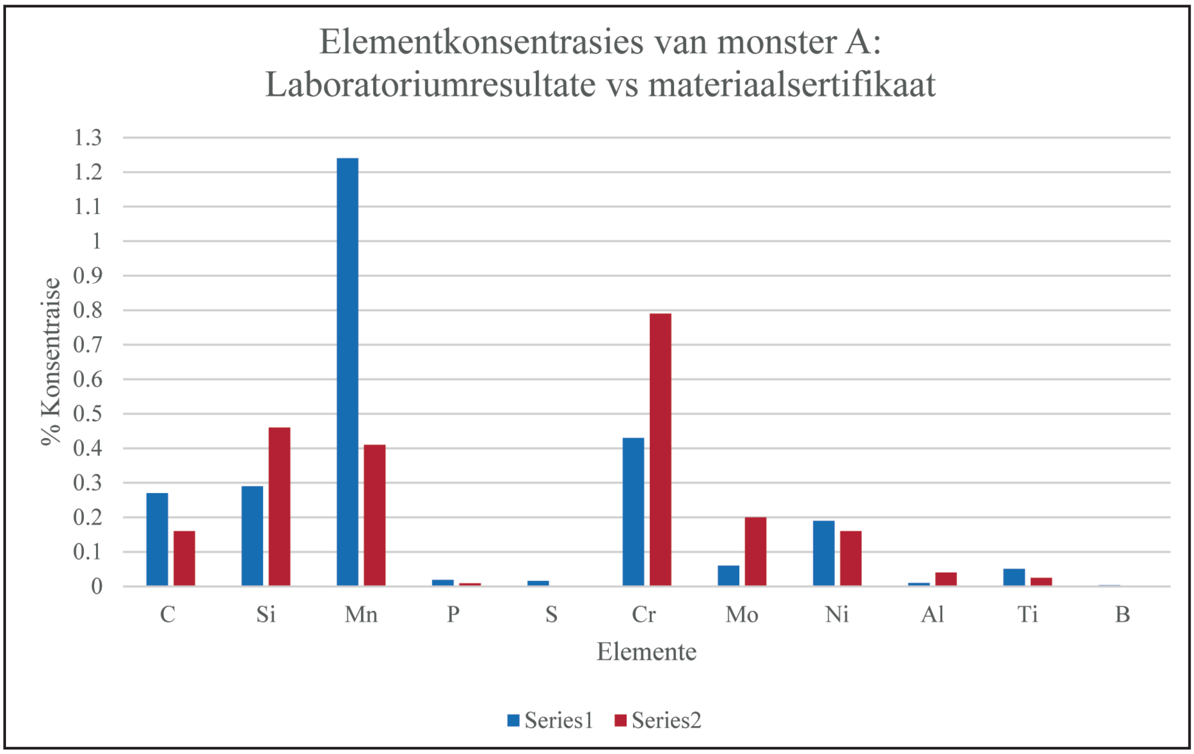


FIGURE 10: Element concentration comparison of Sample A

indicated that, depending on the application thereof, CCO plates will have a higher wear resistivity than standard liner plates, however, the CCO material will be susceptible to significant wear once it starts to chip if placed in areas where exposed to impact and it was found that the CCO material has visible layers (Carter, 2020). This observation is congruent with what was observed by field service during production and corresponds with the research done, that the base material fusion layer and overlay deposit are all visible upon inspection.

Carter (2020) indicates that, although the overlain material provides good abrasion resistance, and is harder than generally observed in steels, it will result in a material that is restricted in terms of toughness (Carter, 2020). Laboratory testing and microstructure evaluation, illustrated in Figure

TABLE II: Sample A Mechanical property laboratory test results

Certificate No.:		20-0912-B	
Plate Thickness:		20 mm	
Material Specification:		TH400	
Test Method		ISO 6892-1, ISO 6506-1, ISO 148-1	
Test Specification Requirements		UTS (MPa)	1350
Test Specification Requirements		Hardness (HBW)	360-418
Yield Load (kN)	**Maximum Load (kN)**	**Extension (mm)**	**Final Ø (mm)**
122,7	131	4,9	7,3
Yield Stress (MPa)	**UTS (MPa)**	**Elongation (%)**	**Hardness (HBW)**
1590,8	1698,4	9,9	444

(IMP Labs, 2020).

TABLE III: Sample B Mechanical property laboratory test results

Certificate No.:		20-0912-A	
Plate Thickness:		30 mm	
Material Specification:		TH400	
Test Method		ISO 6892-1, ISO 6506-1, ISO 148-1	
Test Specification Requirements		UTS (MPa)	1350
Test Specification Requirements		Hardness (HBW)	360-418
Yield Load (kN)	**Maximum Load (kN)**	**Extension (mm)**	**Final Ø (mm)**
120,3	128,2	3,6	6,9
Yield Stress (MPa)	**UTSe (MPa)**	**Elongation (%)**	**Hardness (HBW)**
1534,8	1635,9	7,2	388

(IMP Labs, 2020).

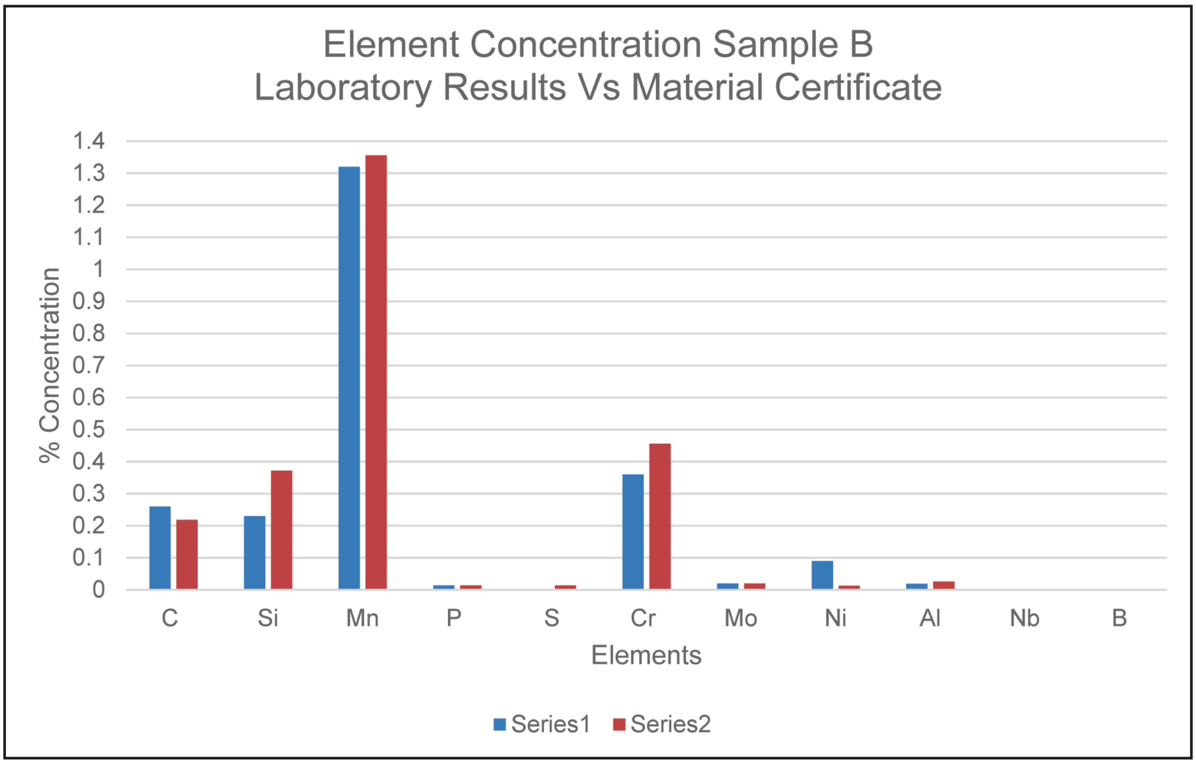


FIGURE 11: Element concentration comparison of Sample B

12, indicated that an additional layer was deposited on top of the first layer of overlay.

Carter found that the overlay coating on the composite liner plate submitted was deposited in two stages, the analysis of the Etched Nital-2, magnification from 20 µm scale photos indicated that the overlay had an intermediate layer between the substrate and the overlay; all layers had different microstructures (Carter, 2020).

Material cost analysis

The data analysis of the material cost estimates for both components revealed that upon initial inspection it is more cost-effective to repair the component using standard liner plate material.

Borox Wear Parts (Pty) Ltd indicated that the material cost of repairing the CCO liner plate component was R805 995.90, however, the component could have been repaired using standard liner plates which had an estimated material cost of R430 505.10 (Borox Wear Parts (Pty) Ltd, 2018).

The above mentioned indicates that the standard cost of relining an RH340 face shovel front jaw component is approximately 46.59% less when using standard liner plates to reline the component as opposed to using composite liner plates to reline the component.

The cost of repairing the component using composite liner plate is nearly 1.87 times higher than when repairing the component using standard liner plates. The production efficiency of the component must increase proportionally to justify the additional cost of repair and relining the component using the alternate liner plates.

The cost of the components in terms of production efficiency was analysed to gain a comprehensive overview of the overall and material cost of the CCO plates. An analysis of the material cost indicated that it cost R32.20/kg and R63.51/kg to repair the component using AR-plates and CCO, respectively.

The material cost of the CCO plate is calculated based on the CTS area to be overlaid, as opposed to the material cost of standard liner plates which is calculated by obtaining the mass of the CTS part. An operational cost rate of only the material was calculated based on what the material used to repair the component costs per production hour.

The operational cost per hour of the material used to repair the components was approximately R93.06 R/h for the AR-plates and R167.81 R/h for the CCO plates with the CCO plates being approximately 80% more expensive. The rate calculated was based on the hours each component maintained in its respective production cycle.

Although this rate indicates what the material needed to repair the component costs, it is wholly dependent on the production hours maintained by the component. The more hours the component manages, the less expensive the cost of the material will become.

The preliminary scope of work for the repair of both components that the total estimated material cost for the second repair of the component repaired, using standard liner plates, was R311 341.47 for approximately 10 650.95 kg material (JCB-Gearvest (Pty) Ltd, 2019).

Similarly, components repaired using composite liner plates, preliminary SOW indicated that the total estimated material cost for the second repair was R385 070.43 for approximately 14 122.67 kg material (JCB-Gearvest (Pty) Ltd, 2019).

The data analysis of the second repair material indicated that although at first glance components repaired using composite liner plates required more material and appeared to be more expensive, the cost of the repair was 7.18% less than the estimated repair cost for components repaired using standard liner plates.

Although the material cost estimate indicated that the composite liner plate did not necessarily protect the structure plates any more than the standard wear package, the component repaired with composite liner plates sustained less structural damage than the component repaired with standard liner plates.

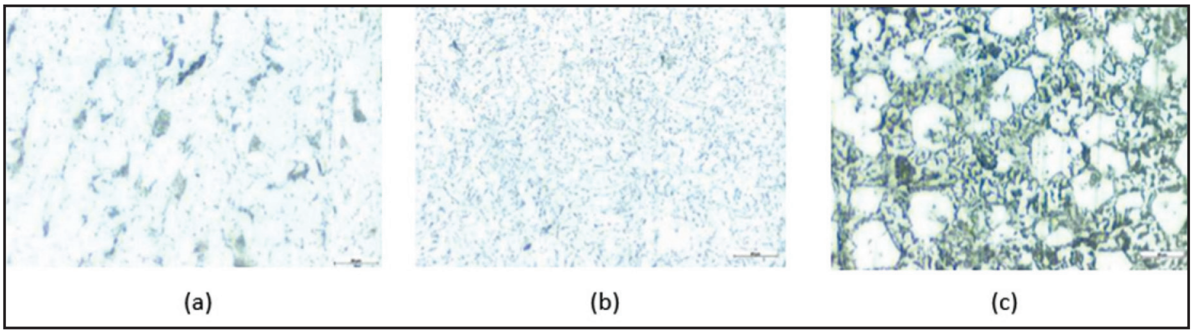


FIGURE 12: CCO sample evaluation: (a) Substrate microstructure of ferrite and pearlite, (b) Intermediate layer microstructure of ferrite and carbides, (c) Overlay microstructure of chunky carbides and pearlite
(Carter, 2020).

Conclusion

This study is concluded by integrating the observations on repaired components, the theoretical research done in the literature review as well as the results of metallurgical material testing.

The broad objective of this study was to investigate the viability of using CCO composite plates, as opposed to standard AR liner plates, as an alternative material in the repair and lining of RH340 face shovels. The investigation objective included reaching and/or exceeding the minimum desired 3 500 hours production with the alternative material; this included understanding the wear and impact capabilities, the component mass implications of both material options and the relationship between the material cost and production performance.

Composite liner plates sufficiently exceeded the minimum desired number of production hours and exhibited considerable wear resistivity. An increase in material cost to production is noted, although only marginally higher than that of standard liner plates. The use of CCO composite liner plates is recommended as a viable alternative solution.

The observed increased wear capabilities, the marginal decrease in wear package mass and the possible increase in production efficiency or output support the conclusion that CCO composite liner plates may be recommended as a suitable alternative to standard liner plates.

The above-mentioned conclusions are further supported by the following considerations:

From a business point of view, it may be critical that anticipated production hours are met, more so than only dealing with the cost of repair ratios. The 250% discrepancy in anticipated production hours, using standard liner plates, significantly increases the risk of doing business and the possible loss in compounded production and turnover. Indications are that the material properties of the standard liner plates cannot be guaranteed at the noted maximum higher end of 4 328 production hours.

Subsequently, the face shovel with standard liner plates could potentially have a more extended downtime and a lower, limited production cycle, affecting possible business planning and production sales. This creates a potential for uncertainty and a lack of predictability in doing business. It is uncertain whether conclusions based on a single observation of CCO performance can be extended to all CCO liner plates, and the likely performance of standard plates lacks predictability due to the 250% discrepancy in production hours achieved. This difficulty may require further study from a business point of view and not necessarily from a mechanical properties point of view.

A further conclusion is that a combination of CCO and standard liner plates may warrant further consideration, with specific reference to the location and plate orientation for purposes of wear and impact. Although this study is based on a CCO repair and relining on a single face shovel, the experience gained in addressing some of the critical failures, like delamination may result in a considerable reduction of lead times.

Limitations

Since the geological content with which the components interact is one of the factors influencing the rate of wear of both the AR plates and the composite liner plates, the outcome of this study, the data analyses, discussion, and conclusions are specific to components operating in platinum mines in the Limpopo province in South Africa.

The research and outcome of the study are based on the laboratory results of the material samples, literature review, desktop research and observations made on a single component repaired using composite liner plate. There is a potential for variation of performance of the wear package depending on the location the component is operating in, since geological content and operations affect the type of wear mechanism on, and wear rates of, the wear packages.

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