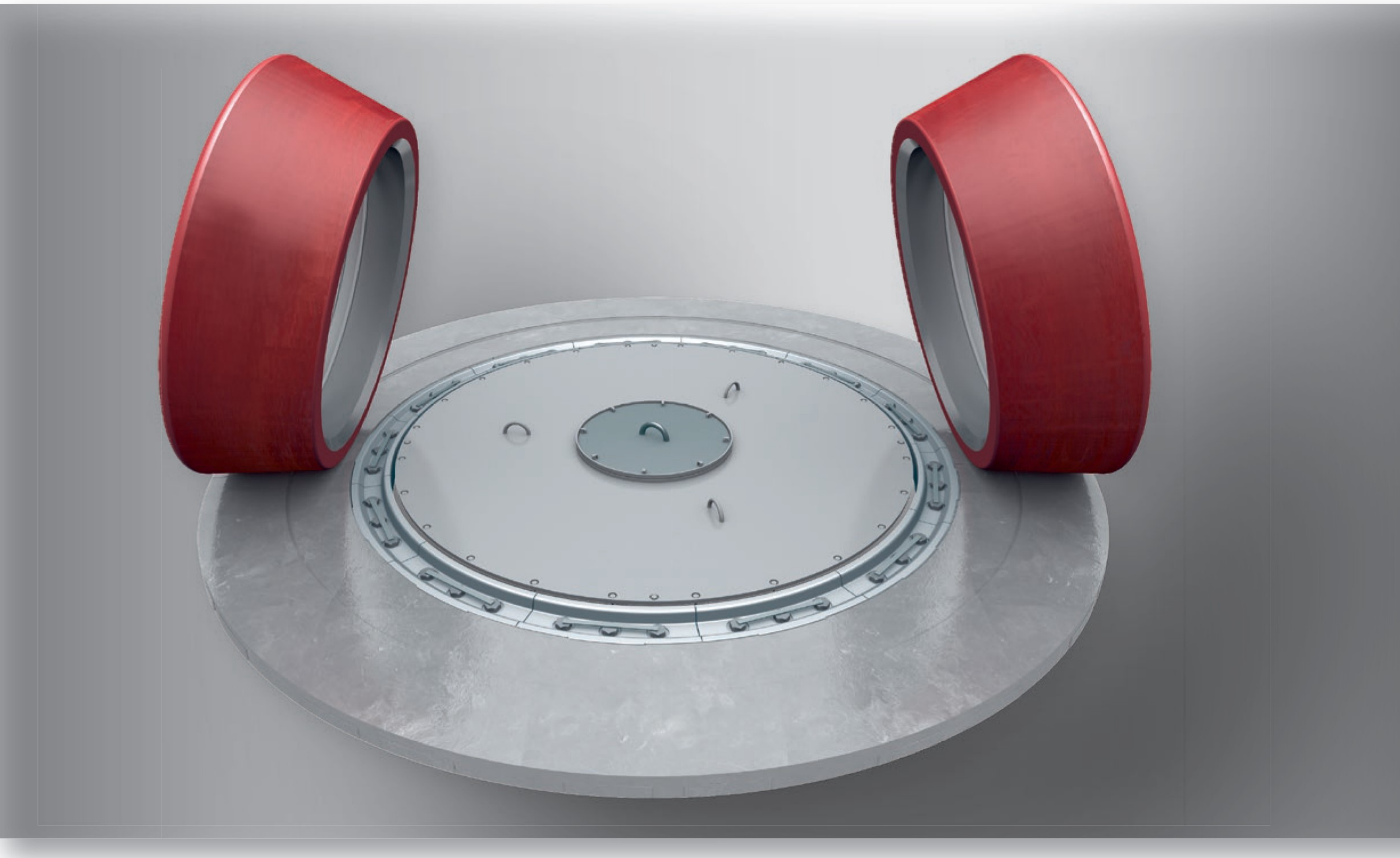

SETTING A NEW BENCHMARK

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Setting a new benchmark

As ever-higher efficiencies are demanded of grinding equipment, cement plants require a new benchmark for grinding component performance. Addressing wear through regular maintenance and repair is one strategy with the sustainable supply of grinding parts and management of mill wear as key factors in keeping mills running.

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Wear is an implicit phenomenon during grinding. It has a cumulative effect over time and results in significant changes in the shape of rollers and tables of milling equipment, ultimately determining their replacement or refurbishment. The degradation in efficiency is progressive, reducing throughput and increasing power consumption. A new benchmark is required to meet the challenges of efficient grinding in distributed locations, in a world of ever-increasing mill sizes and capacities. This article expands the presentation at the 111th year Loesche Symposium at the Maritim Hotel in Düsseldorf in September 2017 and reviews some of the issues associated with grinding components, the empirical data and available models to mitigate the negative effects of wear over the efficiency and throughput.

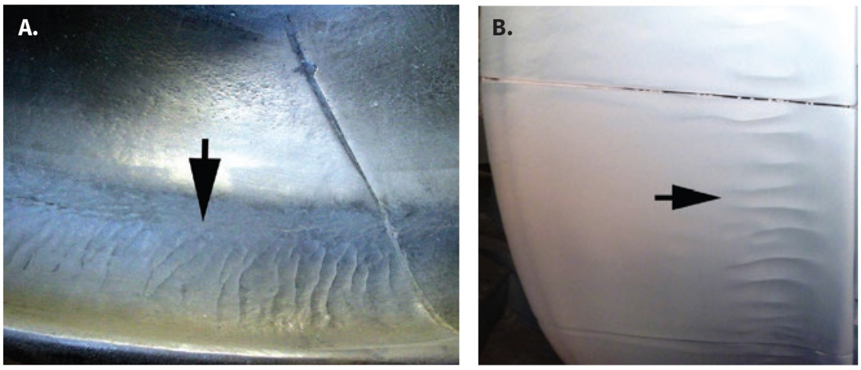


Figure 1: typical wear profiles. The arrows indicate the areas of maximum wear. Deeper wear profiles may lead to a loss of efficiency, ie, lower throughput, and/or higher specific energy consumption and/or higher vibration. A: table plates B: roller tyre

Understanding the operational period of rollers and tables due to wear

In the present context, the operational period of the component refers to an arbitrary time or throughput mass after which it is taken out of operation for replacement or refurbishment. The critical decision to replace or remove may depend eg, on the throughput being unacceptably low, or the specific power consumption or the vibration being too high, or due to planned maintenance schedules. In raw mills, operation becomes normally difficult when the maximum wear is deeper than 50mm whereas in slag mills this may occur after 30mm depth only. Naturally, the operation time and/or throughput to the end of operation may vary according to the abrasivity of the media.

Assuming reproducible and stable mill operation, it is possible to distinguish a trend in milling throughput or specific power consumption relative to time – from the installation of new components to the end of their operation. It is interesting to observe that similar trends appear to occur with all mill designs and grinding component material.

This trend is consistent with the models proposed previously by Tecco,[1] reproduced in Figure 3. The model is useful because it distinguishes between modes of plant operation as a first step towards optimisation:

- **Throughput model:** the case of a plant aiming at maximum production, irrespective of electrical consumption. For example, a favourable market when all production is entirely sold out. The operator would be trying to maintain throughput as close to P_N as possible (see Figure 3a). However, the actual throughput would be dependent on wear.
- **Specific electrical consumption model:** the case of a plant trying to minimise cost through energy savings.

Figure 2: a raw mill throughput record for one operation period and a set of hardfaced rollers and table, corresponding to approximately 12 months. The red line is the regression for each of the three stages of wear. The spurious points below the normal operation scatter band refer to instances when the mill was not operating steadily but were captured by the data recorder. Event A designates the completion of hardfacing in situ, and Event B designates the end of operation for maintenance

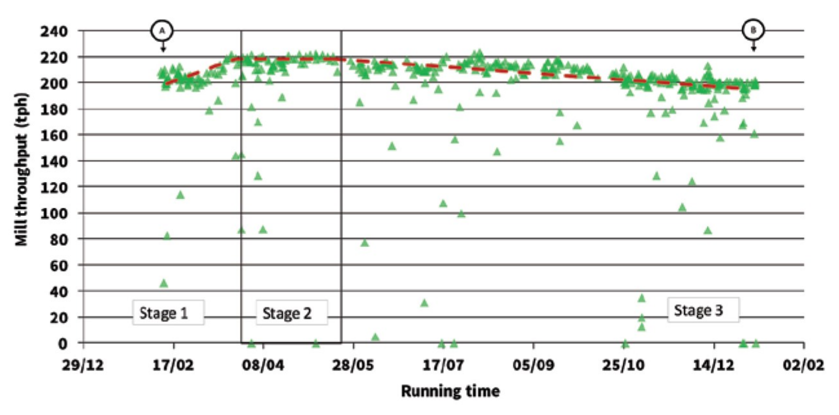
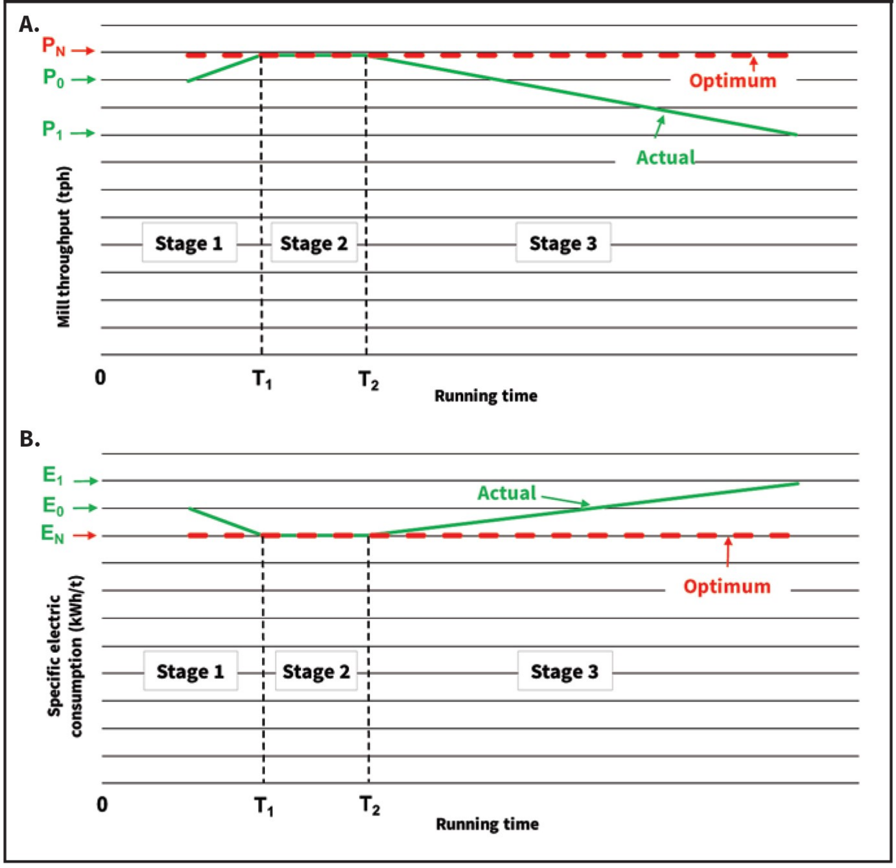


Figure 3: mill efficiency models.[1] Stage 1 refers to the bedding-in period from the original design dimensions. Stage 2 corresponds to the optimum operation. Stage 3 corresponds to a gradual loss in efficiency due to wear. A: throughput model showing the evolution in throughput during the operational life of the components at fixed specific electrical consumption. B: specific power consumption model showing the analogous trend in specific electric consumption at fixed throughput



For example, a competitive market with depressed prices, requiring a fixed cement quota at minimum production cost. In this case, the plant would be trying to keep consumption as close to E_N as possible. However, the actual consumption would be also dependent on wear.

Most plants would expect to operate in-between these two extremes in practice.

Stage 2 corresponds to the maximum efficiency under operating conditions. Stages 1 and 3 are wasteful and are associated with higher vibrations, higher energy consumption, lower throughput and higher emissions.

The models can assist plant operators in estimating the direct economic impact of wear or how to mitigate it. For example, a simple regression using the data in Figure 1 throughput model in Figure 3A indicates a deficit in throughput in the order of 62,464t, due to the departure from P_N. From this information it should be possible to assess the cost implications, eg, assuming a recovery from limestone to clinker and knowing the plant's profit margin. It is possible to carry out a similar analysis using the specific electrical consumption model and calculating the cost due to departure from E_N using the local energy cost.

The evolution of grinding components

For many years the standard material of choice to produce grinding components was high-chromium white iron. Carbon is present in these materials to increase hardness and abrasion resistance, but it markedly decreases toughness and therefore, is limited to around 3.5 weight per cent. Even with the controlled chemistry, these irons are notoriously brittle. Any pre-existing defects may propagate catastrophically when mechanically or thermally stressed (eg, metal-to-metal contact or thermal shock). Figure 4 shows a representative sample that was subjected to an increasing load – and fractured catastrophically without noticeable plasticity when the load reached a critical value of around 14kN.

Around 20 years ago the development of hardfacing equipment and procedures made it possible to reconstitute the worn components to their design shape, or to manufacture new, enhanced components in comparison to the white irons. Hardfacing by welding is efficient and requires a fraction of the electric power needed to cast a new component. It is possible to hardface with a wider variety of alloys than previously possible with the castings, with carbon contents even higher than five weight per cent. Due to

Figure 4: three-point bending KIc test of a 25mm-thick high-chromium white iron sample with nominal 60 HRc according to ASTM E-399. A: stress/strain curve, with brittle fracture just after 14kN. B: resulting crystalline surface after fracture

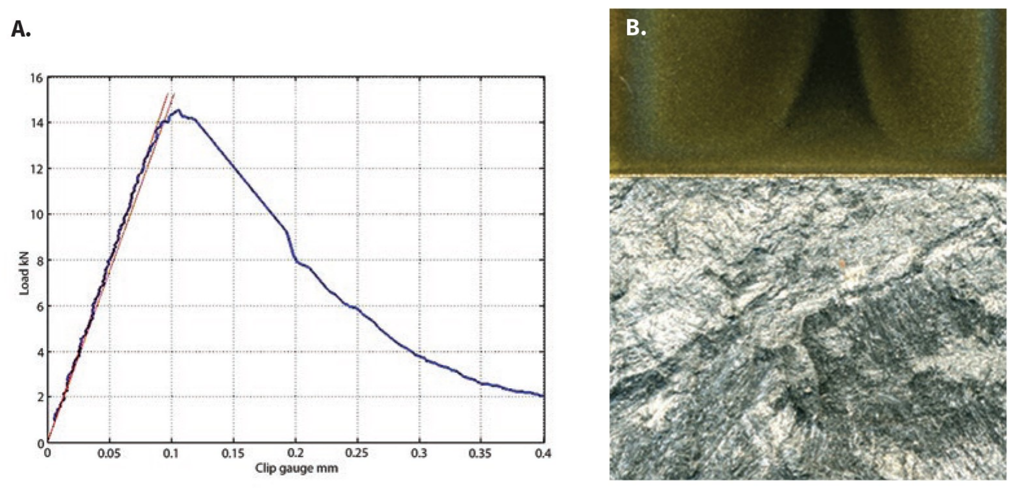
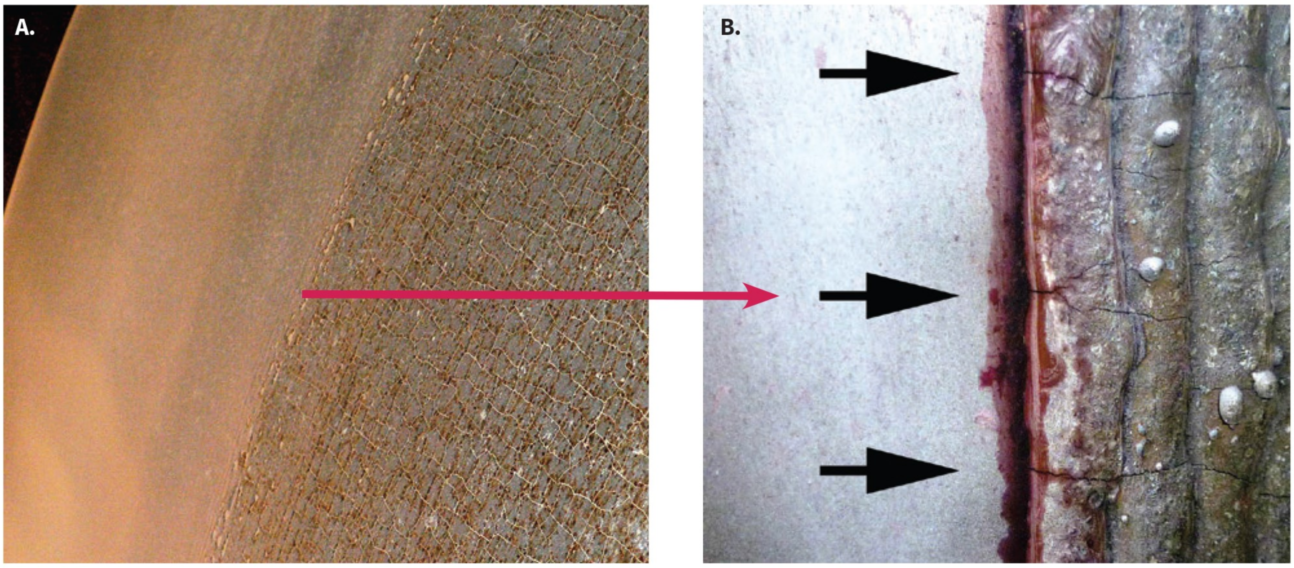


Figure 5: hardfacing high-chromium white iron by means of welding is a successful technique when properly applied. A: a conical tyre with accurate geometry after successful operation. B: close-up of hardface edge after dye-penetrant testing; with the correct welding conditions, the check cracks are formed in the hardface metal, but they do not propagate into the base



the enhanced chemistry and nobler alloys, the abrasion resistance is comparatively higher. The welding stresses can be relieved via the formation of stress relief (also known as "check cracks"), protecting the substrate (see Figure 5). Despite the success, there are records of fractures, excessive vibration and other undesirables, which can be attributed to poor service and lack of care for the mill geometry, engineering standards, qualifications or controls.

From around 2000 the development of a ceramic/metal composite was successfully carried out, which became a patent in later years. This technology is now well established in the market and is associated with good operational periods particularly with raw material grinding, due to the long lifetime. However, the composite cannot be refurbished, which is an issue in view of the extended losses and vibration under Stage 3 (see Figure 3). This is a concern since the losses in throughput and/or higher electrical consumption may outweigh the cost of the components themselves.

The new benchmark for grinding components

The growth of the cement industry worldwide and the foreseeable increase in mill dimensions and capacity[2] presents some exciting opportunities for the sustainable supply of grinding parts and the management of wear in service. Enhanced supplies and management concepts are required to maintain milling efficiency irrespective of the mill location, going beyond the simple purchase of catalogue parts or unspecialised services.

To avoid the inherent brittleness of the old and conventional high-chromium white irons from the past, there are important developments in the manufacture of composite parts by adding welded layers to tough bases. This design is well-established in other industry sectors (eg, continuous casting of steel billets) since it makes it possible to combine distinct properties to the finished part (eg, high toughness and high abrasion resistance).

Composite grinding elements are now becoming available in the wider market and further development is expected soon to fine tune the material properties to the abrasivity of the local materials and the grinding conditions.

There are also interesting developments linked to the identification and tagging of grinding parts to allow for enhanced traceability, improving the control of operational life and mitigation of inefficiencies associated to wear. This may also improve the quality control of these parts, enable further specification improvements and data-sharing across grinding plants.

Even if the cost of grinding components may be small in comparison with the losses due to low efficiency and loss of throughput, or if the carbon footprint in the supply of grinding components is minor compared to the overall cement production, it is worth remembering that refurbishment is a desirable means to allow for the re-use of parts. Re-use helps reducing wastefulness and the carbon footprint. Adequate management is needed to ensure that the parts can be used many times before they are worn past the point of refurbishment.

Clark properly cites the need to tune the geometry of the dam ring to avoid excessive vibration.[3] In addition, when it comes to retaining the correct shape of the tyres, the gap with the table is of paramount importance as it also affects the efficiency and departure from the optimum ranges discussed previously in this article (see Figure 3). In this sense, continuous refurbishment and other initiatives to retain the geometrical accuracy may be beneficial to avoid the wastefulness of Stage 3.

The accurate control of the mill geometry demands the intrinsic participation of the mill designer for the supply of adequate replacement parts and the proper refurbishment in-situ. ■

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