

EFFICIENT WELDING REPAIRS IN THE CEMENT INDUSTRY

Jürgen Tuchtfield¹, Thomas Assion¹, Issam Chiguer²

¹ UTP Schweißmaterial Zweigniederlassung der Böhler Schweißtechnik Deutschland GmbH,
Elsaesser Strasse 10., D-79189, Bad Krozingen, Germany

² Soudokay SA, Rue de l'Yser 2, B-7180, Senefte, Belgium

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Abstract

Handling bulk and abrasive material is daily routine in the cement industry. At each production step beginning with quarrying of the raw material, the crushing and milling of the limestone up to the point of the calcination of the limestone, the cement manufacture components encounters tough wear conditions, resulting in significant abrasive wear. Abrasion is obviously the main wear phenomenon, however high temperature corrosion and fatigue may also accelerate the material degradation.

Welding applications in this environment are mainly hardfacing applications of highly stressed components as well as weld-joining of broken parts. The choice of the optimal material for the specific application depends on the type of wear that occurs and on the plant component itself. Specially designed welding consumables and welding techniques are applied to meet the requirements of the different wear problems and different materials.

In this article some typical repair jobs will be discussed. Examples will be the repair of a rotary kiln tire with special nickel base welding consumables and the hardfacing of typical crushing and milling equipment. Using optimal adapted welding consumables to those plant components establishes welding as a cost effective solution for a maintenance concept with long-term duty cycles in a cement plant.

1. CEMENT PRODUCTION PROCESS STEPS

Cement production starts by the extraction of raw materials in a quarry. The chemical composition varies for each country or region, but the ingredients of the most spread cement type, the so called Portland cement, are mainly limestones (75 to 80wt%) and clays (20 to 25 wt%). Raw materials are removed from the quarry by blasting or by excavation. In any case, the aim of the extraction is to remove material from the quarry with a limited size of rock in order to ease the transport to the factory. After the extraction, raw materials are carried to the cement plant by conveying belts, trains or dumpers. To decrease transport costs, cement plants are always located close to the quarry.

Limestones are crushed in a primary crusher to reduce the raw material size. At each production site, the installation of jaw crushers, roller crushers or impact crushers depends on the nature of the raw material. The crushing process is followed by a grinding process in which the raw material is reduced into powder.

In modern cement plants the grinding process is carried out by a vertical mill or by a combination of a ball mill together with a high pressure roller press, Figure 1 A-C. A ball mill is a cylindrical steel shell partly fulfilled with steel balls and partly with the raw material. The cylinder rotates and put the balls into motion which mechanically grind the raw material. The grinded product comes out as a fine abrasive powder with a particle size less than 100 μm .

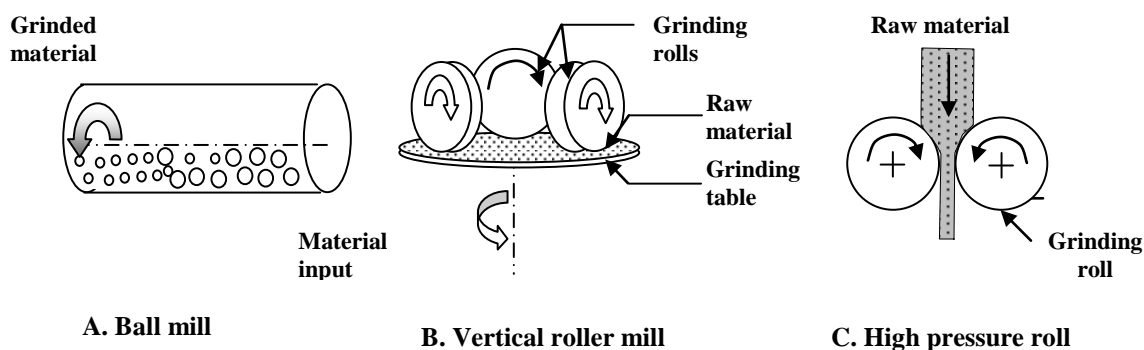


Figure 1: Different mill types

The grinding principle is a table rotating about a vertical axis is driven through gearing accommodated in a gear box. The grinding rollers, mounted in fixed positions, are pressed down on the table under spring loading. The axes of the tapered rollers are inclined. In combination with the horizontal grinding surface of the table they achieve optimum grinding effect.

The big narrow rollers perform not only a purely rolling motion, but also a sliding motion, because the roller axis and grinding table axis do not intersect in the plane of the table. The differential speeds due to this configuration are a desirable feature, producing additional action by the shearing forces developed. The mill throughput rate increases in proportion to the square of the roller diameter, the advantage of using big rollers is evident.

The raw material is fed centrally from above or from one side onto the rotating grinding table. On passing under the rollers the raw material is ground by their action assisted by the pressure of the hydro pneumatic spring loading of the rollers. When the rollers travel over the bed of material on the table, a system of rocker arms and rods connected to the working piston of a hydraulic cylinder causes oil to be displaced from the space above the piston into gas filled hydraulic accumulators.

The pulverized raw material is flung by centrifugal forces into the zone over the air ring surrounding the table, where the raw material particles are swept upwards by the stream of hot air or gas into the classifier.

The intimate contact with the hot gas causes moisture contained in the raw material to evaporate, so that the desired exit temperature of the pulverize product from the mill -70°C to 130°C – is already attained in the grinding chamber. This powder is then preheated at about 800°C in a preheating tower and introduced into a rotary kiln furnace. Due to a slight inclination of the furnace, the powder progresses downwards in the direction of a gas burner, where the calcination of the material takes place. At a temperature of approximately 1450°C the raw material powder is transformed into clinker. After emission of the furnace the clinker is cooled down with fresh air, crushed and grinded again. During the calcination about 5% of gypsum has to be added. Slag or flying ashes from steel mills are also frequently added to obtain the final product.

2. WEAR PHENOMENON IN THE CEMENT INDUSTRY

Cement plants are amongst the industry with the highest wear condition. All along the production process all parts in contact with raw material, clinker or cement are subjected to abrasive wear. Beside abrasion, other wear phenomenons are present.

Abrasive wear

To simplify the description of abrasive wear, only the three-body abrasive wear is considered in the following paragraph. The abrasion system is shown in Figure 2.

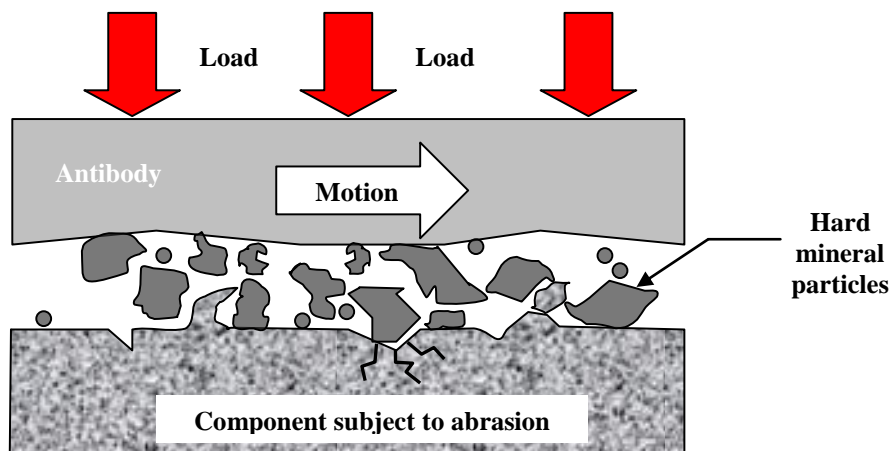


Figure 2: Three-body abrasion system

The component which is subject to abrasion is worn due to the contact with mineral particles located between the component and the antibody, Figure 2. The abrasive wear on the surface is accentuated by the pressure applied by the antibody on the interface particles. As mineral particles are much harder than the component material, several mechanism of abrasive wear can be observed. Due to friction and pressure, the interface particles may groove, plow or locally deform the surface of the component. The hardness, the pressures, the size and form of the interface material strongly influence the abrasion rate.

In practice, the wear system sketched in Figure 2 appears for instance in vertical roller mills. The antibody would be a grinding roll. The component would be a grinding table and the interface material would be clinker or raw material. Interface particles are grinded by comminution and not by direct contact with the metallic parts.

Materials with a high hardness exhibit a higher abrasion resistance than soft materials. Moreover, the addition of carbides (chromium, tungsten, vanadium) increases the lifetime of a part exposed to abrasive wear. UTP welding consumables such as the stick electrode UTP 75 have a carbide content of 80 wt% and are perfectly suited for abrasive wear applications without impact.

Table 1: Abrasion resistant welding consumables: UTP 75 and UTP Ledurit 61.

Welding consumables	Chemical composition of the pure weld in wt%			
UTP Ledurit 61	3,5%C	1,0%Si	35%Cr	Bal. Fe
UTP 75	Fe CrC WC alloy			

Surface fatigue

Stresses applied under the tensile strength of a metal can lead to a decrease of its mechanical properties. A cyclic load can result in dislocation motion and pile-up. After a certain number of repetitions, a crack may appear. The continuous stress cycles favour crack growth until the bearing surface is not large enough to support the stress. Finally, the part completely breaks.

The phenomenon which leads to the break of a kiln tyre is slightly different. When a cylinder or a ball is rolling over a flat surface, the maximum stress concentration is not directly located at the material surface, but slightly under the surface as shown in Figure 3.

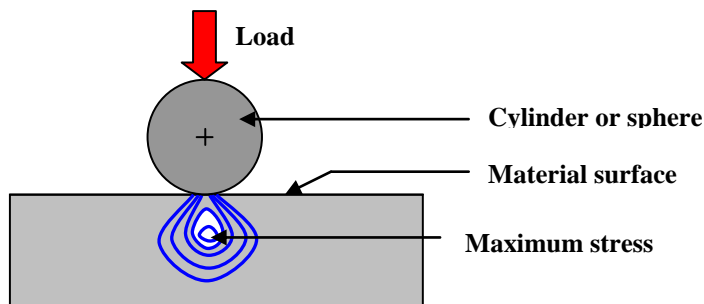


Figure 3: Stress distribution

Cracks start in the vicinity of the maximum stress. Cracks appear generally where a defect is already present such as casting defects or inclusions. This effect explains the formation of sub-surface cracks.

Impact wear

Impact wear occurs when a solid surface is submitted to percussive load due to another solid. As a consequence, two main effects occur in metallic materials: surface work-hardening and material fatigue. Work-hardening is described as a strength increase due to plastic deformation at ambient temperature. Tensile strength increases and therefore the hardness increases, but the ductility is reduced.

In cement plants, abrasive wear is always combined to impact wear so that abrasion, fatigue and work-hardening contribute to the global degradation of a component.

3. SELECTED REPAIR APPLICATIONS

Rotary kiln tyre

Rotary kiln furnaces are long cylindrical ovens driven by support rollers localised on both sides of the cylinder, Figure 4.

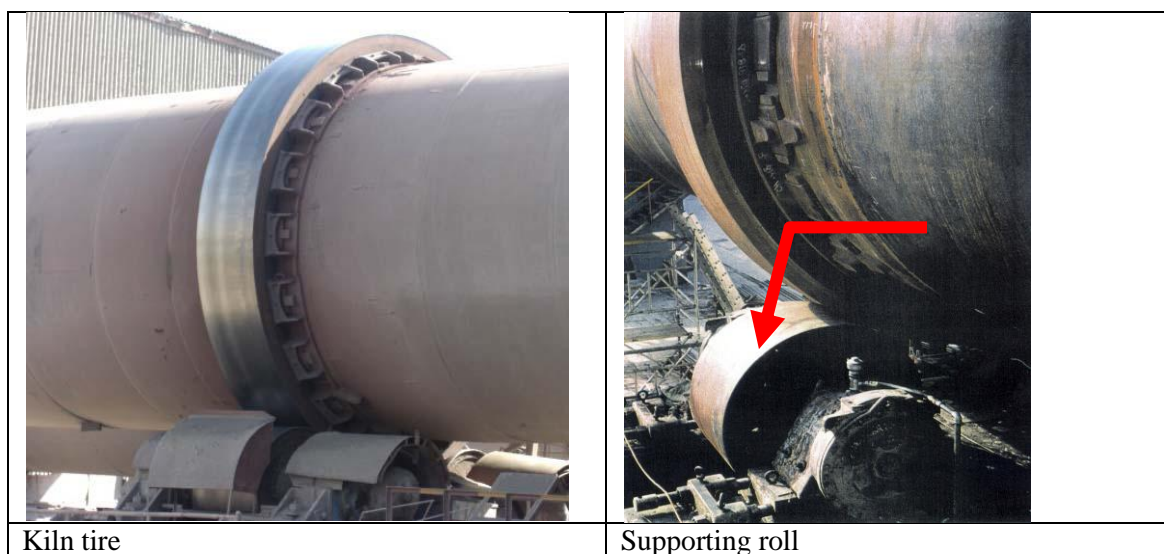


Figure 4: Kiln furnace and support rolls.

Support rolls are in contact with a tyre fixed on the circumference of the rotary kiln furnace. Tyres are about 1 m wide and distributed at regular intervals all along the furnace surface. Tyres

support the entire weight of the rotary kiln oven. The weight of more than 100 tons squeezes locally the kiln tyre which causes surface fatigue cracks.

Cracks are not visually detectable until they reach the surface for the reasons explained in paragraph 2.2. After a certain time, large pieces from the tyre surface spalls off ,Figure 5.

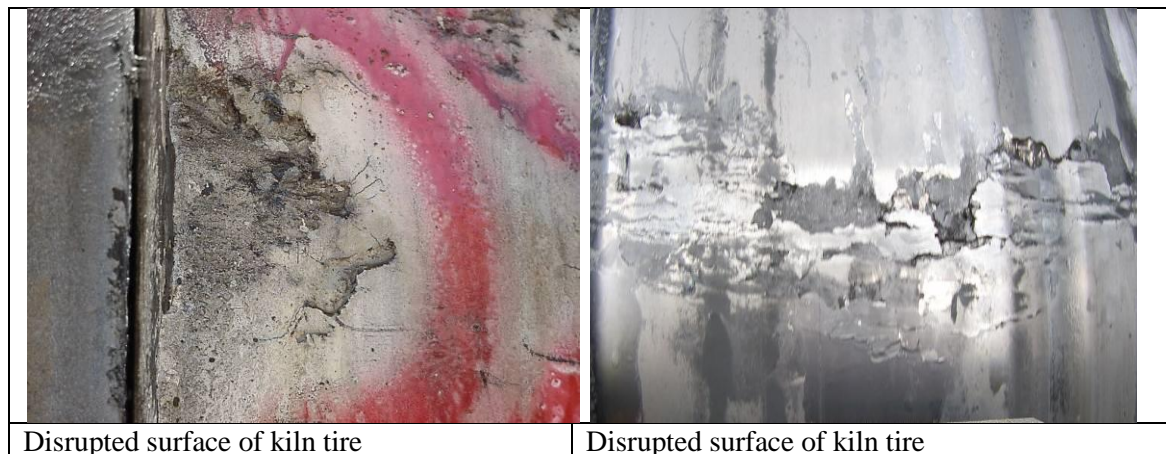


Figure 5: surfaces degraded by surface fatigue.

Tyres are carbon steel cast components with high mechanical properties. The chemical composition and the strength of the base material are detailed in the following tables.

Table 2: Typical chemical composition of kiln tyre base material.

C	Si	Mn	P	S	Fe
0,25 - 0,33	<0,60	1,2 - 1,6	<0,05	<0,05	Balance

Table 3: Mechanical properties of the base material.

Mechanical properties	Base material
Tensile strength [N/mm ²]	>620
Yield strength [N/mm ²]	370
Elongation [%]	13
Hardness [HB]	<217
Impact value at RT [J]	35

Joint preparation and choice of welding consumable

Before welding, the weld must thoroughly be prepared. The absence of cracks in the bevel is a crucial criterion for the repair quality and has to be checked by dye penetrant test. Moreover, the surface should be smooth, free of dust or other impurities to ensure a porosity- and inclusion-free weld deposit. Considering that the repair has to be done on site and that the environment of a cement plant is inevitably dusty, welding areas have to be prevented from external factors such as wind and rain, which negatively influence the welding operations. The preparation of the welding area must also allow welders to have a good accessibility to the welding area.

Repair of base materials with a chemical composition as given in table 2 can be done using similar (iron base) or dissimilar (nickel base) welding consumables.

The choice of a similar welding consumable would request preheating to avoid cold cracking and a post weld heat treatment to relieve stresses in the base material and in the weld deposit. Depending on the thickness of the tyre and on the chosen welding consumable, the preheating temperature can be estimated to at least 150°C. Due to the huge dimensions of the rotary kiln furnace, no heat treatment can be realized for obvious practical and cost-effectiveness reasons.

Nickel base welding consumables and especially the stick electrode UTP 068 HH present several advantages for the kiln tyre repair. Most of nickel base alloys exhibit a high ductility. This high ductility partly compensates the lack of elongation of the base material and thus decreases risks of cold cracking while welding. Preheating of the base material can thereby be neglected.

The stick electrode UTP 068 HH exhibits also high mechanical properties and an extremely good resistance against hot cracking. Furthermore the strength of UTP 068 HH can also be increased by work hardening. For sure, the deposition rate by SMAW is lower in comparison to GMAW or submerged arc welding. Nevertheless, SMAW process has several decisive advantages, especially for welding on site:

- Last generations of power sources are easily portable.
- No need of shielding gas.
- Slag decreases the cooling rate and shapes the bead. This minimizes risks of undercut and thereby risks of cold cracking.
- Low dilution is achievable by using low amperage and small electrode diameters.
- Stick electrodes are weldable in position.

Welding procedures

Cold cracking is the main risk while performing a repair. The welding procedure has to be adjusted in order to expose the base material to the smallest possible amount of welding stresses.

Welding starts with a diameter not exceeding 3,2 mm for the first layer. Firstly, the inside of the bevel has to be cladded using a buffer technique in order to allow free shrinkage of the weld. The welding sequence is schematically represented in Figure 7.

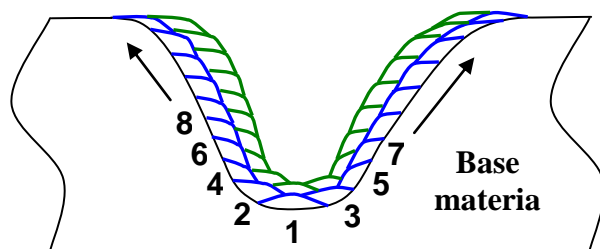


Figure 7: Welding sequence for the two first layers.

Welding starts with a first bead located at the bottom of the bevel. The next beads have to be alternatively welded on each side of the first bead until the complete bevel surface is cladded. The next layers have to be welded following the same welding sequence as for the first layer.

Low parameter settings are really important to ensure low dilution with the base material and to keep a low heat input. Stringer bead and the side change for each bead also contributes to limit the heat input.

After welding the first layer, electrode diameters larger than 3,2 mm can be used. To peen each bead is highly recommended to relieve partly shrinking stresses and at the same time to remove the slag. Each beach should be thoroughly brushed to guarantee the absence of slag inclusions inside the weld metal.

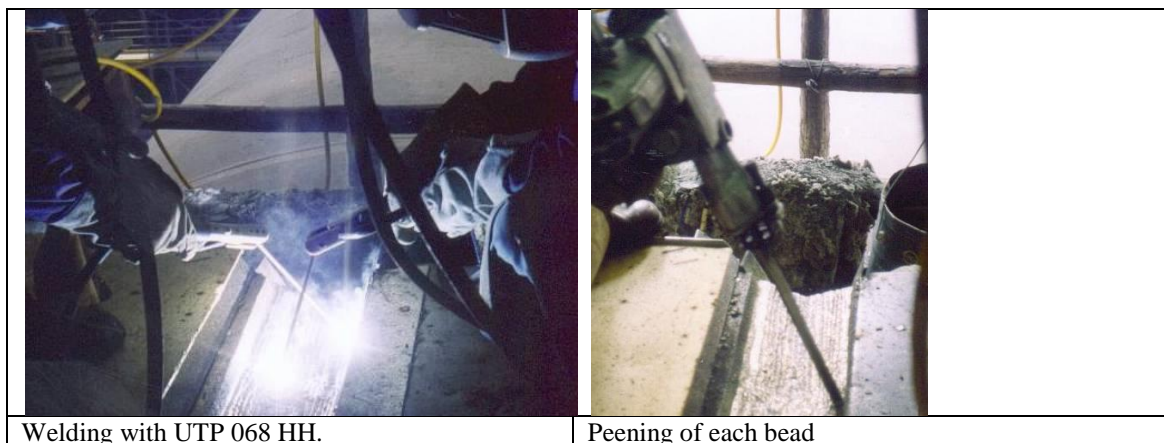


Figure 8: repair of a kiln tyre

After welding, the repaired area is machined to the original tyre shape. The described procedure to repair kiln tyres is also applied for kiln support rolls which are subjected to similar mechanical loads and thereby to similar wear phenomenon.

Impact crusher hammer

Impact crushers are widely used to reduce the size of raw materials. Hammers are generally made of manganese steels.

The addition of manganese to steel yields in the high work hardening properties of the alloy. The surface hardness dramatically increases although the inside of the part remains ductile and crack resistant. The work hardened surface provides an excellent resistance to impact combined with moderate abrasion resistance. The material ductility prevents hammers from breaking in service.

Nevertheless, material losses always take place and worn hammers have to be replaced by new one or have to be repaired by welding.

Welding of manganese steels necessitates special cautions to keep the original material properties. Beside work hardening, manganese steels have a high thermal expansion coefficient which leads to strong deformation while welding. The microstructure also tends to embrittlement when exposed to temperatures above 300°C. As a consequence, the temperature has to be kept under a maximum of 250°C during the whole repair.

Hammers are rebuilt to their original shape by using welding consumables with similar chemical composition such as UTP CHRONOS, UTP 7200 or UTP BMC. The chemical analysis of manganese steel and matching welding consumables used for hammers are given in table 4. The chromium additions of UTP BMC increase the mechanical strength and the resistance to abrasive wear. The pure weld metal deposit of UTP BMC has a hardness of approximately 250 HB. After work hardening, the surface hardness obtains 55 HRC.

Table 4: Typical chemical compositions

	C	Si	Mn	Cr	Fe
Base material	1,1	0,4	12	2	Balance
UTP CHRONOS	0,9	0,8	13	-	Balance
UTP BMC	0,6	0,8	16,5	13,5	Balance
<i>UTP DUR 600</i>	<i>0,5</i>	<i>2,3</i>	<i>0,4</i>	<i>9</i>	<i>Balance</i>

Before welding, hammer surfaces are grinded to remove dust and impurities. Stick electrode UTP BMC in diameter 4,0 mm is used to rebuild the hammer to its original shape. Stringer beads

with an overlap of 50% are advised to obtain a smooth surface after welding. The last two layers are welded with the stick electrode UTP DUR 600. The weld deposit of UTP DUR 600 exhibits a martensitic microstructure resistant to abrasion and impact. The pure weld metal of UTP DUR 600 obtains 58 HRC directly after welding. UTP DUR 600 prevents the initially soft manganese steel deposit from an excessive material loss due to abrasion in the phase where the manganese steel is not already work hardened.

Vertical mill repair

The base metal for rollers and tables of the majority of the vertical mills is Ni-Hard cast iron. For this material which is difficult to weld the welding procedure has to be strictly followed in order to reduce the maximum level of welding stresses.

Table 5: Typical chemical composition of Vertical mill base material.

C	Cr	Ni	Mo	S	P	Si	Mn	Fe
2,5 - 3,6%	7-11%	4,5-7%	1,5% max	0,15% max	0,1% max	2% max	2% max	Balance

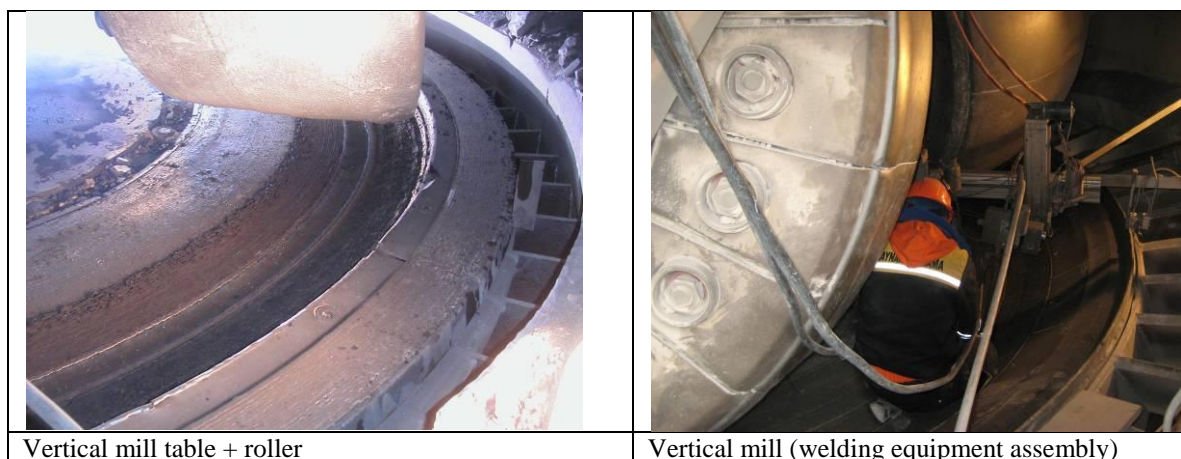


Figure 9: Vertical mill

Joint preparation and choice of welding consumable

In this case, there is no joint preparation as we speak about hardfacing of whole surface. The chemical composition of Ni-Hard falls in the Hypo-eutectic or eutectic zone. The inadequacy of wear resistance of each material is anticipated because eutectic carbide, $(Fe,Cr)_3C$, produced in either zone is small both in grain size and quantity. Accordingly hard overlay weld metals, to be highly wear resistant, should be those which would fall in the hyper-eutectic zone to the right of the eutectic line and which therefore would be high in C and Cr contents.

Welding procedures

The absence of cracks is again very critical and has to be checked by dye penetrant test.

The preheating temperature is 60°C. Begin the first pass at a distance of 1 inch from each edge of the roller in order to prevent bi-axial stresses which can lead to spalling. The successive layers will be gradually widened to fill up the gap. The interpass temperature should be kept within 60-90°C in order to achieve a tight weld cross cracks pattern, such as perpendicular crack to the bead every 10mm. It is very important to have a weld deposit with many small cracks.

The control of heat is the key success factor in this process. To reach that goal, apply cooling by means of compressed air on the deposited beads just after welding. Upon completion of the welding repair let the whole roller let cool down slowly using, if necessary, a shelter of insulating matter.

Welding once started must be completed in one operation without intermediate cooling to room temperature. NEVER EXCEED INTERPASS TEMPERATURE.



Repair of a vertical mill table with SK 866-O (in situ)

Vertical mill roller hardfaced with SK A 43-O (workshop)

Figure 10: repair of a vertical mill

Table 6: Abrasion resistant welding consumables

Welding consumables	Chemical composition of the pure weld in wt%				
SK 866-O	4,5%C	0,8%Si	24,5%Cr	Bal. Fe	
SK 164-O	5,4%C	1,3% Si	27%Cr	Bal. Fe	
SK 256-O	5,5%C	1,3%Si	25,7%Cr	Bal. Fe	
SK A43-O	5,6%C	1,2%Si	20,2%Cr	6,7%Nb	Bal. Fe

The hardness of the applied welding consumables is in the range of 60 to 63HRc.

4. CONCLUSION

From raw materials to the final product, all production equipment of a cement plant is exposed to tough wear. Although abrasion is the dominant wear phenomenon, impact and surface fatigue are also present.

The kiln tyre degradation appears after several years and is characteristic of a surface fatigue wear. To stop a rotary kiln furnace means to stop the complete cement production. Therefore a specialised welding procedure must be applied to avoid any risk of cracking or defect in the repair. Repair of kiln tyre is done without preheating by using a nickel base welding consumables such as UTP 068 HH to ensure a long lifetime.

Impact crusher hammers are subjected to high impact and abrasion wear. Welding with UTP BMC to build-up the part to its original shape and with UTP DUR 600 to confer a good abrasion resistance enhances hammers' lifetime. Welding is also very cost effective solution.

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