Operational Environment Considerations for Reliability

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Abstract

The environments in which the various industrial equipment operate in mostly limit the operational life of the equipment. The operational environment ranges from hot, cold, corrosive, non-corrosive, strong forces, etc. and no universal material selection is ideal for all operating conditions. A lot of effort needs to be put into the material selections and designs of industrial equipment in order to withstand the relevant operating environment. Physical assets reliability is highly affected by the operating conditions and the applicable maintenance actions need to be deployed to prevent catastrophic equipment failures. The magnitude of failures is also sometimes heavily determined by the operational conditions and the maintenance actions that are taken to counteract the impact of failures are vital considerations for the physical assets reliability. The study is an exploration of reliability aspects pertaining to physical assets in the various operating environments.

Keywords
Environment, maintenance actions, material-selections, corrosion-erosion

1. The operational environment and equipment

The field of reliability engineering considers that machine part failures are broadly categorized in three segments, and these comprise of infant mortality; stochastic and wear- out failures (Hall and Strutt 2003:233). This gives birth to reliability modelling that takes cognizance of uncertainty concomitant with stochastic variabilities of the functional effects and strains (Hall and Strutt, 2003:234). A corrosive environment degrade ferrous mechanisms and this is propagated by salts, chlorides, acids and hydrogen among other corrosive agents, while aluminum is prone to corrosion due to salts and alkalis, and rubber materials are affected by hydraulic-oils and ozone (Pakale and Tuljapure, 2015:413). Different equipment operate in varying conditions and this poses maintenance challenges for practitioners, for instance offshore wind turbines are located in deep water and harsher conditions compared to onshore wind farms, and therefore the maintenance strategies definitely differ in such instances (Sørensen 2009:493). The performance of the likes of wind-turbines is dependent on a multitude of uncertainties which embody the operating environments, constructional material features and environmental settings (Sørensen, 2009:495). The maintenance considerations for such physical assets such as wind-turbines take cognizance of such uncertainties into attention, as they will intensely impact on the futuristic performance of the assets (Sørensen, 2009:495). The effectiveness of maintenance actions to inspect with the aim of detecting and quantifying degradation and then restoring the assets, hinges on the intensity of control of maintenance systems, and the effectiveness of the inspections themselves may be liable to substantial ambiguity, and this has to be considered during the planning phase of the maintenance strategies and techniques like the probability of detection (POD) curves can be applied (Sørensen, 2009:495). The likes of offshore wind-turbines entail that in complete contrast to onshore physical assets and structures, workman are less likely to spend maintenance time in the locality of offshore physical assets compared to onshore assets, therefore, it can be prudent to allude that the reliability of offshore assets is generally considered lower than that of onshore installations **(**Sørensen, 2009:496). Some operational environments subject process equipment to corrosion and the erosion–corrosion synergistic factors (Tian et al 2009:2042). Erosion–corrosion is aptly defined as a physical deterioration spectacle that befalls hydraulic equipment that handle turbulent slurry fluids, and various industrial entities endeavor to alleviate this puzzling phenomenon by revising the machine component designs by applying higher erosion–corrosion resistant alloys (Giourntas et al 2015:1055). The strategic options availed to counteract erosion-corrosion usually entails selecting corrosion-resistant alloys which unveil reliable performance in the harsh operational environment and the application of coating practices to armor susceptible metals such as carbon-steels (Giourntas et al., 2015:1055). Figure 1 below illustrates an experimental corrosion behavior of high-alloy white cast-iron under experimental conditions.

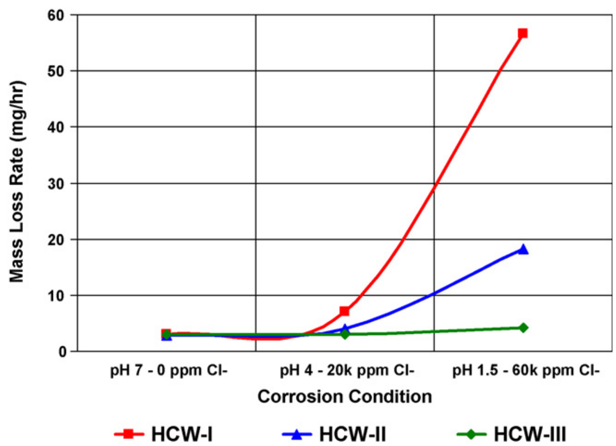

Figure 1. Mass loss rate variation with corrosion intensity at 10 microns (D50) solids particle size at 32 ◦C for high-alloy white cast-iron (Tian et al 2009:2042)

Temperature is regarded as a highly influential factor on the corrosive intensity and generally, high temperatures accelerate the corrosive impact on mass loss of particles under experimental conditions, which translates to the real industrial set-up as the norm (Tian et al 2009:2042). Operational conditions such as high temperatures and corrosive substance intensity have a strong influence on the rate of degradation of material in an industrial setup (Tian et al., 2009:2042). The figure below depicts an experimental set up of high-alloy white cast-iron being subjected to temperature increase and also under high chloride acidic concentration condition.

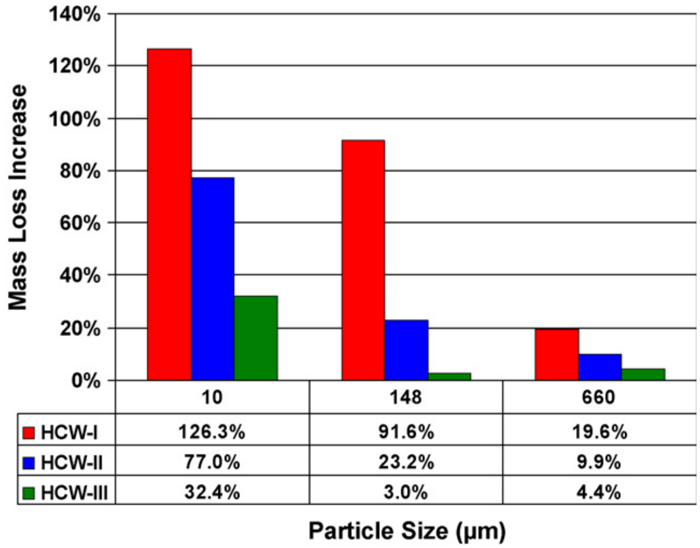

Figure 2. The increase of mass-loss-rate as temperatures increase from 32 ◦C to 47.5 ◦C at pH of 1.5 (Tian et al 2009:2044).

Figure 3 below shows the impact of corrosion intensity on mass-loss rate of high-alloy white cast-iron under experimental conditions.

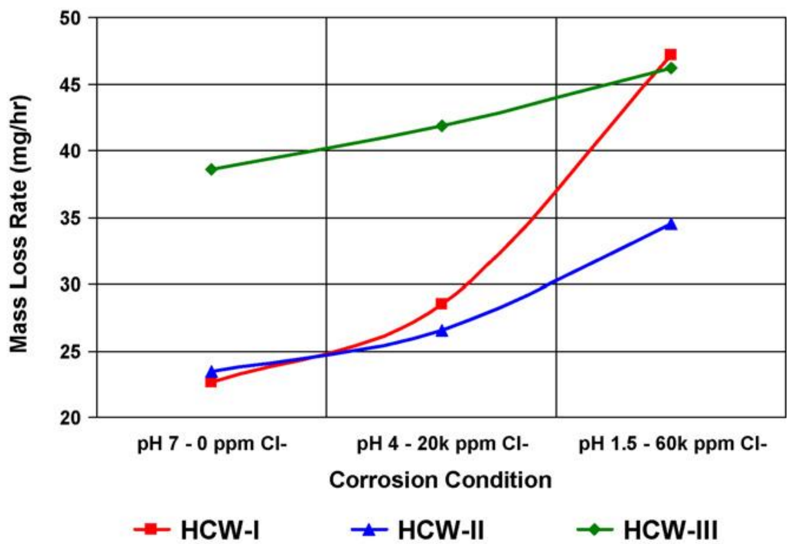

Figure 3. Depiction of mass-loss rate as corrosion-intensity increases for 148 microns (D50) solid particles at a constant temperature of 32 ◦C (Tian et al 2009:2043)

Many industrial operations subject equipment to situations of material mass loss attributable to the blend of erosion and corrosion, and experiments have depicted that as the corrosion factor intensified with pH value becoming more acidic, the mass-loss rate of the metal increased hastily, more so for metals with comparatively minimum corrosion resistance (Tian et al 2009:2047). Any temperature upswing considerably upsurges the corrosion intensity of the corrosive agent, but the chromium element in many alloys plays the pivotal role of resisting corrosion in white irons, thus the higher chromium content promotes passivation at considerably high corrosion intensities and overcoming the depletion-effect (Tian et al 2009:2047).

2. Materials engineering as the propellant of physical assets reliability

The field of materials science and engineering has progressed significantly in developing smart and inexpensive techniques to improve machinery constructional properties as dictated by design requirements in the industrial set-up (Lima et al 2015:123). There have been new developments in material-coatings or surface-modifications of the base-material to come up with appropriate structures that could endure the harsh operational environments that industrial conditions present, and techniques such as welding-overlay and thermal- spraying are widely applied and regarded as handy for the industrial purposes (Lima et al. 2015:123).

A multitude of industrial applications need constructional materials with superb resistance to both corrosive and wear degradation, and materials like high-alloy white cast-iron can be used to withstand severe abrasive and erosive circumstances, and they also possess fair- to-excellent corrosion resistance in different situations when they contain comparatively high intensities of chromium and additional alloy elements, making them suitable to withstand corrosive atmospheres brought about by reducing acids (Tian et al 2009:2039). It has been proven that the corrosion-resistant alloys are able to reliably withstand some harsh marine environments, and even though these alloys still have some limitations, and their performance is superb under such unbearable conditions, leaving room for a comparative analysis of the different alloys for specific operations (Giourntas et al 2015:1051). Stainless steels as one specific alloy group carry the capability to withstand extraordinary flow-rates of a diversity of aqueous fluids, and therefore their selection in diverse industrial applications is prevalent as they significantly depict good erosion–corrosion capability under solid-free liquid-impingement circumstances (Giourntas et al 2015:1051). Needless to say, their chromium rich composition render the stainless steels with an oxide-passive film that resists breaking down even in turbulently flowing fluids at significantly high temperatures of even up to 60 degrees Celsius (Giourntas et al 2015:1051). The resilience of stainless steels also declines when suspended-solids are found in the fluid (Giourntas et al 2015:1051).

Austenitic stainless-steels are broadly utilized within the food-processing, petro-chemical and marine industrial establishments, as a result of their high corrosion resistance capability, significant mechanical strength and resilience (Zhao et al 2015:464). The surface-erosion of the austenitic stainless-steels by particulate material impact results in significant surface damage, and this has culminated in the pioneering of novel erosion protection methods such as the ribbed-bend technology, meant to lessen the pipe-wall erosion in gaseous particles flow (Zhao et al 2015:464). When it comes to liquid-particle flow, the austenitic stainless-steels degrade swiftly due to solid particulate material that will be impinging the pipe walls resulting in the protective film damage and culminating in speeded erosion-corrosion (Zhao et al 2015:464). Also stainless steel can be brutally corroded in reducing atmospheres such as in hot and diluted sulfuric-acid solutions as the passive-film would be unstable in such media, but by alloying stainless-steel with the platinum group elements or palladium , the corrosion-resistance of the stainless-steels may be greatly enhanced due to the superior passivation rendered by the noble-metals (Li et al 2015:200). Even the higher grades of stainless-steel like the grade 316L, in hot dilute sulfuric acid, it cannot be securely passivated, thus it is susceptible to severe corrosion, and palladium or chromium plated films can greatly increase 316L stainless-steel's resistance to corrosion in such an environment, even though erosion–corrosion obfuscates the entire process (Li et al 2015:208). When the stirring speed is low at around 700 rpm, the erosion impact is not pronounced, but as the stirring speed gets higher, erosion becomes more and more dominant within the erosion–corrosion (Li et al 2015:208). The figure below illustrates the erosion corrosion process for varying samples of material composition.

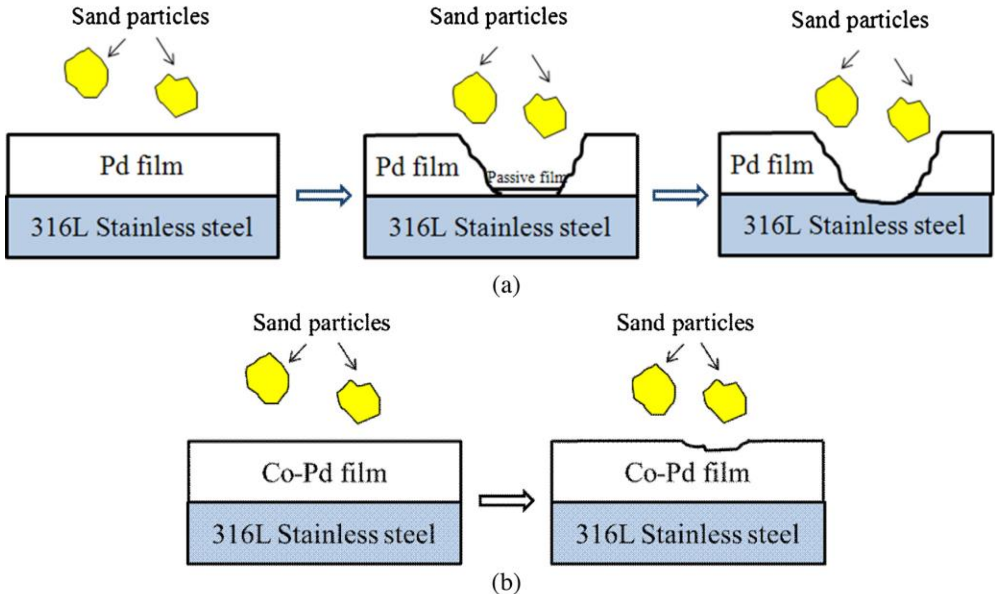

Figure 4.Depiction of the erosion corrosion processes, (a) Palladium plated Stainless Steel sample, (b) Chromium-Palladium plated Stainless Steel sample (Li et al 2015:208).

The interactive actions of wear and corrosion is fundamental in material engineering applications as the dynamics of the synergistic influence of corrosion and wear simultaneously acting together on a metal surface raises significant physical assets reliability issues in different operational conditions, the studies around combustion engine components like pistons, piston rings and engine bore, and marine structures have yielded findings that in many instances, the joint actions of mechanical and electro-chemical mechanisms, the material-loss pertaining to erosion-corrosion regularly exceeded the summation of the isolated corrosion and wear-loss (Lee et al 2012:503).

Likewise, the hypoeutectic aluminum based alloys are expansively used for aerospace and automotive industries because of their weightlessness, superb abrasion and corrosion resistance, coupled with great mechanical-strength and excellent casting properties, of which these exceptional features are derivative of the chemical formulation and constituent metal elements, the alloy microstructural features and metallurgical processes applied to improve performance like heat treatment or hardening (Lee et al 2012:503). One alloy Ale7Sie0.3Mg (A356) comprises of primary a-Al, eutectic Si and Fe-bearing intermetallic segments, and past investigations revealed that the introduction of a chemical modifier such as sodium (Na), strondium (Sr) and antimony (Sb) altered the morphology of eutectic Si element and thereby extended the wear-resistance of A356 (Lee et al 2012:503).

This momentous drive of developing new materials to address reliability engineering problems is highly plausible and relevant to reliability amelioration of physical assets operational in punishing environments, and the resultant scenario is incorporation of higher equipment quality, extension of equipment service life, and minimal maintenance costs (Zumelzu et al 2002:250). In parallel to new materials development, the advances of novel methods and thermal-treatment of cast iron and alloys enable the newly developed materials to have improved mechanical features and better corrosion-resistance when subjected to severe or aggressive operational circumstances (Zumelzu et al, 2002:250). When evaluating newly developed alloy materials that are formulated to function in destructive media, it is imperative to understand the conversions endured during thermal-treatments and their effect on the projected mechanical and corrosion attributes (Zumelzu et al 2002:250).

3. Fitting physical assets to operational environment to enhance reliability

Selecting the appropriate or fitting materials for the operational atmosphere e.g. highly corrosive, excessive temperatures, is a precursor to high equipment reliability. The reliability of a physical asset is broadly influenced by the operating environment, for instance, a pump may perform reliably in a slurry situation but not in a corrosive atmosphere coupled with high temperatures above 70 degrees Celsius. Corrosion is considered as the dominant cause of failures of physical assets within the oil and gas or chemical industries, and this calls for the allocation of fitting materials-of-construction to physical assets to function reliably within the harsh operational environments (Bahadori 2014:9). Constructional materials are commonly designated based on properties that demonstrate reduced corrosion at a predictable rate and a provision is allowed for this in specifying the material thickness and size (Bahadori 2014:9). Numerous corrosive agents are present within the petro-chemical facilities and these incorporate organic-acids, physical-acids such as sulfuric acid, hydrogen, sodium hydroxide and ammonia (Bahadori 2014:11). Materials-of-construction allocation should have a basis based on engineering principles or findings and consideration should be given to the following: white chrome cast-irons are presently being used in diverse application areas, and most prominently in mechanical components subjected to austere wearing, and additionally, they are applied in environments where high corrosion-resistance is obligatory (Zumelzu et al 2002:250).

Further considerations to be taken when selecting appropriate constructional materials encompass the following: Carbon-steels and low alloy-steels have a penchant of getting brittle when subjected to alkali or caustic environments and there is a possible conversion of carbide materials to graphite material when subjected for long periods to temperatures above 427 °C of carbon and carbon/silicon steels. The probability of stress-corrosion cracking of austenitic stainless-steel exposed to solutions such as chlorides and additional halides, and their susceptibility to particulate corrosion after exposure to temperatures ranging from 427 °C to 871 °C. The possibility of aluminum-alloys rusting from concrete/plaster, or other high alkali materials used in civil structures. The prospect of deterioration of titanium and the derivative alloys when subjected to temperatures exceeding 316 °C and the possibility of tantalum reacting with any other gases exclusive of inert-gases (Bahadori, 2014:12).

Harsh operating situations apart from those associated with the environment such as undue thrust loads, extreme misalignment, high humidity, high concentration of chemical vapors dust, extreme heat or highly vibratory exposure must be evaded as this can shorten the physical asset’s service life Kamani, (2014:4), Knotek, (2016:78)). Preventing undue mechanical stressing and/or areas of extreme stress concentration in physical assets exposed to corrosive vicinities is one fundamental facet of safeguarding physical assets reliability in their operational locations (Bahadori, 2014:12).

4. Case Study – Flexible rubber coupling exposed to high heat environment.

A construction products manufacturing firm in Johannesburg was experiencing frequent rubber coupling failures for an agitator drive assembly for one of their calcining process equipment. The rubber coupling designation was a F80 type rubber coupling. The general arrangement of the coupling and the gearbox is as depicted below.

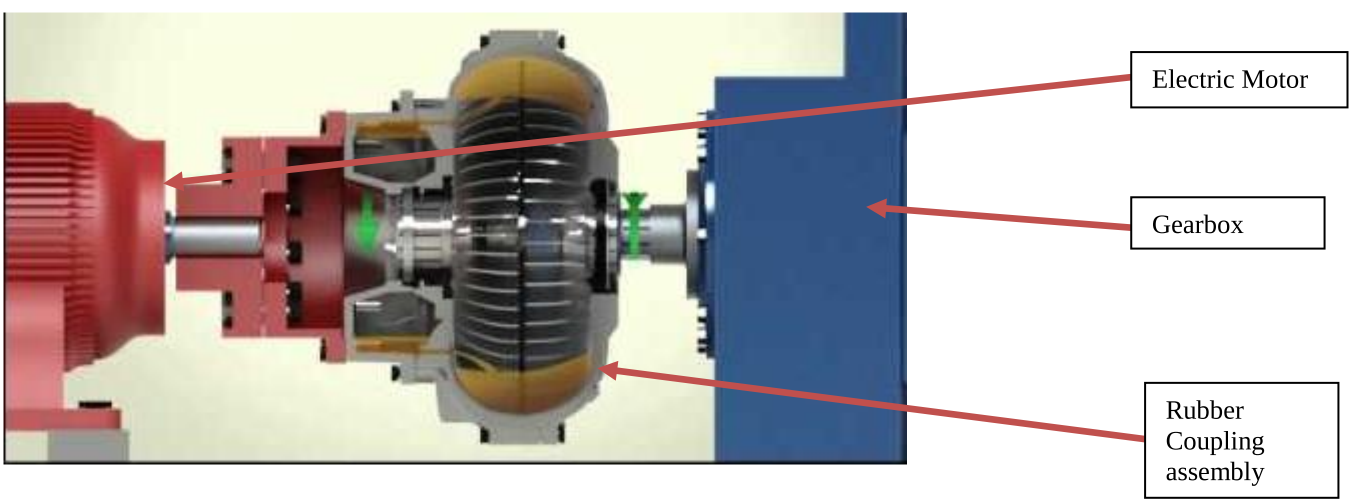

Figure 5: Coupling Arrangement between gearbox and motor (Muganyi 2017)

The rubber coupling constructional features are as shown in Figure 6 below which illustrates the designation cross-sectional assembly of the rubber coupling.

(a) (b)

Figure 6. F80 Rubber Coupling designation (a) and cross-sectional assembly (b) as extracted from supplier's manual (Muganyi 2017)

The criterion that was used for selecting the type of coupling initially considered the type of application, torque-rating, misalignment-capability, costs, the RPM and space limitation, but this excluded environmental factors. Each criterion was singularly assessed to ascertain the coupling's suitability for the purposed application.
The drive system of the calcining equipment carried the following specifications:

The Electric motor power = 15kw
Electric motor rated speed = 1470/89 rpm
The electric motor rated toque = 1610 Nm
The calculated motor torque was derived from the Power formula below.

Power = torque x angular speed (1)

$P = W / dt. = T\,\theta / dt. = T\,\omega. = 2\,\pi\,n\,T. = 2\,\pi\,(n\,\mathbf{rpm} / 60)\,T.$ (2)

Where P = Power, W is the work done, T= Torque, ω=angular speed and n = revolutions per minute.

The Table below shows the power rating for the selected coupling.

Table 1: Speed and power rating selection of rubber coupling (Muganyi 2017)

POWER RATINGS (KW)

Speed rev/min	Couplings Size														
	F40	F50	F60	F70	F80	F90	F100	F110	F120	F140	F160	F180	F200	F220	F250
100	0.25	0.69	1.33	2.62	3.93	5.24	7.07	9.16	13.9	24.3	39.5	65.7	97.6	121.0	154.0
200	0.50	1.38	2.66	5.24	7.85	10.50	14.10	18.30	27.9	48.7	79.0	131.0	195.0	243.0	307.0
300	0.75	2.07	3.99	7.85	11.80	15.70	21.20	27.50	41.8	73.0	118.0	197.0	293.0	364.0	461.0
400	1.01	2.76	5.32	10.50	15.70	20.90	28.30	36.60	55.7	97.4	158.0	263.0	391.0	486.0	615.0
500	1.26	3.46	6.65	13.10	19.60	26.20	35.30	45.80	69.6	122.0	197.0	328.0	488.0	607.0	768.0
600	1.51	4.15	7.98	15.70	23.60	31.40	42.40	55.00	83.6	146.0	237.0	394.0	586.0	729.0	922.0
700	1.76	4.84	9.31	18.30	27.50	36.60	49.50	64.10	97.5	170.0	276.0	460.0	684.0	850.0	1076.0
720	**1.81**	**4.98**	**9.57**	**18.80**	**28.30**	**37.70**	**50.90**	**66.00**	**100.0**	**175.0**	**284.0**	**473.0**	**703.0**	**875.0**	**1106.0**
800	2.01	5.53	10.60	20.90	31.40	41.90	56.50	73.30	111.0	195.0	316.0	525.0	781.0	972.0	1229.0
900	2.26	6.22	12.00	23.60	35.30	47.10	63.60	82.50	125.0	219.0	355.0	591.0	879.0	1093.0	1383.0
960	**2.41**	**6.63**	**12.80**	**25.10**	**37.70**	**50.30**	**67.90**	**88.00**	**134.0**	**234.0**	**379.0**	**630.0**	**937.0**	**1166.0**	**1475.0**
1000	2.51	6.91	13.30	26.20	39.30	52.40	70.70	91.60	139.0	243.0	395.0	657.0	976.0	1215.0	1537.0
1200	3.02	8.29	16.00	31.40	47.10	62.80	84.80	110.00	167.0	292.0	474.0	788.0	1172.0		
1400	3.52	9.68	18.60	36.60	55.00	73.30	99.00	128.00	195.0	341.0	553.0	919.0			
1440	**3.62**	**9.95**	**19.10**	**37.70**	[illegible]	**75.40**	**102.00**	**132.00**	**201.0**	**351.0**	**568.0**	**945.0**			
1600	4.02	11.10	21.30	41.90	62.80	83.80	113.00	147.00	223.0	390.0	632.0				
1800	4.52	12.40	23.90	47.10	[illegible]	94.20	127.00	165.00	251.0	438.0					
2000	5.03	13.80	26.60	52.40	78.50	105.50	141.00	183.00	279.0						
2200	5.53	15.20	29.30	57.60	86.40	115.00	155.00	202.00							
2400	6.03	16.60	31.90	62.80	94.20	126.00	170.00								
2600	6.53	18.00	34.60	68.10	102.00	136.00	184.00								
2800	7.04	19.40	37.20	73.30	110.00	147.00									
2880	**7.24**	**19.90**	**38.30**	**75.40**	**113.00**	**151.00**									
3000	7.54	20.70	39.90	78.50	118.00	157.00									
3600	9.05	24.90	47.90	94.20											

The figures in heavier type are for standard motor speeds. All these power ratings are calculated at constant torque. **For speeds below 100 rev/min and intermediate speeds use nominal torque ratings.**

Selected coupling size.

PHYSICAL CHARACTERISTICS – FLEXIBLE TYRES

Therefore, the torque transmitted from the electric motor to the gearbox is given by:

$T = P \times 60/(2\pi N)$
$T = 15\,000 \times 60/(2\pi \times 1470)$
$\mathbf{T = 97.44\ Nm.}$

The torque transmitted from the gearbox is calculated as:

For a gearbox with a speed that is as follows: Input speed = 1470 rpm and output speed = 60 rpm. Therefore the output torque is given by:

$$T_o = T_i \times n_i/n_o \quad (3)$$

Where T_o = output torque, n_o = output speed (rpm), n_i = input speed (rpm).
Therefore the output torque for the gearbox was calculated as:

$T_o = 97.44 \times 1470/60$
$\mathbf{T_o = 2387.28\ Nm}$

Table 2 below shows the torque rating of the F80 coupling.

Table 2. F80 Coupling torque rating (Muganyi 2017)

PHYSICAL CHARACTERISTICS – FLEXIBLE TYRES

Characteristics	Coupling Size														
	F40	F50	F60	F70	F80	F90	F100	F110	F120	F140	F160	F180	F200	F220	F250
Maximum speed rev/min	4,500	4,500	4,000	3,600	3,100	3,000	2,600	2,300	2,050	1,800	1,600	1,500	1,300	1,100	1,000
Nominal Torque Nm T_{KN}	**24**	**66**	**127**	**250**	**375**	**500**	**675**	**875**	**1,330**	**2,325**	**3,770**	**6,270**	**9,325**	**11,600**	**14,675**
Maximum Torque Nm $T_{K\,MAX}$	64	160	318	487	759	1,096	1,517	2,137	3,547	5,642	9,339	16,455	23,508	33,125	42,740
Torsional Stiffness Nm/°	5	13	26	41	63	91	126	178	296	470	778	1,371	1,959	2,760	3,562
Max. parallel misalignment mm	1.1	1.3	1.6	1.9	2.1	2.4	2.6	2.9	3.2	3.7	4.2	4.8	5.3	5.8	6.6
Maximum end float mm ±	1.3	1.7	2.0	2.3	2.6	3.0	3.3	3.7	4.0	4.6	5.3	6.0	6.6	7.3	8.2
Approximate mass. kg	0.1	0.3	0.5	0.7	1.0	1.1	1.1	1.4	2.3	2.6	3.4	7.7	8.0	10.0	15.0
Alternating Torque ± Nm @ 10Hz T_{KW}	11	26	53	81	127	183	252	356	591	940	1,556	2,742	3,918	5,521	7,124
Resonance Factor V_R	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Damping Coefficient Ψ	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Maximum torque figures should be regarded as short duration overload ratings for use in such circumstances as direct-on-line motor starting.
All Fenaflex tyre couplings have an angular misalignment capacity up to 4°.

The angular misalignment was confirmed using laser technology to be below 2 degrees and this was within the prescribed range for the coupling. The MTBF of the rubber coupling was established to be three and as half weeks, after an analysis of the failures on the coupling was carried out over a period of twelve months. The coupling's prevalent failure mode was as depicted in the figure below, where stress like cracks developed on the rubber coupling body due to heat exposure. A detailed root cause analysis revealed that heat stress was the major cause of coupling failures.

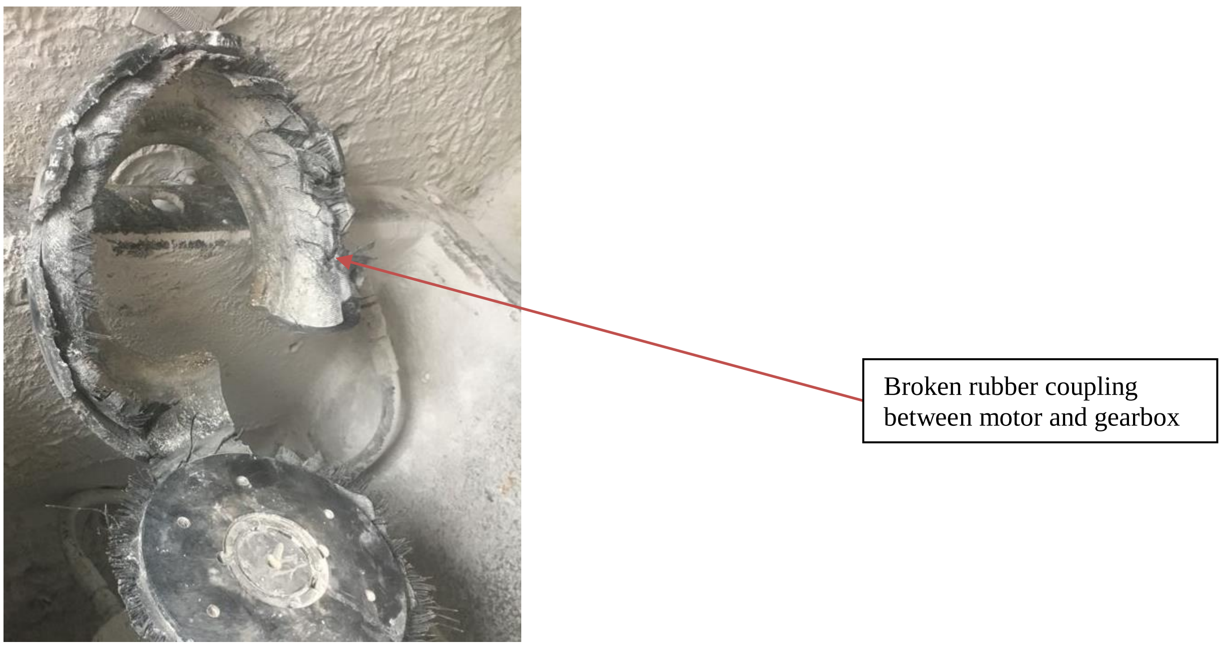

Figure 7. Failed Rubber coupling connected between electric motor and gearbox (Muganyi 2017)

The ambient environment temperature was measured using a temperature gun and was found to be in excess of 70°C and an infrared thermography camera was used to determine the temperature on the rubber coupling itself and it was exceeding 74°C. Table 3 below shows an extract of the rubber coupling characteristics relative to temperature within the environment.

Table 3. Temperature operational ranges and installation specifications (Muganyi 2017)

Maximum torque figures should be regarded as short duration overload ratings for use in such circumstances as direct-on-line motor starting.
All Fenaflex tyre couplings have an angular misalignment capacity up to 4º.

FLEXIBLE TYRE CODE NUMBERS

Unless otherwise specified Fenaflex flexible tyres will be supplied in a natural rubber compound which is suitable for operation in temperatures –50ºC to +50ºC. A chloroprene compound is available which is Fire Resistant and Anti-Static (FRAS) and has greater resistance to heat and oil.

This is suitable for operation in temperatures –15ºC to +70ºC. For temperatures outside these ranges – consult your local Authorised Distributor.

The FRAS tyre variant is used with specifically modified metal flanges to create the Ex ATEX approved variant.

Size	Natural	FRAS
F40	033A0048	033A0068
F50	033B0048	033B0068
F60	033C0048	033C0068
F70	033D0048	033D0068
F80	033E0048	033E0068
F90	033F0048	033F0068
F100	033G0048	033G0068
F110	033H0048	033H0068
F120	033J0048	033J0068
F140	033K0048	033K0068
F160	033L0048	033L0068
F180	033Q0048	033Q0068
F200	033M0048	033M0068
F220	033N0048	033N0068
F250	033P0048	033P0068

Coupling Size	M Dimension (mm)	Gap Between Tyre Ends (mm)	Clamping Screw Torque (Nm)	Screw Size
F40*	22	2	15	M6
F50*	25	2	15	M6
F60*	33	2	15	M6
F70	23	3	24	M8
F80	25	3	24	M8
F90	27	3	40	M10
F100	27	3	40	M10
F110	25	3	40	M10
F120	29	3	50	M12
F140	32	5	55	M12
F160	30	5	80	M16
F180	46	6	105	M16
F200	45	6	120	M16
F220	55	6	165	M20
F250	59	6	165	M20

*Hexagonal socket caphead clamping screws on these sizes.

According to Table 3 above, natural rubber couplings are suitable for environmental temperatures ranging from -50◦C to +50◦C unless if the rubber is impregnated with a chloroprene compound which allows it to operate within a range of -15◦C to +70◦C. This environment was definitely not suitable for the F80 coupling, although all the other technical specifications were being met when the coupling was installed.

5. Discussion of results

The coupling had a power rating of 62.80 Kw compared to 15 Kw, and this showed that the power rating was well within specification for the selected F80 coupling. In terms of the torque rating, the calculated torque transmitted through the coupling was found to be 97.44 Nm compared to the nominal torque of 375 Nm for the F80 rubber coupling as per Table 2 above. The sizing of the coupling was correct in terms of both power and torque rating. The coupling was running at a speed of 1470 rpm in the field and Table 2 showed that the F80 coupling was rated for a maximum speed of 3 100 rpm, which is more than the actual speed, therefore the speed rating was within the designed operational specifications of the coupling.

The installed coupling was not grossly misaligned as the laser alignment results showed that the angular misalignment was within 2 degrees. The other pertinent F80 coupling specifications like stiffness, inertia and shaft mounting were all found to be within the design specifications of the coupling, and so it was left to the environmental factors to ascertain their suitability for the rubber coupling.

The ambient temperature was found to be above 70◦C which significantly pointed out that the coupling was being used in an environment with temperatures that were not suitable for its design parameters whereby a high performing variant of a rubber coupling could only reliably operate within temperatures not exceeding 70◦C. This scenario compelled the manufacturing firm to design out the rubber coupling failure problem by replacing the rubber coupling with a geared motor unit that completely eradicated the need for a coupling between the motor and the gearbox. This assembly withstood the ambient temperatures of above 70◦C and has proven to have a MTBF of over 12 months, thus greatly improving the reliability of the calcine equipment agitator system. Figure 8 below shows the geared motor assembly which was sized according to the original electric motor and gearbox drive assembly.

Figure 8. Geared motor assembly that replaced rubber coupling between motor and gearbox (Muganyi 2017)

The criteria applied for selecting the physical assets should always consider the type of application, technical factors like torque or misalignment and stiffness, service factors, costs, and most importantly, environmental factors. Each criterion must be individually assessed to ensure that the physical asset is suitable for the application and does not result in premature failures, and this process of evaluation must be repeated for any change in conditions throughout the application's lifecycle.

Any system's maintenance necessities and tasks are commonly a function of the particular application, duty cycles, operating parameters, environment and other factors. Any maintenance or service plan for the system as a whole is envisioned to evade equipment failures wherever within the system, and it is affected if other system parts' functional features force them to operate external to the design specifications. Thus a maintenance system need to ascertain among other aspects that environmental conditions are always met by the physical asset and that all system components fall within the environmental design constraints in order to uphold the asset reliability. In the event of an asset's functional failure, it is imperative to determine and document the conditions within the system in which the failure occurred and this allows for appropriate corrective action, including specification of a different physical asset to address any changes in the application.

6. Conclusion

All physical assets ought to match their intended purpose and application parameters, including several diverse performance, environmental, application and service factors. All must be met for the physical asset to operate reliably and properly. When selected with these design parameters in consideration , and when installed and operated correctly, a physical asset should have no reliability issues over its lifetime, but when one of the factors like environmental factors are not met, then the asset can prematurely fail, resulting in reduced asset reliability and high maintenance /operational costs incurred by the firm. The two primary environmental issues that cause physical assets failures are temperature-related (above or below the rated temperature of the asset), or chemical-related (where the asset is not compatible with a chemical present within or around it). Over temperature conditions can manifest as heat stress cracks on the material, whilst chemical attacks generally make the asset swiftly deteriorate and fail, sometimes breaking-off in pieces. Therefore compatibility of assets with environmental factors is a crucial aspect when it comes to ensuring reliability.

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