# DEVELOPMENT OF WATER-TOUGH (WTF®) BEARINGS FOR STELL MILLS LONGER LIFE IN HARSH ENVIRONMENTS [1]

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**Abstract**

NSK contributes to energy saving through bearing life extension. This report introduces that NSK has developed Water Tough Bearing (WTF® bearing), which has longer life than conventional bearings under water-infiltrated lubrication such as in steel mill. To understand the mechanism of water-induced flaking and thereby enable countermeasures to be devised, the analyses of past experiments, including bearings that actually failed in services were carried out. In addition, fatigue life test methods that reproduce short life under water-infiltrated lubrication were developed. Using these methods it was possible to observe the flaking process precisely and to study what material parameters affect the bearing life. It was found that failure water-infiltrated lubrication initiated from non-metallic inclusions on the rolling contact surface. The fatigue crack propagation was initially intergranular and then changed to transgranular, eventually resulting in flaking. Higher cleanliness, which means less failure initiation sites, and nickel, which strengthens the grain boundaries, were found to improve bearing life under water-infiltrated lubrication. Water Tough Bearing material has such the higher cleanliness and stronger grain boundaries.


**Key words:** Bearing; Steel mills.

## DESENVOLVIMENTO DE ROLAMENTOS PARA LAMINAÇÃO DE PRODUTOS SIDERÚRGICOS - NSK ROLAMENTOS WATER TOUGH - WTF


**Resumo**

Este relatório apresenta o desenvolvimento NSK de rolamentos para cilindros de laminação, que possuem melhor performance quando submetidos a infiltração de água. Para entender o mecanismo de falha prematura induzida pela infiltração de umidade no interior do rolamento e permitir planos de controle, foram realizadas análises de experimentos do passados e análises de rolamentos que falharam em serviço. Foram desenvolvidos métodos de teste que reproduzem a falha prematura relacionada a contaminação do lubrificante do rolamento. Utilizando estes métodos foi possível observar precisamente o processo de fadiga prematura e estudar quais os parâmetros afetam os materiais que compõem os rolamentos. A propagação das microtrincas inicialmente eram intergranular e posteriormente passavam a ser transgranular, ocasionando eventualmente o lascamento de componentes e a falha prematura. O desenvolvimento e utilização de materias com teor de pureza mais elevado foram fundamentais para reforçar os contornos dos grãos e torná-los mais resistentes a contaminação por água.


**Palavras-chave**: NSK; Rolamento; Materiais; Performance.

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## 1 INTRODUCTION

Operation conditions of roll neck bearings at steel mills include water-infiltrated lubrication and ingress of foreign particles, such as scale, which can cause flaking of rolling contact surfaces of the bearings. Such as operating environment is no doubt very harsh. NSK bearings are designed for use in such harsh environments with tight seals on both sides[(1)] to prevent grease outflow and to prevent ingress of water and foreign particles. Today's needs of steel mills, however, demand greater sealing performance.
Failed bearings are sent as scrap to a melting furnace to be reused as raw material for steel products. This recycling system is so well established that our bearings have long been contributing to an appreciable level of energy savings. For greater energy savings, however, it is important to lengthen the bearing recycling intervals by extending bearing service life that has been terminated by flaking. In light of this, NSK has developed a water-tough (WTF®) bearing material that achieves longer bearing life for roll necks used at steel mills, as reported in the following sections.

## 2 PRIMARY OBJECTIVES OF DEVELOPMENT

We developed the (WTF®) bearing with the primary objectives of:
(1) Determining what the flaking mechanism is for bearings under water-infiltrated lubrication;
(2) Establishing fundamental improvements based on such findings; and
(3) Extending the actual service life of bearings in the field by at least twofold.
To meet our objectives, we thoroughly examined bearings that had failed in the field. We then built a testing machine capable of simulating bearing flaking under water-infiltrated lubrication in the field, analyzed the flaking process in detail, and identified the fatigue life-relevant elements. We then tested our newly developed (WTF®) bearings in the laboratory and in the field. Results of our analysis, which validate the effectiveness of this product, are discussed here.

## 3 FLAKING MECHANISM UNDER WATER INFILTRATED LUBRICATION

If bearing lubricants, such as oil or grease, could remain free of contamination, fatigue life would be 20 to 100 times as long as its theoretical life,[(2)] and would have no problems related to fatigue life. According to fatigue life theory,[(3)] flaking originates from nonmetallic inclusions (a material defect) slightly below the rolling contact surface of the bearing material. Such a flaking mechanism was experimentally proven to be correct by the authors.[(4)] Figure 1 shows schematically the mechanism of flaking under uncontaminated lubrication, and Figure 2 shows a nonmetallic inclusion from which flaking actually originated, which was an alumina type inclusion located in the center of the spalling area.

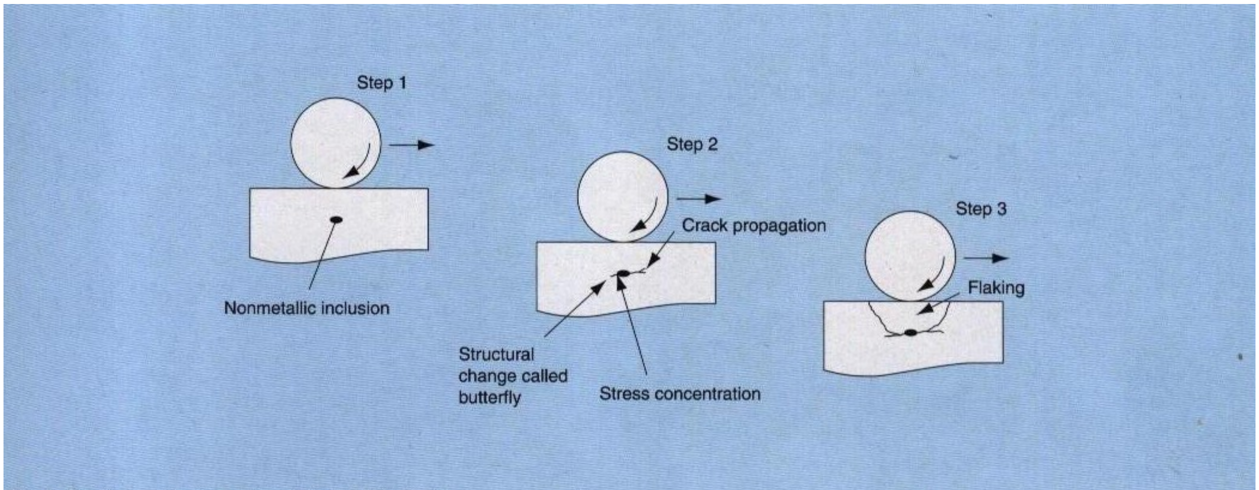


Fig. 1 Flaking mechanism under clean lubrication

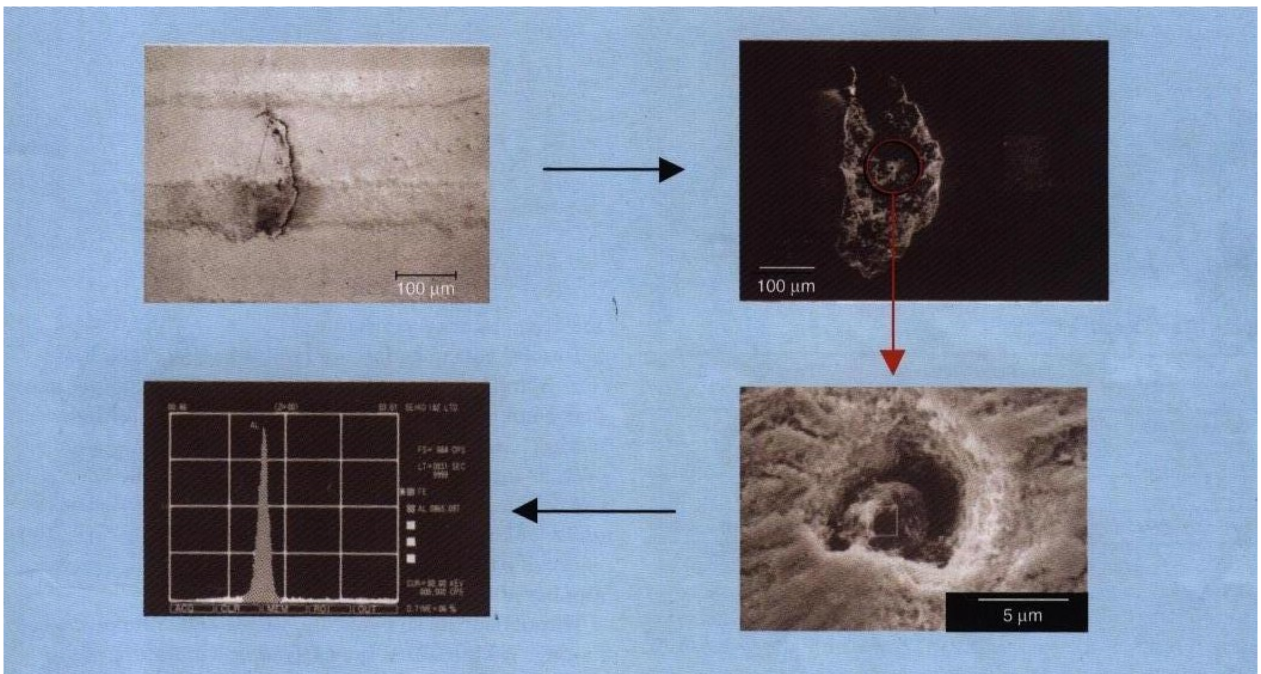


Fig. 2 Origin of flaking due to a nonmetallic inclusion

Our tests[5] verify that under water-only lubricated conditions, flaking does not occur, but rather abrasion takes place. What would the failure morphology be if water were added to oil or grease lubricant? Figure 3 shows an outer ring of a roll neck bearing that experienced failure in the field. The failure type is flaking. The flaking location of roll neck bearings in steel mills is often at a load zone of outer rings.

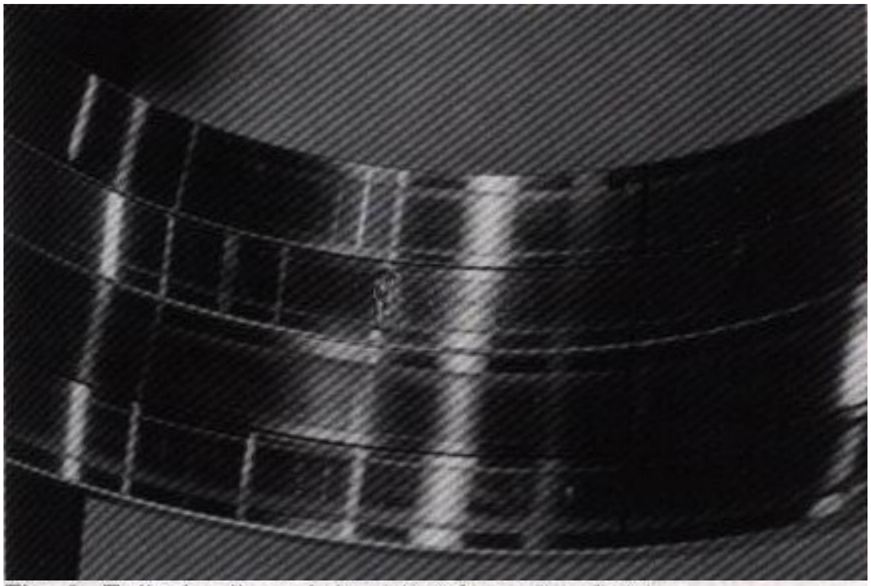

Fig. 3 Failed roll neck bearing from the field

What is the initiation of flaking under water-infiltrated lubrication? We observed early-stage flaking of the outer rings of roll neck bearings that failed in the field (Figure 4). This flaking has a small pit in the raceway surface, with a crack running inwards. Thus flaking originated in the raceway surface. As mentioned earlier, under ideal lubrication, flaking originates from nonmetallic inclusions located slightly below the raceway surface. Then, under water-infiltrated lubrication, from what in the raceway surface does flaking originate?

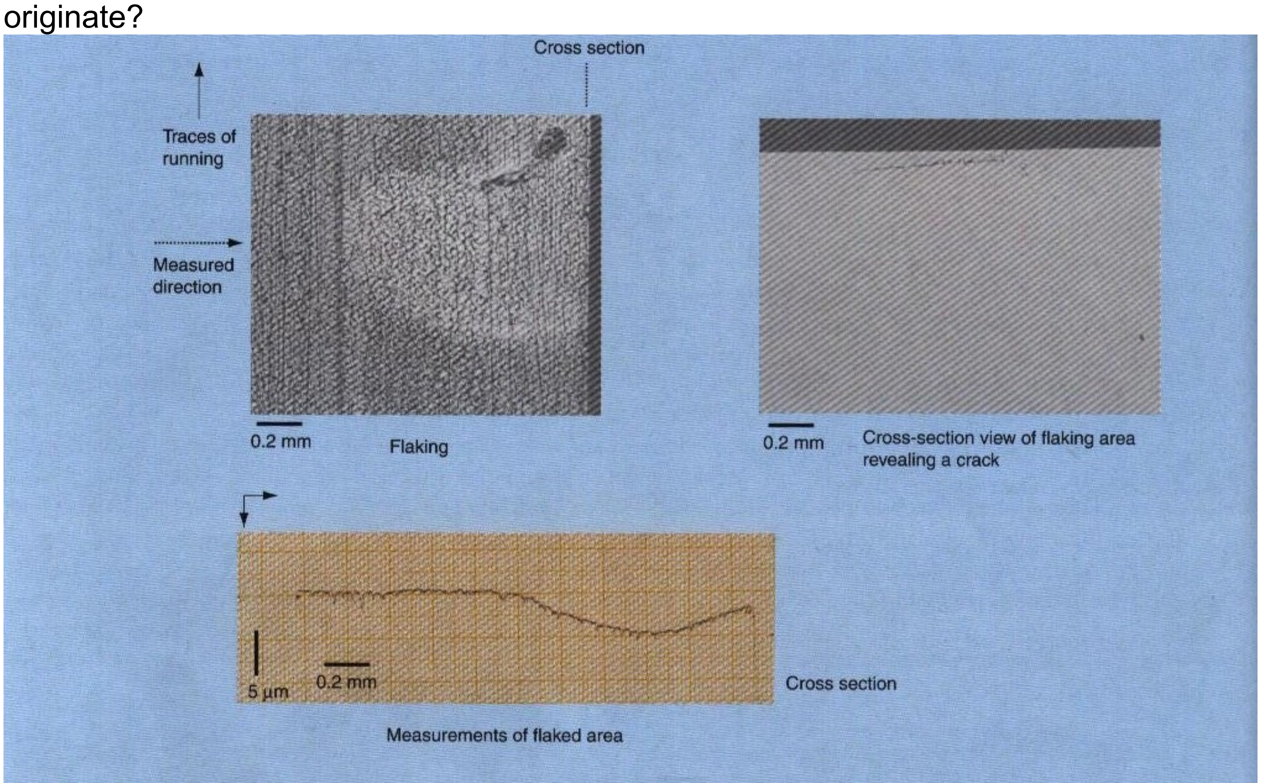


Fig. 4 Water-induced flaking in early stage in service

To solve this question, we built a testing apparatus (Figure 5) in the laboratory that was capable of simulating field conditions (Table 1) and reproducing water-induced flaking. Grease-lubricated tapered roller bearings were used as test bearings. Roll neck bearings were used as test bearings. Roll neck bearings for work rolls in the field usually such bearings. In addition, ball bearings under oil and water-infiltrated lubrication were also tested to provide a minute observation of flaking and a greater number of test results.

Table 1 Test Conditions

| Test bearings | Tapered roller bearing ($\phi$85 × $\phi$130 × 30 mm) | Thrust ball bearing ($\phi$25 × $\phi$52 × 18 mm) |
|---|---|---|
| Water infiltration rate | 20 mℓ/7h | 30 mℓ/24h |
| Lubricant | Lithium soap grease (60g) | VG10 oil (70 mℓ) |
| P/C | 0.25 | 0.35 |
| Running speed | 1500 $min^{-1}$ | 1250 $min^{-1}$ |

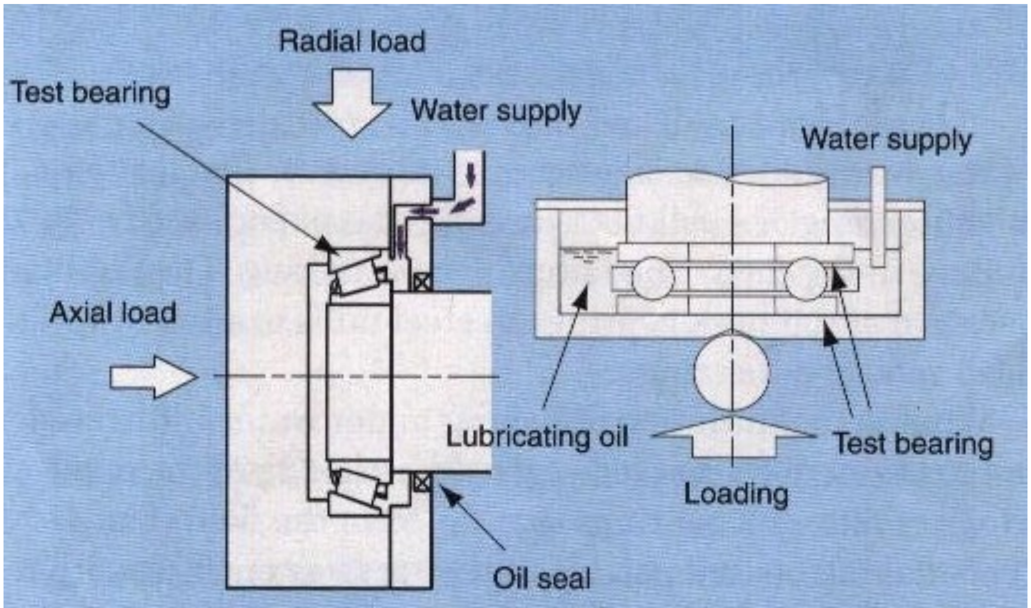


Fig. 5 Testing machine arrangements for reproducing flaking under water-infiltrated lubrication (Roller bearing / Ball bearing)

Throughout these two tests, we observed the process of flaking. We identified the early stages of flaking of the tapered roller bearings under grease and water-infiltrated lubrication (Figure 6). Cracks nucleated from the pits and the propagated deeper into the subsurface area. Both field roll neck bearings and experimental room test results show that flaking mostly occurs in the load zones of the outer rings. To analyze how the pits in the raceway surface are made, we conducted a study using bearings whose rings were made of martensitic stainless steel and super-clean steel to see if pits in the raceway surface were caused by corrosion or by nonmetallic inclusions on the surface.

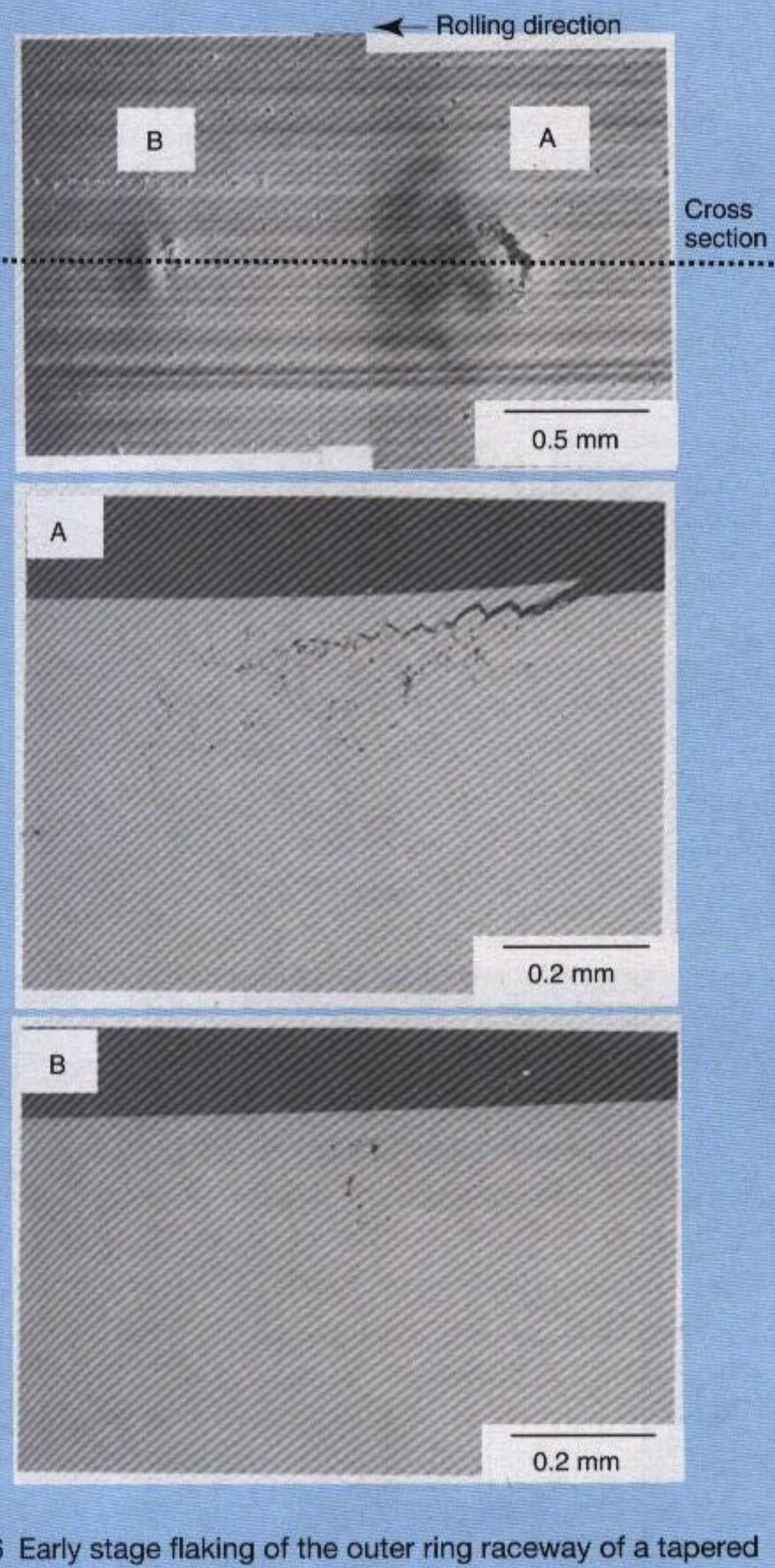


Fig. 6 Early stage flaking of the outer ring raceway of a tapered roller bearing under water-infiltrated grease lubrication

Figure 7 shows the fatigue life test results of bearings. One bearing consisted of martensite stainless steel rings; the other bearing consisted of standard 52100 steel rings; The fatigue life of highly corrosion-resistant martensitic stainless steel showed no improvements over that of standard bearing steel AISI52100. This means that the pits in the raceway surface are not caused by corrosion.

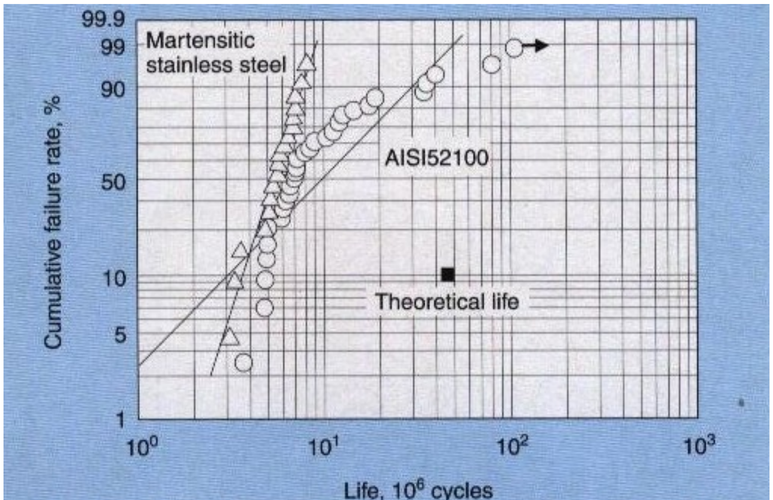


Fig. 7 Influence of corrosion resistance upon fatigue life under water-infiltrated lubrication

Figure 8 shows the fatigue life results of bearings. One bearing consisted of super-clean steel rings; the other bearing consisted of standard 52100 steel rings. Fatigue life of the super-clean steel was three times longer than that of the standard 52100 bearing steel. This would suggest that spalling of nonmetallic oxide inclusions caused the formation of pits in the raceway surface.

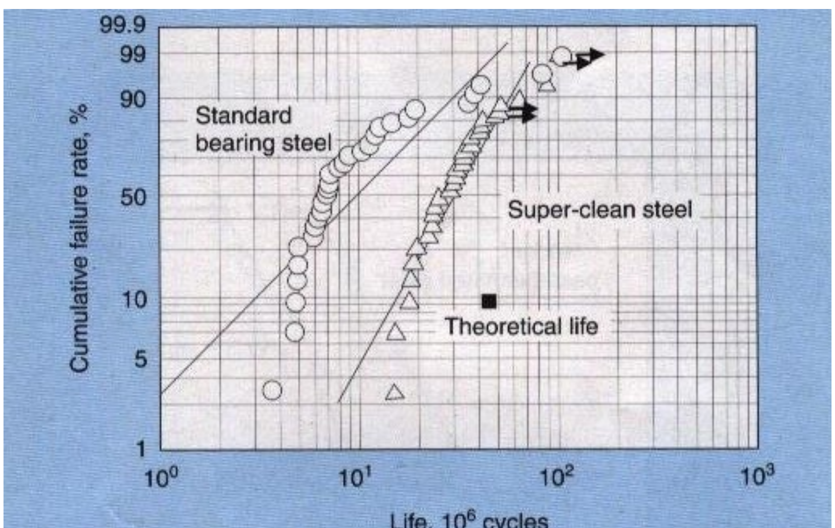


Fig. 8 Influence of steel cleanliness upon fatigue life under water infiltrated lubrication

The mechanism of flaking of bearings under water-infiltrated lubrication is illustrated in Figure 9. Under water-infiltrated lubrication, oil film formation between the rolling elements and the rings was insufficient, which eventually resulted in wear of the rolling contact surfaces. For roll neck bearings, the load zone of the outer ring is the most severe because the number of stress cycles and wear depth is the maximum of the bearing. This means that the flaking occurs in this region. As the wear of the raceway surface develops, oxide inclusions become protrusive and become points of stress concentration. High contact stresses eventually cause cracks. If no water is present in the lubricant, such early cracking will not take place because of the high fatigue strength of steel.

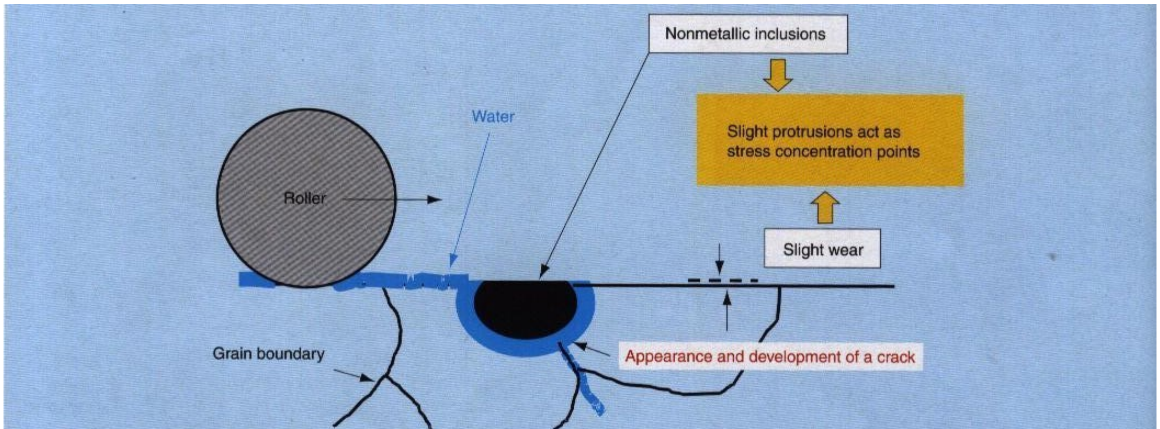

Fig. 9 Water-induced flaking

However, if water is present in the lubricant, the fatigue strength of steel is reduced, giving rise to this phenomenon. This is similar to the significant reduction in fatigue limit(6) seen in rotating bending fatigue tests conducted in water and steam environments. The oxide inclusions that have acted as stress concentration points will flake off in the course of time, while water will infiltrate into the cracks. Cracking will develop faster in the presence of water than when no water is present, eventually causing failure. Cracking takes place at the matrix in contact with nonmetallic inclusions. Microscopic observations reveal the first propagation of cracking is along grain boundaries where the material strength is low in the present of water.(7)

## 4 FEATURES OF WTF® BEARINGS

WTF® bearings are made of super-clean steel. The surface retained austenite content is controlled to an optimum level, which improves fatigue life under debris-contaminated lubrication. The stronger grain boundary is achieved by optimum alloy balance.

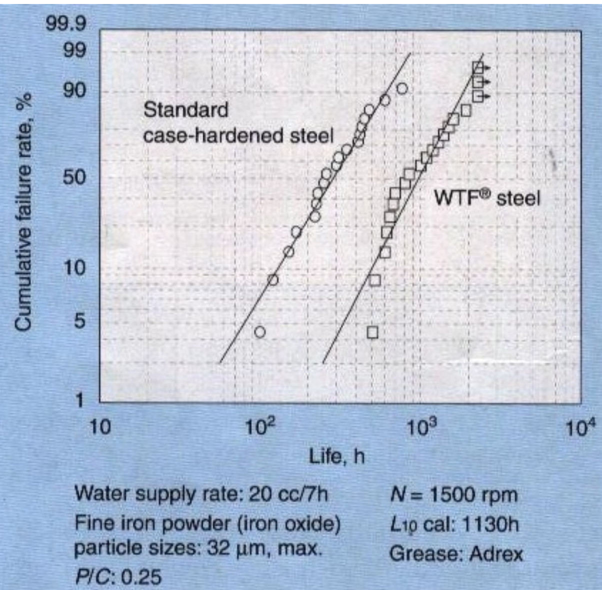


Fig. 10 Longer life of WTF® tapered roller bearing under grease lubrication contaminated with water and dust simulating actual service condition

Figure 10 shows the fatigue life results of the WTF® bearing operating under water-infiltrated grease lubrication and powder debris (iron oxide) contamination simulating actual operating conditions. Figure 11 shows the test results from an actual cold strip mill. In both of these tests, the WFT® bearings showed a life approximately three times longer than bearings made of conventional case-hardened steel.

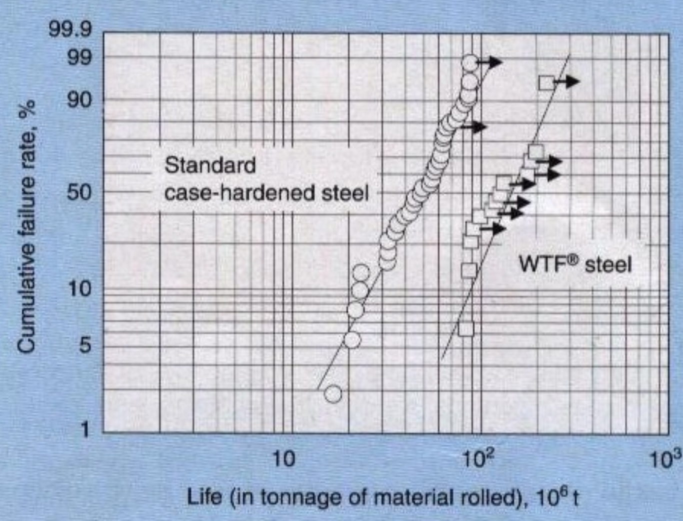


Fig. 11 Longer life of WTF® roll neck bearing used in cold strip mills

## 5 CONCLUSION

We have reported that WTF® bearings have achieved a life approximately three times longer than conventional bearings, as simulated tests in our laboratory and actual field applications demonstrate. Therefore, we believe that the use of this bearing in a harsh environment can contribute to further energy savings.

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