

## Corrosion-wear of NST 60-Mn steel in Cocoa Mucilage

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**Abstract:** This paper presents the report of an investigation on the effect of different microstructures of NST-60 Mn steel on its corrosion wear resistance in cocoa mucilage. The corrosion wear resistance was investigated under an instrumented pin-on-disc wear test rig. The microstructure of the steel was varied by heat treatment procedures such as water-quenching, austempering, martempering and water-quenching plus tempering at 250°C. A variation of the pH, time of exposure and applied load on the corrosion wear resistance of the heat treated samples were evaluated. The results obtained showed that hardness is inversely proportional to the rate of wear of the NST-60 Mn steel. Also, the microstructure of the water-quenched sample exhibited the greatest wear resistance in air, cocoa mucilage of pH3.9 and pH4.2 while the as-received NST 60 Mn steel showed the poorest corrosion wear resistance in the same media.

**Key words:** Steel, corrosion, wear, heat treatment, cocoa mucilage

### INTRODUCTION

NST-60 Mn steel is one of the high strength steel produced in Nigeria. Like many steels, its microstructure and mechanical properties depend on heat treatment. Zum-Gahr<sup>[1]</sup> reported greater abrasive resistance for lower bainite matrix, when compared to tempered martensitic matrix with the same hardness, under a pin-on-disc test. The high volume fraction of high carbon retained austenite characteristic of the bainitic structure of these materials is used to explain this behaviour. Martensitic matrices are also known to present good wear resistance and high ultimate tensile stress with low toughness depending on the tempering temperature<sup>[2]</sup>.

Corrosion is the chemical or electrochemical phenomenon that destroys the above properties of steels in service when exposed to aggressive species. Wear unlike corrosion destroys metal through removal of their surfaces mechanically. Corrosion-wear is an accelerated means of destroying metals by the combined influence of chemical/electrochemical mechanism of corrosion and the mechanical effect of wear. In the presence of each other, the effects of corrosion and wear are usually greater than pure corrosion and wear as a result of mutual increasing effect<sup>[3]</sup>. According to Oka, *et al.*<sup>[4]</sup> wear enhances corrosion by (1) roughening the surface through formation of fibrous surface textures which intensifies the local electric field and causes corrosion at impact crater tops, (2) deforming and introducing stresses to the surface, making it unstable to subsequent electrochemical reactions and (3) mechanically removing the air-borne oxide layer formed by passivation and exposing the fresh metal to corrosion. Corrosion on the other hand enhances

wear by making materials more active and unstable. This is because dissolution and gas bubbling both encourage detachment of premature deformed lip from its crater. The passive film, too thin to be protective, may also assist wear by dissolving work hardened layers and by roughening the surface.

Investigations have shown that interaction of corrosion and wear is synergistic<sup>[3]</sup>. Factors determining the extent and nature of material loss in corrosion wear are both intrinsic and extrinsic. The intrinsic parameters being the chemical composition, microstructure and nature of mating surfaces, while the extrinsic ones include the applied load, sliding velocity and prevailing environment.

The Nigerian NST 60 Mn steel is one of the hardenable steels produced in Nigeria. It is used in the construction of food processing equipment such as cocoa milling machine where it is exposed to processes of wear and corrosion. Lubrication of some parts of a machine, especially those used for food processing, in order to reduce wear and corrosion, is now considered unwise and unsafe to avoid food contamination or poisoning. It is against this background that this research is investigating the effect of different heat treatments on the corrosion wear resistance of NST 60 Mn steel in cocoa mucilage under an instrumented pin-on-disc wear test rig.

**Experimental details:** The as – received sample of hot rolled 12mm diameter NST 60 Mn steel obtained from Osogbo Steel Rolling Mill, Osun state, Nigeria, has the chemical composition: C(0.35-0.42), Si(0.20-0.30), Mn (0.90-1.20), P (0.04), S (0.04), Cu (.20-0.25), Cr(0.10), N (0.009-0.011) and Sn(0.05). Specimens of 15 mm length

and 12 mm diameter were cut from the rod to make them suitable for use on wear test rig. The samples were later heat treated according to the following procedures:

**Water quenching:** Six of the samples were pre heated at 400°C for 30minutes, austenitized at 860°C for 60 minutes and quenched in cold water at ambient temperature.

**Water quenching and tempering:** Three of the water quenched samples were tempered to 250°C.

**Austempering:** Three as -received samples were pre-heated at 400°C for 30minutes, austenitized at 860°C for 60 minutes, immediately quenched in an alkali bath of 20% NaOH and 80% KOH at 380°C for 60 minutes before they were air cooled to room temperature.

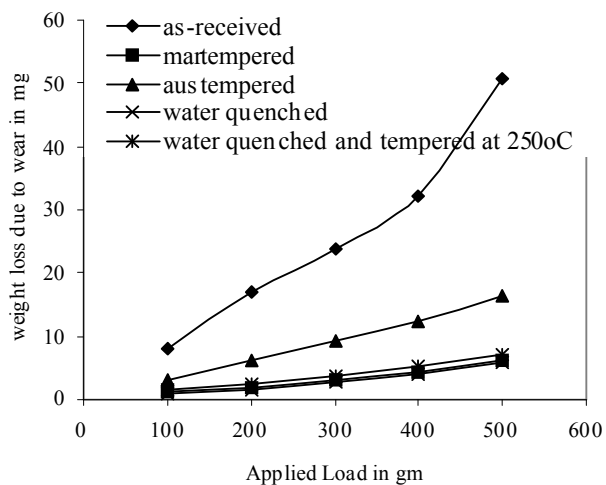
**Martempering:** Three as received samples were preheated at 400°C for 30mins, austenitized at 860°C for 60mins, quenched in an alkali bath of 20% NaOH and 80% KOH at 380°C for 1min and then air - cooled to room temperature.

Prior to heat-treating, all the samples were ground on 240, 320, 400 and 600 grit emery papers. After heat-treating the sample surfaces were reground to 600 grit finish to remove salts and scales from their surfaces. Some of the samples needed for microstructural examination were subsequently polished to mirror finish and etched in 2% nital solution. Prior to exposing samples in the cocoa mucilage, their weights were measured on PB 153 Mettler Toledo digital weighing balance.

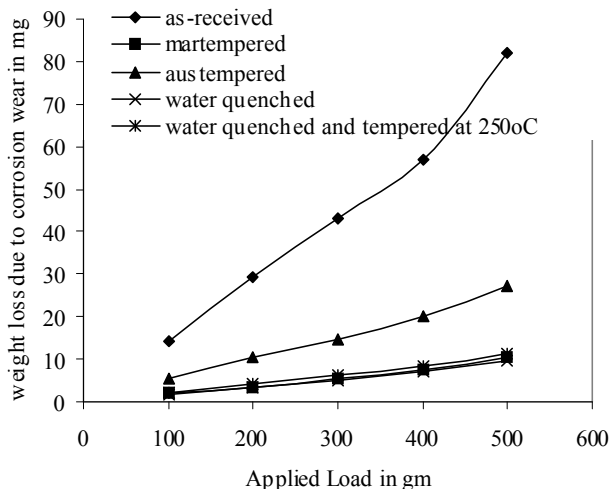
The corrosive medium was prepared as follows: seeds from cocoa pods obtained from Obafemi Awolowo University Teaching and Research Farm were put in a basket with a bucket underneath to collect the cocoa mucilage that was later preserved in a refrigerator. The pH of the freshly obtained cocoa mucilage was determined before and after exposure in the mucilage at intervals of 48 hours. The mass of each sample before and after the corrosion wear test were taken and recorded. The experiment was allowed to run for 2000 cycles before detachment. The load applied during the test varied from 100 to 500g at intervals of 100g.

**RESULTS AND DISCUSSIONS**

Figure 1 illustrates the effect of different microstructures of NST-60 Mn steel on its wear resistance in dry air. The steel microstructure was modified by heat treatments such as austempering, martempering, hardening by water quenching and by a hardening and low temperature tempering at 250°C. From Fig. 1 it is found that wear resistance of the steel in dry air was



**Fig. 1:** Effect of heat treatment on the wear resistance of NST 60-Mn steel in dry air



**Fig. 2:** Effect of heat treatment on the wear resistance of NST 60-Mn steel in freshly prepared cocoa mucilage

low with respect to normalized (i.e. as-received) and austempered structures. All the structures evolved through the three hardening treatment exhibited significant resistance in the dry air condition. The water quenched and tempered sample showed the best resistance to wear out of the 3 of them. It is interesting to note that in Fig. 1 the martempered and water quenched microstructures produced the same wear resistant effects on the steel.

Fig. 2 and 3 depict the wear behaviour of the same steel when the wear experiment was carried out in freshly prepared cocoa mucilage of pH4.2 and fermented cocoa mucilage of pH3.9 respectively. The wear resistance of NST-60 Mn steel in the fermented cocoa is lower than that found in the freshly prepared mucilage. This is because the gradient of the slope of the weight

loss versus applied load is greater in Fig.3 for fermented cocoa than the freshly prepared cocoa mucilage (Fig. 2)

Apart from the noticeable differences in the wear resistances, it can be seen in the 3 figures that weight losses increase with applied load.

The increase is less rapid and closely related in the hardened microstructures produced by martempering, water quenching and water quenching plus low temperature tempering.

The relationship between the wear weight losses of NST-60 Mn steel and applied load on the martempered steel in the three different media is magnified in Fig. 4 to show the relative resistances.

Corrosion – wear is a combined mechanism by which materials suffer damage due to wear and corrosion. Corrosion and wear under their mutual influences essentially differ from the pure wear and pure corrosion respectively and the influences of variables pertinent to pure wear or corrosion such as applied load, chemical composition, electrochemical nobility and ability to passivate and stability of passive film could be more pronounced in corrosion – wear<sup>[5]</sup>.

The total weight loss  $W_{cw}$  (Fig. 2) consisting of two components, corrosion weight loss ( $W_c$ ) and wear weight loss ( $W_w$ ) increases with applied load. Therefore, both corrosion and wear must have contributed to the overall weight loss. In slurry wear (Fig. 2 and 3), the increase in weight loss is due to more intensive micro ploughing at higher loads. Moreso, in such a wear loss, higher corrosion loss is expected because of the transport of corrosion species which is faster under the speed of the stylus pin employed in the wear test rig for this investigation.

It can be seen that the wear rate increases as the pH of the cocoa mucilage decreases from 4.2 to 3.9. This implies that the more acidic the mucilage, the more corrosive it becomes and consequently, the greater the wear rate. It is important to point out that the decrease in pH of the cocoa mucilage was probably due to fermentation of the cocoa for 48 hours. Therefore, longer exposure time of the cocoa mucilage would result in lower pH value and hence, greater corrosive attack and vice-versa. Conversely, if the preparation of the cocoa mucilage is carried out under a controlled environment (reducing), the pH would likely be higher and less corrosive.

The water quenched and martempered samples resisted wear most under all the conditions they were subjected to. Since wear is a function of hardness, our work corroborates the finding in the literature that wear rate is inversely proportional to hardness. This explains

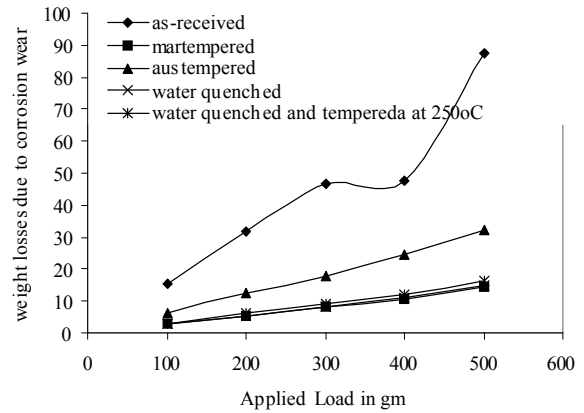


Fig. 3: Effect of heat treatment on corrosive wear resistance of NST 60-Mn steel in fermented cocoa mucilage.

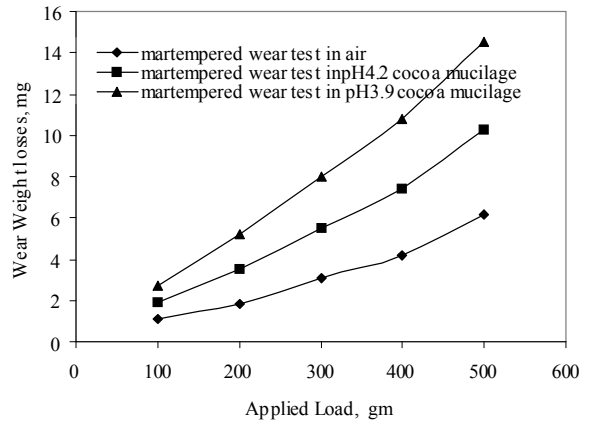


Fig. 4: Relationship between wear weight loss and applied load on martempered steels in different environment

why the water quenched and martempered samples are the most wear resistant, followed by the water quenched and tempered (250°C), austempered and as-received samples exhibiting decreasing corrosion wear resistance in that order.

The mutual effects of corrosion and wear have been more pronounced in the as-received and austempered NST 60 Mn steel because of their high corrosion rate. Ono, *et al.*<sup>[6]</sup> in their work have tried to link the presence of dual phases in the as-received and austempered steels to the non-uniform corrosion on the ferrite and cementite phases.

**Conclusions:** From the results of the work carried out in this research, the following deductions can be made:

- Corrosion wear of NST-60 Mn steel is a function of both corrosion and wear activities.

- Corrosion wear of NST-60 Mn steel in cocoa mucilage is dependent on the microstructures of the steel and on the pH of cocoa mucilage.
- Heat treatments such as martempering, quenching and quenching plus low temperature tempering are capable of improving the structural integrity of NST-60 Mn steel in cocoa mucilage.

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