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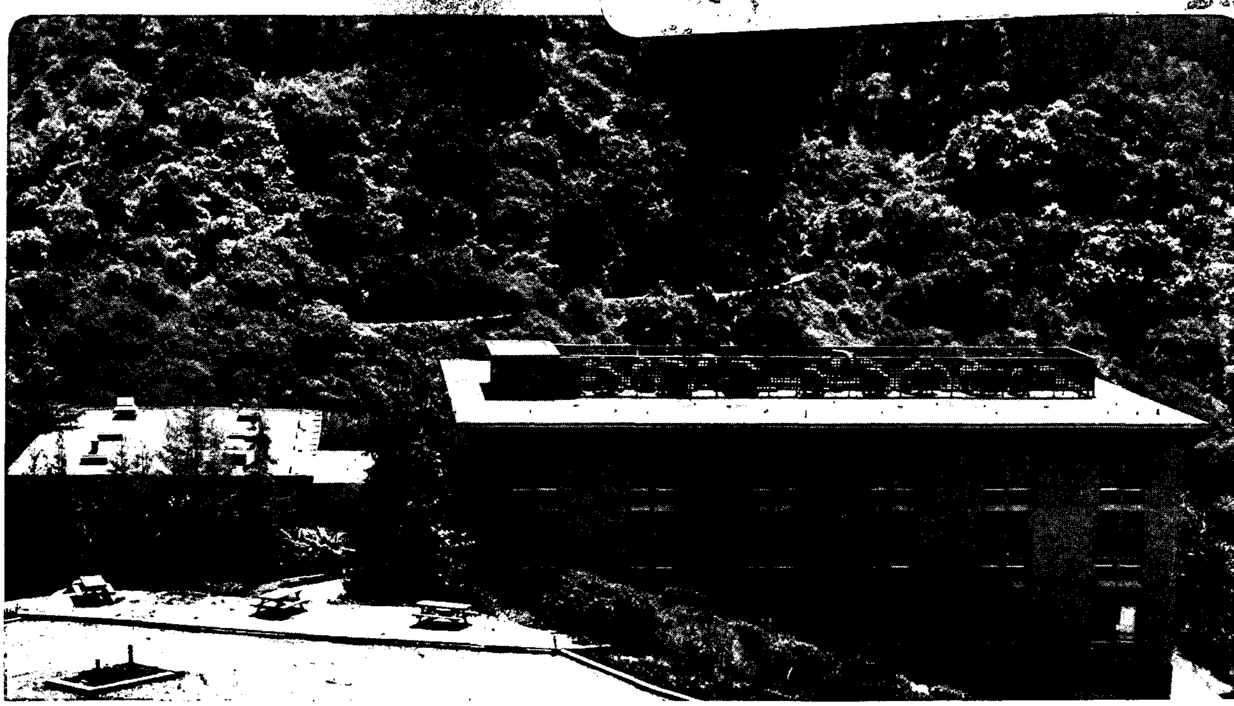

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**DISCLAIMER**

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# SAND-WATER SLURRY EROSION OF CARBURIZED AISI 8620 STEEL

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**ABSTRACT**

The erosion behavior of carburizing AISI 8620 steel for sand slurry service was investigated. The jet impingement type of test was used where sand slurry is directed at flat specimens to determine the erosion rates and mechanism of erosion. The effects of steel heat treatments, slurry velocities and particle concentrations on erosion rates were investigated.

**INTRODUCTION**

A series of tests was conducted to determine the effect of three different heat treatments on the sand-water slurry erosion of carburizing grade AISI 8620 steel at different solids loadings of sand in the water carrier. The test conditions were meant to simulate the slurry flow in piping components of mud pump systems used in oil drilling operations. Limitations of the slurry erosion test equipment prevented the use of the solids loadings, up to 1.9 g of sand/cc of water, that occur in actual service. However, the low 0.24 g and sand/cc of water that were used were sufficient to determine the relative behavior of the different heat treatments of the steel.

The use of an incremental erosion rate measuring technique permitted some understanding to be gained of the sequential wear of a carburized layer of the steel as the eroding particles penetrated through the hardened layer. The effect of comminution of the sand particles on erosivity of the slurry was also studied. The use of the same slurry for each of four erosion increments was determined and compared to using a fresh batch of erodent sand for each test increment. The consideration is important in establishing the cost of performing slurry erosion tests of the type used in this investigation.

## EXPERIMENTAL CONDITIONS

In order to determine the effects of precise variations in slurry flow conditions on the erosion of metals, a jet-impingement tester (JIT) was used to direct measured quantities of slurry at flat specimen surfaces at specific angles to the flow direction. The exposure time can be varied as can the type of slurry and its impingement conditions of velocity, solids loading and impingement angle.

Figure 1 is a schematic set-up of the JIT with the principal elements designated. The equipment operates by air pressurizing the stirred, slurry holding tank which forces the slurry through a 0.5 cm diameter nozzle, into a test enclosure which contains a specimen holder that positions the specimen under the nozzle, approximately 1.25 cm below the nozzle exit at any impingement angle. The equipment is described in Reference 1.

The amount of slurry used in a single exposure is controlled by timing the release of the slurry whose flow rate has been calibrated against the holding tank's pressure level. The on-off valve in the nozzle assembly is used to precisely control the release of the slurry through the nozzle. Calibration of the impingement velocity and holding tank pressure level was done before the experiments began. Results are shown in Figure 2. There is an uncertainty of 3% for slurries containing 0.12 g of sand for each cc of water.

The sand was 20-40 mesh of the type that is used in oil field operations. Tap water was used and the slurry was mixed in the holding tank and stirred for 1/2 hr prior to each test increment. The used slurry was caught in an open bucket and, at the end of each increment of testing was pumped back into the holding tank. The tank's stirrer operated continuously.

AISI 8620 steel specimens 2.5 cm x 1.8 cm x 1 cm in the uncarburized and two carburized conditions were tested at ambient temperature. Three heat treatments were used: non-carburized tempered at 370°C and carburized at 925°C and subsequently tempered at 220° or 385°C. The impingement angle was fixed at 30° and 68 liters of slurry were used for each of four incremental test exposures on the same area of each specimen. The same slurry was reused for each specimen. A comparative test was run where fresh slurry was used for each of the four test increments on a single specimen. Specimens were tested under two different solids loading; 0.129 and 0.24 g of 20-40 mesh size sand in each cc of water. Impingement velocities of 12 and 23 m/s were used with the 0.12 g/cc slurry and 12, 23 and 30 m/s were used with the 0.24 g/cc slurry.

Each specimen was cleaned with soap water and ethyl alcohol after its exposure to the slurry. Weight loss of the specimen was determined by using a Metler balance accurate to 0.0001g to weigh the specimen before testing and immediately after each increment after the specimen was cleaned and dried. Hardness of the steels prior to testing and in the most severe erosion area after testing were determined using a

Rockwell Hardness Tester.

**RESULTS AND DISCUSSION**

The heat treated steels eroded at the overall rates shown in Tables 1 and 2 for the total of 272 liters of slurry that impinged on each specimen in the four test increments. The initial hardness of the surface of the carburized layer and the final hardness at the bottom of the eroded pit after testing are listed in the tables, except for the 12 m/s test series.

The erosion rates increased as the velocity of the slurry was increased, as is expected. The 220° and 385°C tempered specimens underwent less erosion than the normal treatment specimens. The difference in erosion rates between the 220° and 385° tempered specimens was small, 10%, compared to the difference between both of these tempers and the normal heat treatment, 33%. As the solids loading of sand in the water was increased, the erosion rate increased for the same particle velocity. (Compare data in tables 1 and 2).

There was a significant reduction in the hardness of the surface of the erosion groove as the carburized case was eroded away. The lower hardnesses in the deeper erosion grooves of the specimens eroded at 30 m/s fps compared to those eroded at 23 m/s relate directly to the depth of the erosion groove. The hardness variation through the carburized case between specimens appeared to be only somewhat consistent.

The behavior of the steel specimens can be further understood if the erosion data is plotted in curve form. Figures 3 and 4 plot the erosion rates of the steel specimens for the first and fourth 68 liters of slurry test exposures using a 0.24 g/cc slurry. It can be seen that the slopes of the erosion curves are nearly the same, indicating that there was very little comminition of the slurry as the same slurry was used for all four of the incremental exposures.

The erosion rates for the 1st and 4th increments and for the overall rate calculated for the total 272 liters of slurry used for each specimen, (see Table 2), are very nearly the same except for the 385$^{o}$C temper material at 12 m/s. This indicates two important facts:

1. The decrease in hardness at the bottom of the erosion groove as the carburized specimens are eroded does not have an effect on the erosion rate, and

2. The erosion rate reaches steady state in the first $6.8x10^4$cc increment of slurry flow. The absence of erosion rate changes with hardness changes has been observed before.[2] The early onset of steady state erosion conditions has also been observed previously.[2]

The slope of all of the curves was 2 for all three heat treatments. This relates well with velocity term, v, in the kinetic energy of the particles equation, $KE=1/2\ mv^2$, which is the measurement of the eroding force of the particles. The overall erosion rate curves for the 0.12 g/cc slurry in Figure 5 have the same slope and relative position for the 3 heat treatments as is seen in Figures 3 and 4. As discussed above, they can be directly compared to incremental rate curves as the erosion rate reaches a steady state rate during the first 68 liters of slurry exposure.

A comparison of the overall erosion rate curves for the 220°C temper specimens at the two slurry solids loadings are shown in Figures 6 and 7, respectively. It can be seen that the higher solids loading of 0.24 g/cc causes more erosion to occur than the 0.12 g/cc for both heat treatments.

Figure 8 is a comparison of the erosion rates as a function of solids loading for all three heat treatments at the two higher velocities used in the investigation. The erosion rate increased directly with the solids loading, doubling from 0.12 to 0.24 g/cc. These curves should not be extrapolated to higher solids loadings.

The variation in hardness due to the different tempering temperatures and the decrease that occurs down through the carburized layer of the steel specimens and its relation to the erosion rate is shown in Figure 9. The rates plotted are those that occurred after the first 68 liters of slurry has impinged on the specimen. It can be seen that the erosion rate decreases with increased hardness that results from the different tempering temperatures. The effect is more pronounced at the 30 m/s velocity as compared to the 23 m/s velocity. The absence of an effect of hardness on erosion rate in the same specimen as the carburized case is eroded down to lower hardness levels, as shown in Figure 3 and 4, conflicts with the effect of hardness of different specimens on their erosion rate shown in Figure 9.

A probable explanation for the presence of a hardness effect in different specimens, but not in the same specimen relates to the geometry of the eroded groove. As the erosion proceeds, the erosion groove formed becomes deeper with less material exposed along its bottom and more material exposed along its sides. This present a lesser target, effectively a shallower impingement angle, for the impacting particles. In liquid-solid particle erosion, it is known that the erosion rate increases with the impingement angle with maximum erosion occurring at $\alpha = 90^{o}$.[2] Thus, as more of the target surface in the groove is exposed to the slurry at a shallower impingement angle, the resultant erosion rate is reduced. This reduction in erosion rate compensates for the increased rate due to the lower hardness at the bottom of the groove and the result is little or no effect on the erosion rate i a single specimen. This indicates that erosion tests should be terminated before the groove depth becomes significant. Since it has been shown earlier that steady state erosion rates were reached after the first 68 liters increment of slurry had impacted the test surface, short time erosion tests can be used to give reliable long term erosion rates if corrosion of the surface is negligible. In actual service over a wide surface area where narrow grooving in the erosion area does not occur, hardness will have an effect on the erosion behavior, as is discussed below.

The overall erosion rates for the two slurry solids loadings are plotted in Figure 10 for one particle velocity. The erosion rate decreases with increasing hardness as discussed above. The shapes of the two curves are very similar with the 0.24 g/cc slurry curve being slightly steeper than the 0.12 g/cc slurry curve.

**CONCLUSIONS**

1. The 220$^{o}$ and 385$^{o}$C tempers of the carburized 8620 steel have improved erosion resistance over the un-carburized steel.

2. There is a relatively small difference between the erosion resistance of the 220$^{o}$ and 385$^{o}$C tempered steel.

3. Higher solids loading of sand in the water slurry resulted in higher erosion rates.

4. The incremental erosion rates measured after one 68 liters increment of slurry has impacted the surface are the same as after four increments; so long erosion tests are not required.

5. The erosion rates of the three tempers increase with velocity with a velocity exponent of 2, which relates to the kinetic energy of the eroding particles.

6. The erosion resistance of the steel increases with hardness for different specimens at different hardnesses.

7. The hardness of the steels decreases with depth below the original carburized steel surface but the erosion rates do not change accordingly.

8. The geometry of the erosion groove appears to affect the erosion rates as the groove deepens, indicating that erosion tests should be terminated before the depth of the grooves formed is significant. This relates to conclusion 4.

9. The sand erodent particles were not comminuted when they were reused in successive increments of erosion, indicating that they can produce valid data when they are reused several times.

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2. Levy, A.V., and Yau, P., "Erosion of Steels in Liquid Slurries", Report No. LBL-15658, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720.

## FIGURES

Table 1

ERosion IN 0.12 g/cc SAND-WATER SLURRY

| Heat Treatment | Initial Surface Hardness (Rc) | Erosion Pit Hardness (Rc) at | | Overall Erosion Rate ($X\ 10^{-7}$ g/g) at | |
|---|---|---|---|---|---|
| | | Vel=23 m/s | 30 m/s | 23 m/s | 30 m/s |
| 220°C | 60 | 57.3 | 51.6 | 4.60 | 7.94 |
| 385°C | 50 | 49.0 | 49.0 | 5.25 | 8.94 |
| Normal | 30 | 31.3 | 24.9 | 7.31 | 12.43 |

Table 2

EROSION IN 0.24 g/cc SAND-WATER SLURRY

| Heat Treatment | Initial Surface Hardness (Rc) | Erosion Pit Hardness (Rc) at | | Overall Erosion Rate ($X\ 10^{-7}$ g/g) at | | |
|---|---|---|---|---|---|---|
| | | Vel=23 m/s | 30 m/s | 12 m/s | 23 m/s | 30 m/s |
| 220°C | 60 | 54.1 | 44.8 | 1.93 | 8.39 | 14.26 |
| 385°C | 50 | 45.8 | 37.6 | 2.32 | 9.32 | 15.88 |
| Normal | 30 | 28.55 | 25.3 | - | 13.26 | 22.36 |

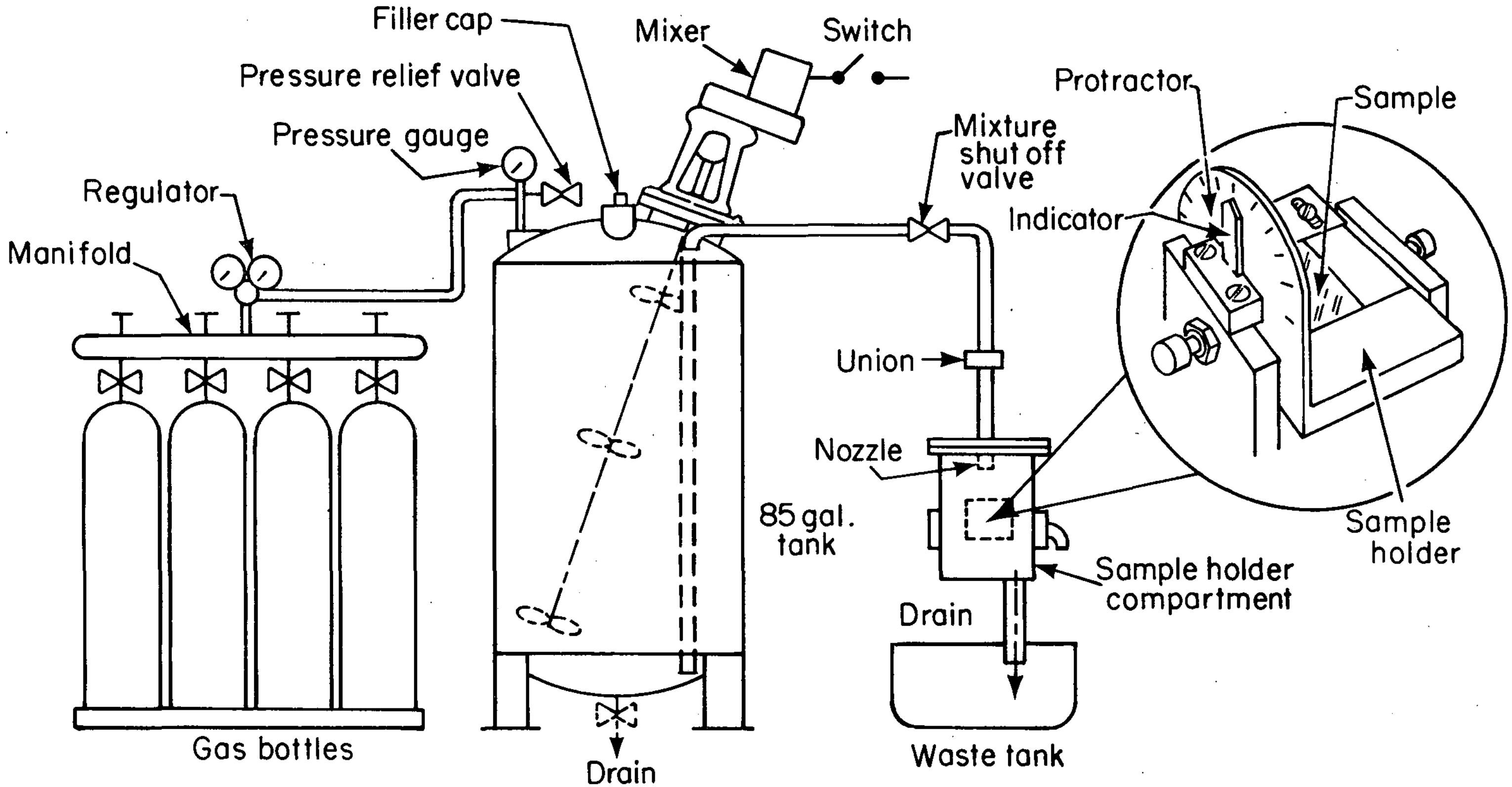


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Fig. 1 Schematic drawing of jet impingement tester (JIT).

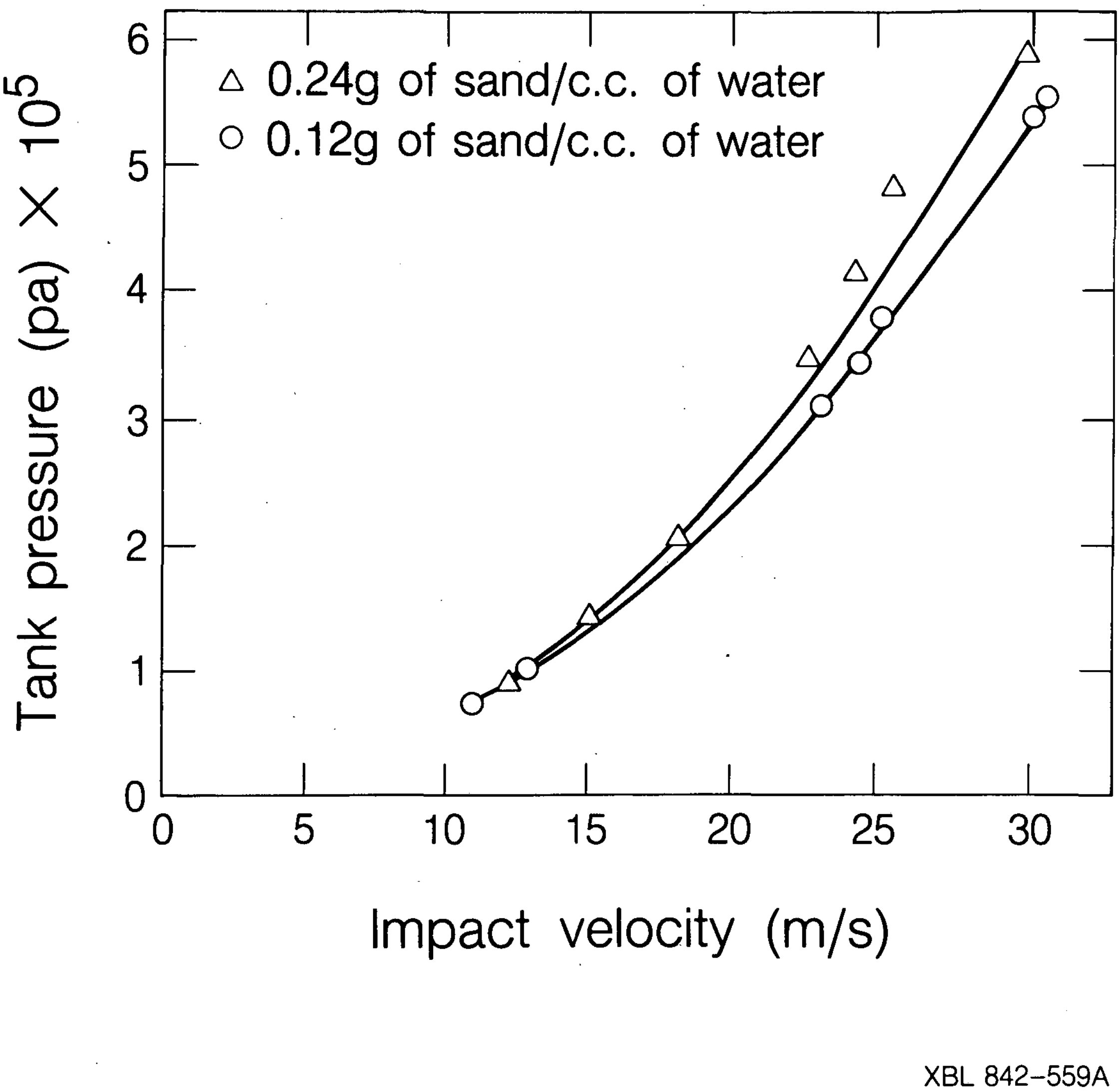


Fig. 2 Calibration curve of holding tank pressure v.s. slurry impact velocity.

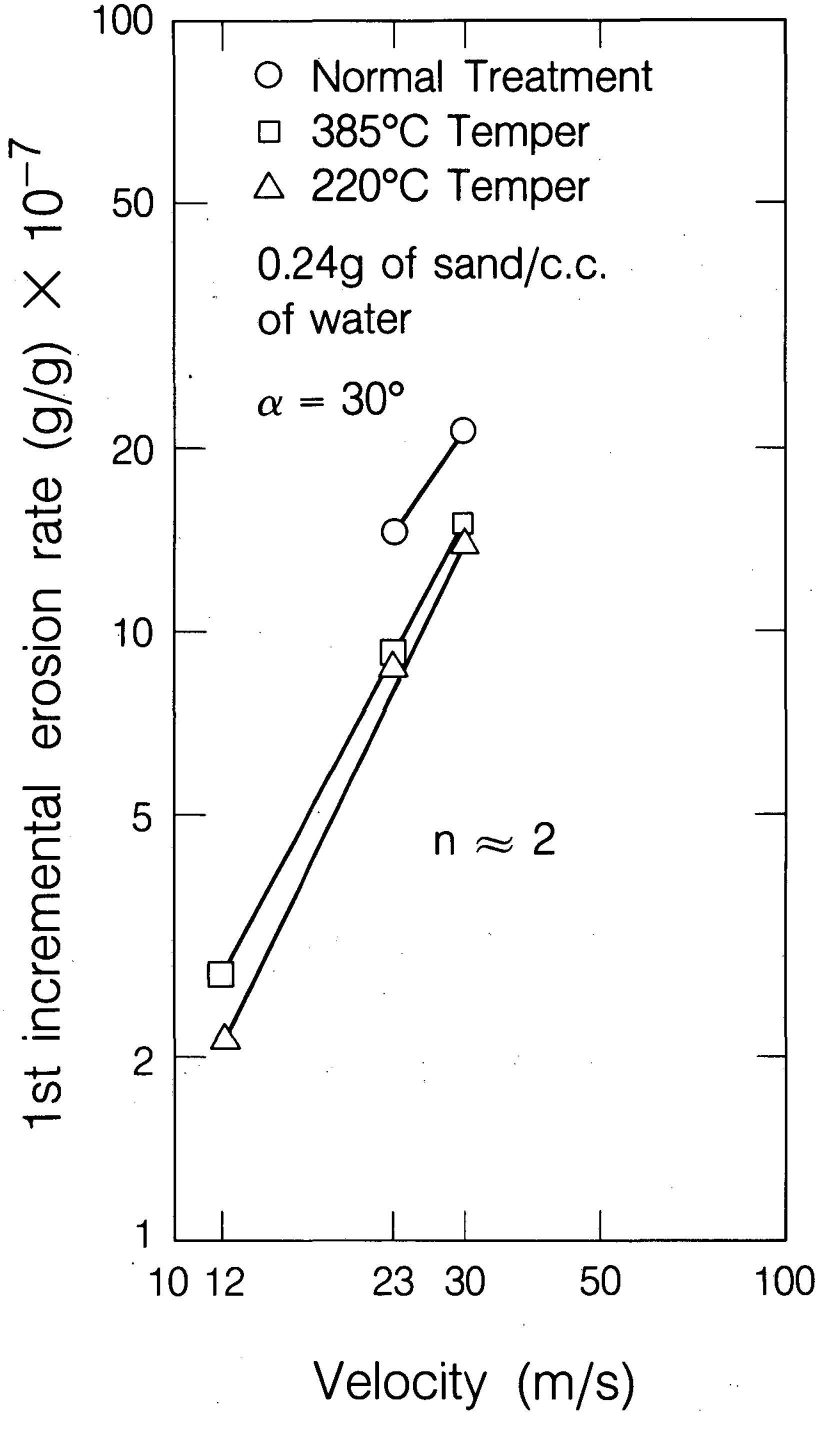


Fig. 3 Incremental erosion rate v.s. velocity for 0.24g/cc slurry test after first 68 liter increment of slurry.

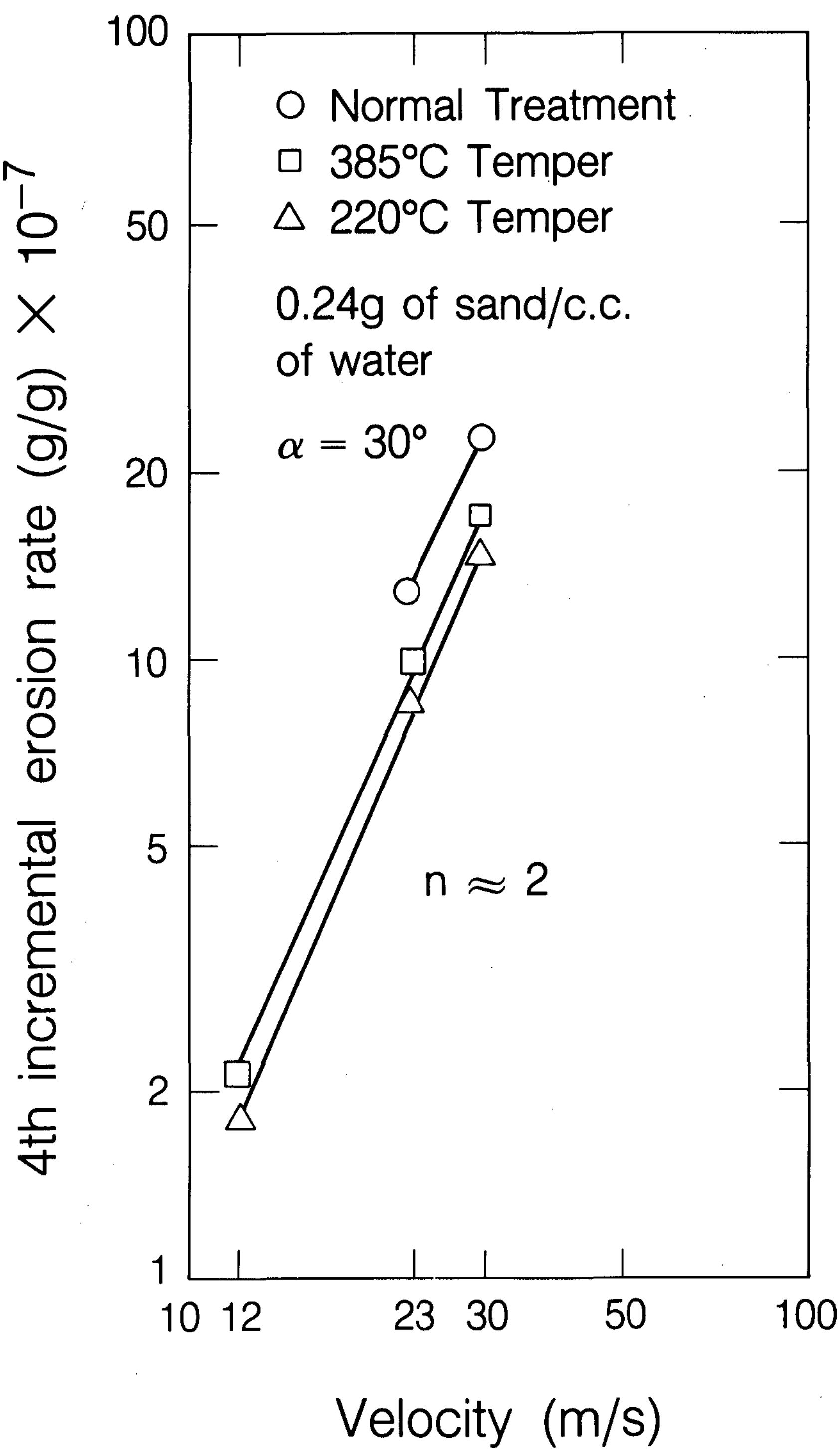


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Fig. 4 Incremental erosion rate v.s. velocity for 0.24g/cc slurry test after fourth 68 liter increment of slurry

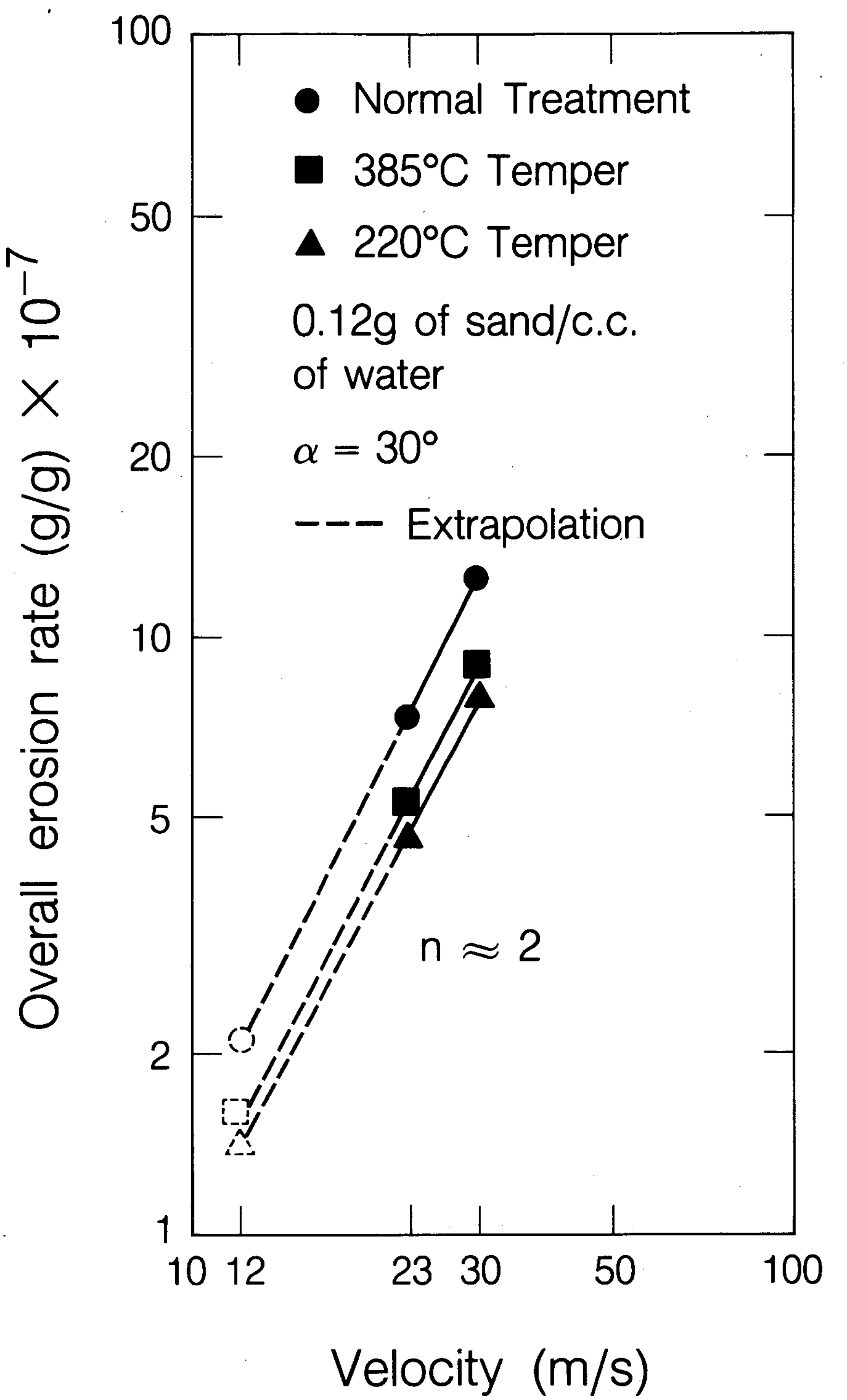


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Fig. 5. Erosion rate v.s. velocity for 0.12g/cc slurry test.

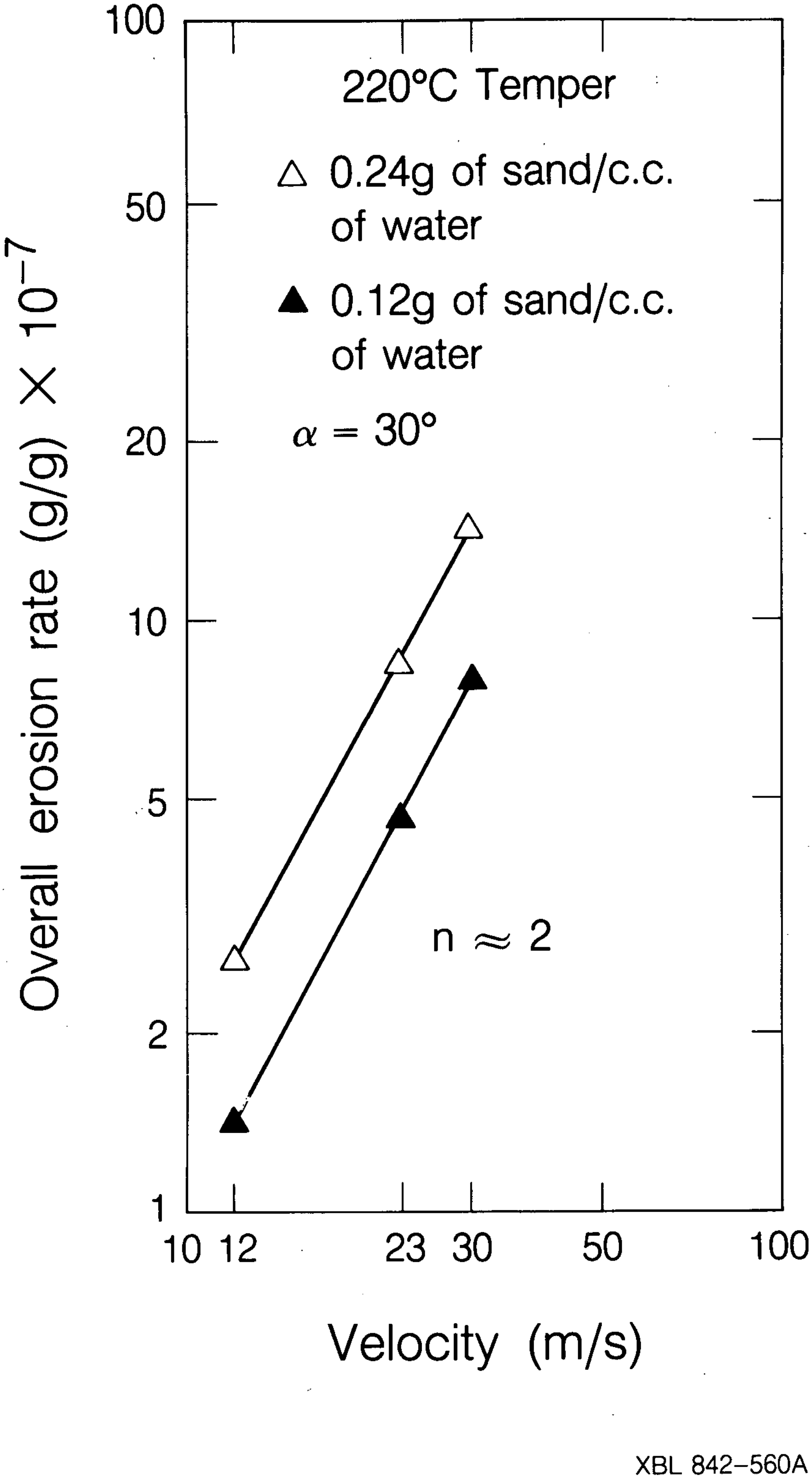


Fig. 6 Erosion rate v.s. velocity for 220°C temper steel.

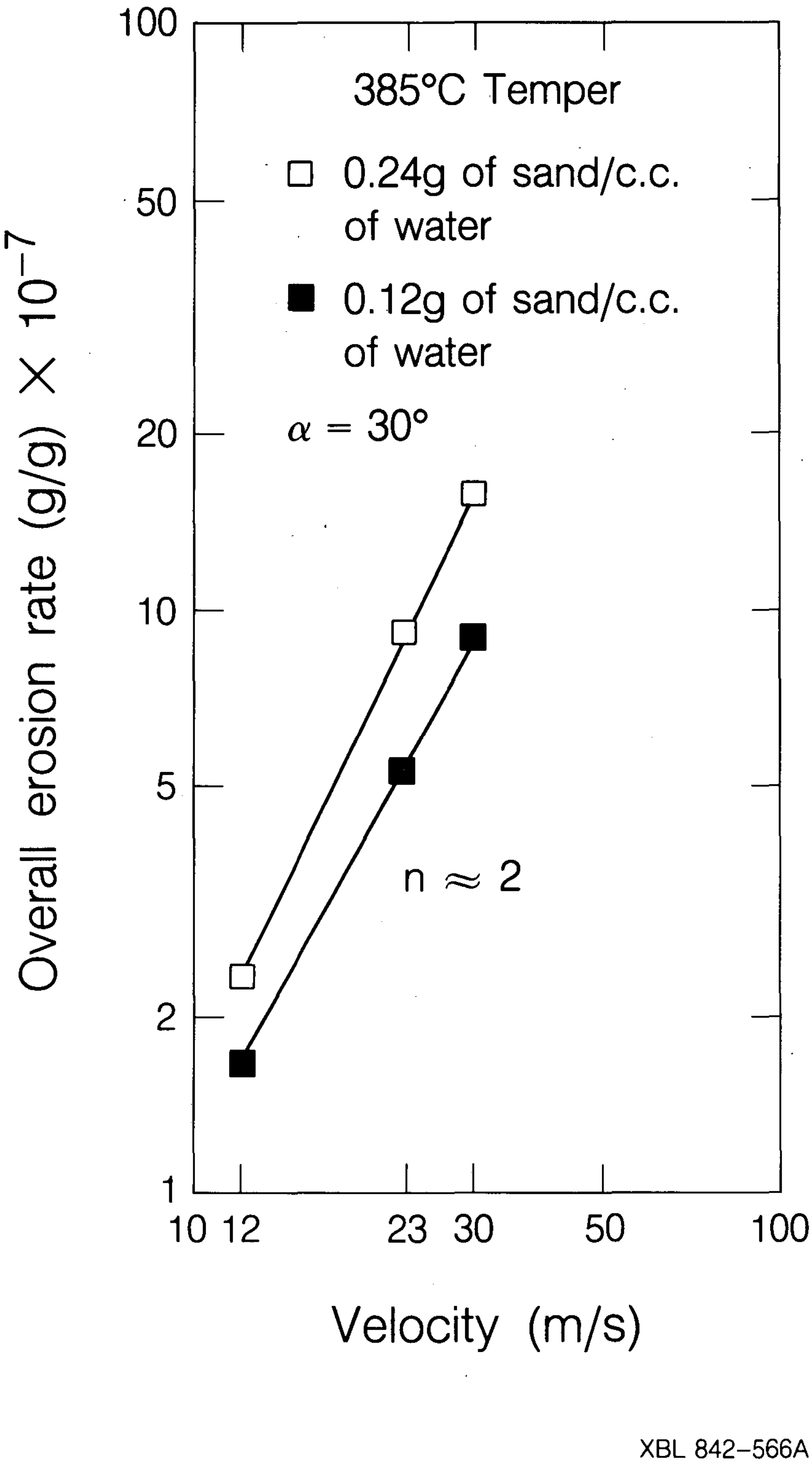


Fig. 7 Erosion rate v.s. velocity for 385°C temper steel.

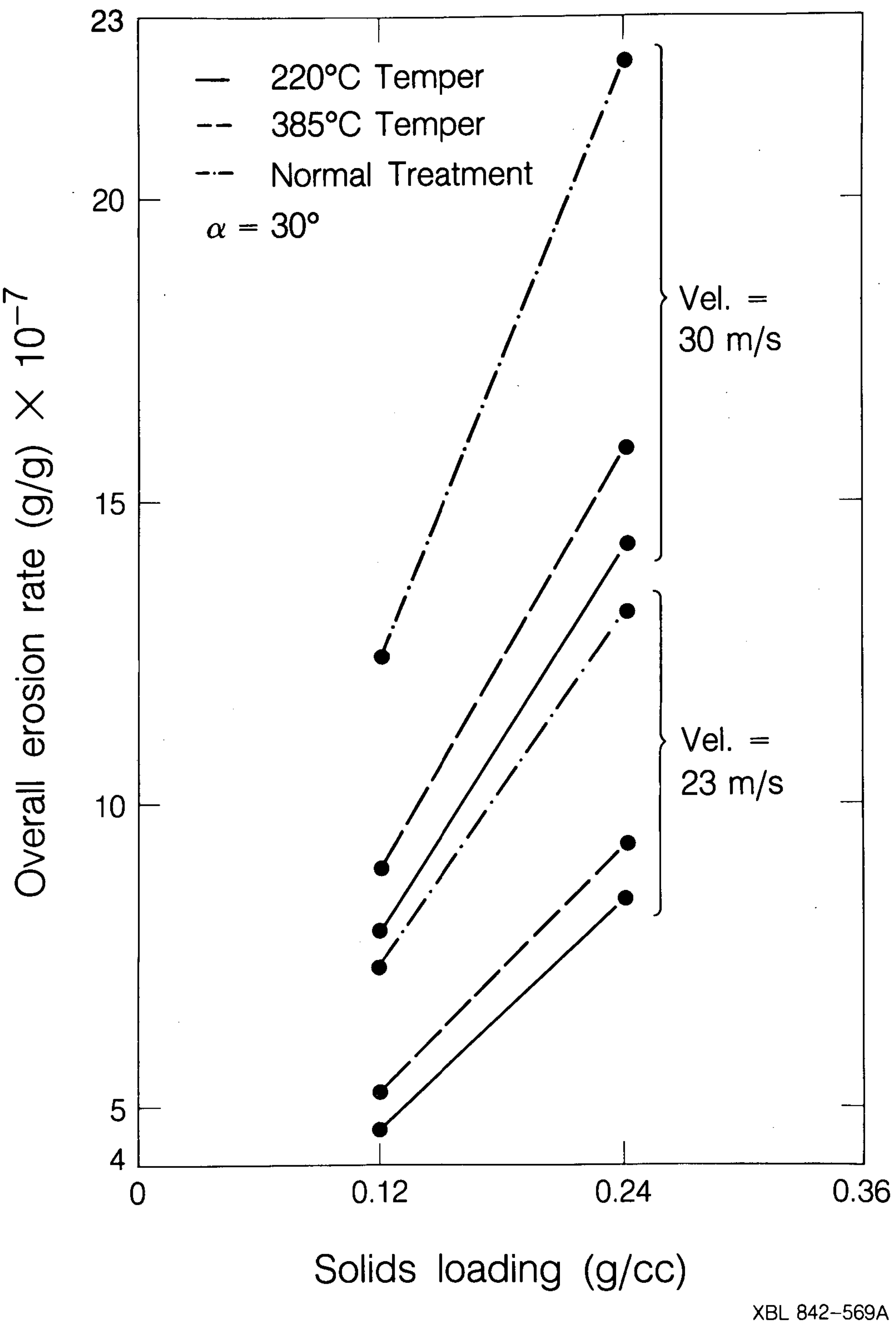


Fig. 8 Erosion rate v.s. solids loading for three tempers of steel.

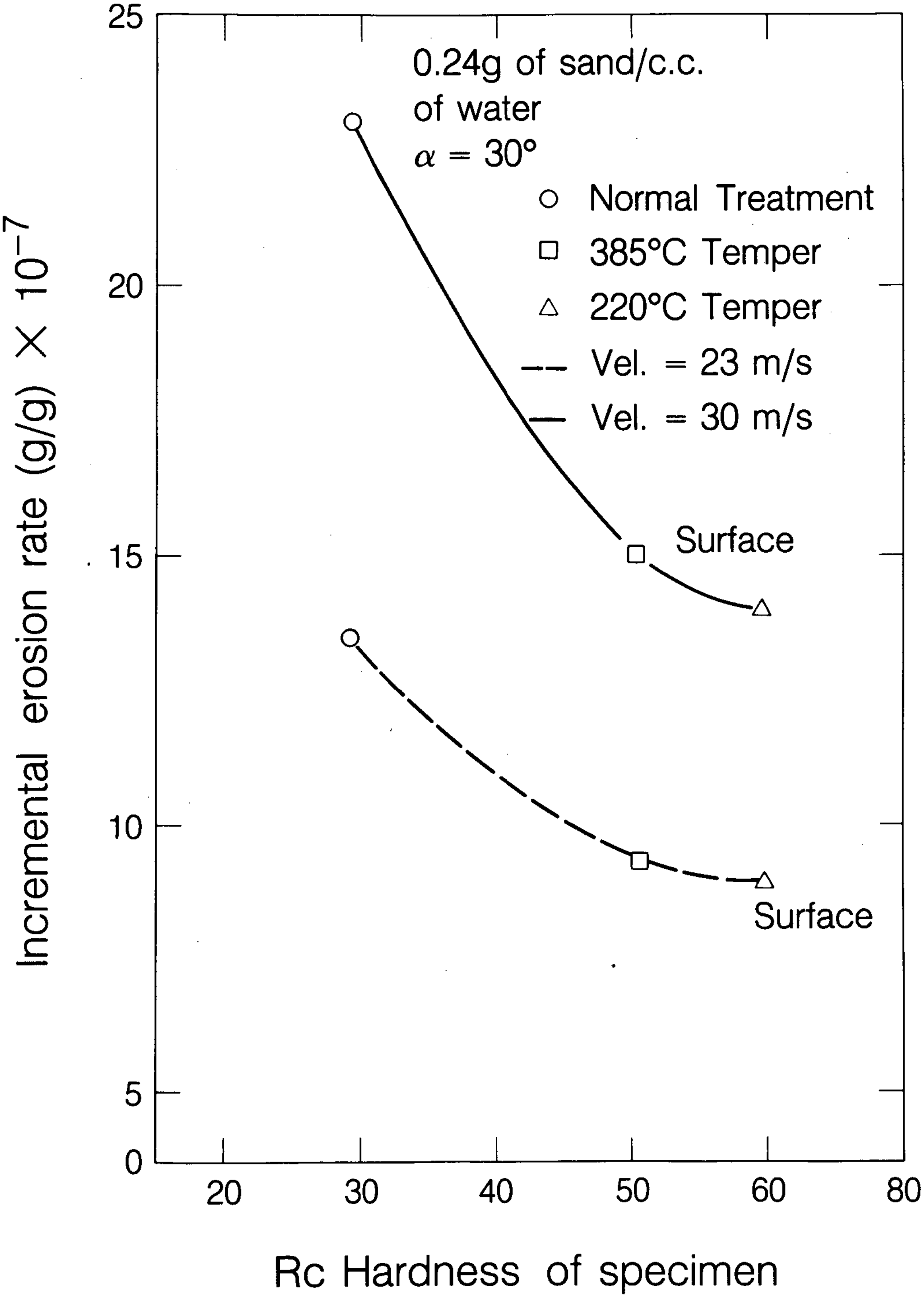


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Fig. 9 Erosion rate v.s. hardness for 220°C and 385°C temper steels.

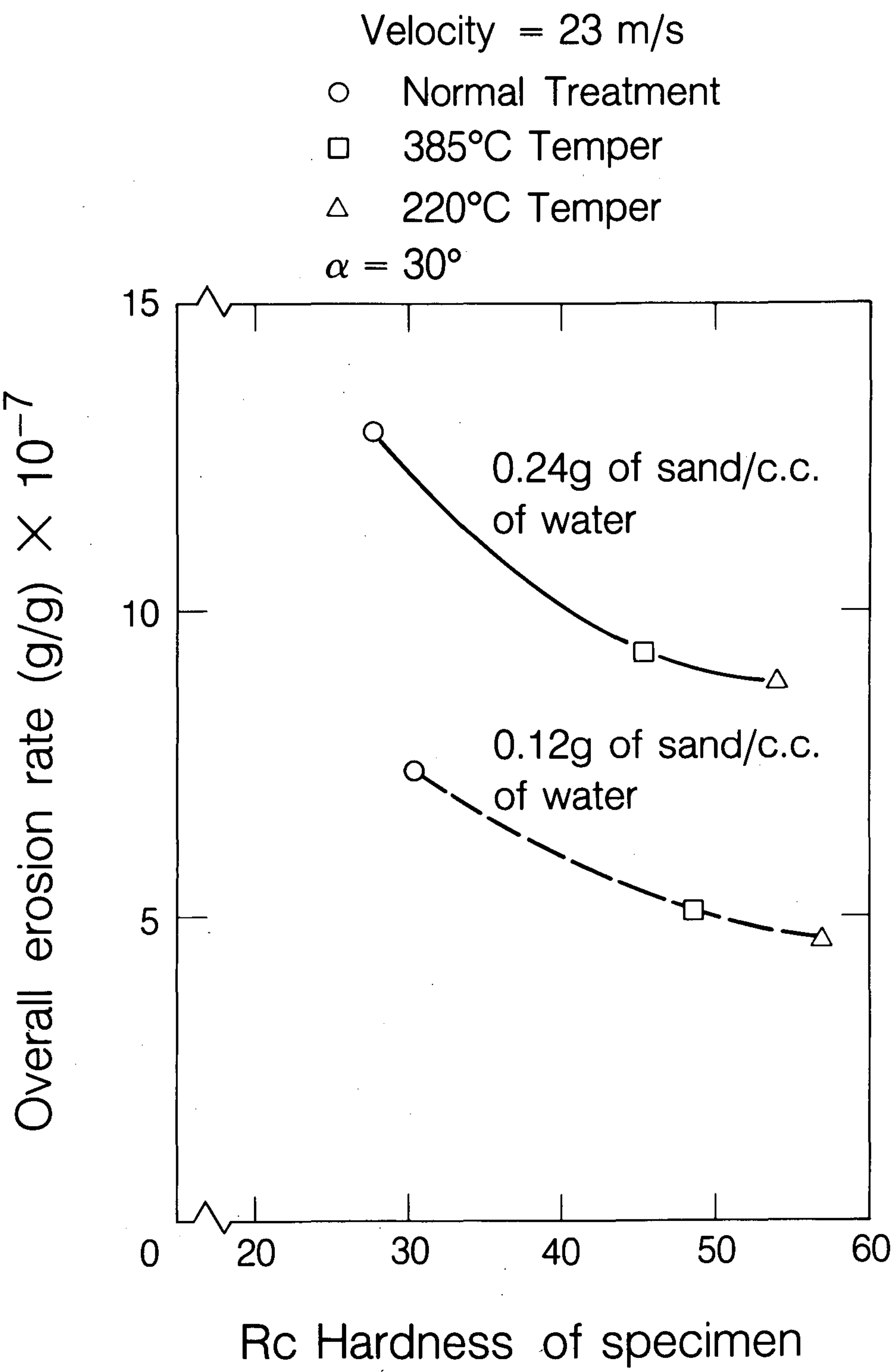


Fig. 10 Erosion rate v.s. hardness for 2 solids loadings of slurry.