THE INFLUENCE OF SURFACE FINISH ON THE CORROSION OF STEEL

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ABSTRACT

Experiments were performed to quantitatively assess the influence of surface finish (fineness or roughness of surface) on the extent of corrosion of mild steel and medium carbon steel when exposed to chosen environments. Surface finish was measured in terms of the roughness average - height (RA) index adopted by the International Standards Organisation (ISO) while the extent of corrosion was measured as weight change of the specimen per unit surface area.

As various types of environment are encountered in service, the representative ones chosen are 0.1M ammonium hydroxide, 0.1M sodium chloride, 0.1M hydrochloric acid and the laboratory atmosphere.

Results obtained show a general increase in the extent of corrosion with increasing surface finish value. However, the variation of surface finish has varying effects on mild steel and medium carbon steel in a given environment. The environmental variations also result in varying corrosion extents for a given surface finish value.

INTRODUCTION

Changes due to corrosion in optical, electrical and physical properties, to mention a few, vary widely for different metals, especially when their dimensional properties are also varied. Such dimensional properties include the metal's surface area, its shape and its surface finish. Dimensional changes alone can also bring about varied corrosion behaviour. This means that test pieces of the same metal exposed to the same environment but having surfaces polished to different degrees of fineness will corrode to varying degrees.

Metal surface conditions usually encountered in service vary from the relatively stress-free surfaces of evaporated metal to the corrugated 'shattered' surfaces obtained by severe machining operations or by vigorously abrading with a coarse abrasive.

Generally, smooth surfaces corrode more slowly than rough ones. For instance, the initial film formed in air at ordinary temperature on an annealed film-free copper surface may be 10A (10^{-7}cm) [l] whereas it may be as much as eight times this amount for a machined or abraded copper specimen [2]. The latter film is probably formed at the high local surface temperature produced by abrasion which may reach several hundred degrees centigrade [3].

The extent of corrosion, as measured by the thickness of the oxide film, on an abraded or machined metal surface may be influenced by [4].

a) stresses induced by abrasion.
b) increased area caused by corrugation, shattered metal and cracks.
c) superficial oxidation by reason of high surface temperatures due to abrasion.

Following the formation of the initial film, other factors come into play in determining the speed of further corrosion. The physical nature of the corrosion product is an important variable. It may be flocculent, freely porous to the environment; a porous corrosion product film being less protective than one non-porous.

Whether or not corrosion product films are porous depends on the relative volume of the corrosion product compared to the volume of the metal consumed in forming it [4]. It is suggested [5] that, for oxidation, if the ration Md/mD (where M is the molecular weight of the oxide, D is its density, m is the atomic weight of the metal multiplied by the number of the metal atoms in the oxide formula and d is the metal density) is greater than unity the oxide coating is protective. Such is the case with copper ($Cu_2 0$) and chromium ($Cr_2 0_3$) which have ratios of Md/mD equal to 1.71 and 2.03 respectively [6]. When this ratio is less than unity, as in the case of calcium (Ca0) and magnesium (Mg0) with ratios equal to 0.64 and 0.79 respectively [6], the coating is non-protective.

The composition of the environment is another factor which influences further attack on the metal surface. For instance, the presence of sulphur-contain-

ing gases and moisture appreciably increases the oxidation rates of copper [7], steel and many other metals and alloys in air [2].

The surface temperature of the metal also has a far-reaching effect on the subsequent corrosion rate. The Arrhenius equation

$$\ln K = \frac{\text{Heat of activation}}{RT} + \text{Constant}$$

where K = specific rate of reaction
R = gas constant
T = absolute temperature.

has been found in many cases to describe the change of reaction rate with temperature.

Another effect of the surface temperature is evident in the case of oxides which crack or spall when their surface temperature fluctuates intermittently. On cooling or heating the oxidised metal, differential contraction or expansion of the oxide and metal cause spalling, thereby exposing the underlying metal to fresh attack. This results in higher reaction rates than for cases of continuous heating or cooling.

This paper reports an investigation [8] of the influence of surface finish (smoothness or roughness of exposed metal surface) on the severity of corrosion of mild steel and medium carbon steel in some chosen laboratory environments. The investigation considers the total influence of surface finish; the individual contributions of the different factors influencing surface corrosion, as highlighted above, are not investigated.

2. EXPERIMENTAL PROCEDURES

2.1 Material Specifications: The test materials were of the specifications shown in Table 1.

Table 1: Composition of Test Materials

Test Material	Main Element	Composition of other Elements
Mild Steel	Iron	Carbon 0.15 to 0.25% Sulphur 0.05% Phosphorus 0.05% Manganese 0.50% Silicon 0.25%
Medium Carbon Steel	Iron	Carbon 0.35 to 0.40% Sulphur 0.02 to 0.04% Phosphorus 0.035% Manganese 0.50 to 0.80% Silicon 0.10 to 0.40%

2.2 Choice of Exposure Environments:

The type and composition of environments to which steel is exposed in service vary widely. Correspondingly, the mode and extent of corrosion would vary widely.

As a demonstration of the effect of varying the surface finish on mild steel and medium carbon steel exposed to some of these environments we choose the laboratory atmosphere and 0.1M solutions of sodium chloride, ammonium hydroxide and hydrochloric acid. These solutions represent, respectively, salt, basic and acid environments as may be encountered in service.

2.3 Preparation of Specimens:

The specimens were cylindrical rods of mild steel and medium carbon steel, about 60mm long and 10mm diameter, turned on a 'Colchester Chipmaster' lathe. By varying the turning parameters (turning speed, feed rate, depth of cut, cutting tool geometry and rake angle) specimens of different surface finish were obtained. After turning each specimen to the required dimensions it was degreased by washing with a piece of cotton wool in acetone and then stored in a desiccator until the first weighing before exposure in the relevant environment. Degreasing presents the free surface of the specimen to the surface finish measuring instrument and, subsequently, to the test environment.

2.4. Corrosion and Surface Finish Measurements:

Several corrosion measurement techniques are explained in available literature [9, 10, 11]. Of these, the weight change determination was chosen for this experimentation due to its simplicity and as the required labortory instruments were readily available.

With the specimens exposed in the laboratory atmosphere, some degree of flaking off of corrosion product was inevitable, but with careful handling this was minimised and periodical weighings on the same specimen were done. Thus a corrosion-time graph was drawn for each specimen. With the specimens exposed in liquid environments, appreciable quantities of the corrosion product were washed off the surfaces so that successive weighings on the same specimen were not done. A set of specimens with close surface finish values and dimensions were then required to obtain a corrosion-time graph, the mean surface finish value being the representative surface finish value of the set.

After preparing the various corrosive solutions, each specimen was taken out of the desiccator and its surface finish measured with a 'Talysurf 10'

stylus instrument. The dimensions of the specimen were accurately measured with venier callipers. It was then weighed on a 'Satorius 2400' digital analytical balance and then exposed to the relevant environment.

2.5 Exposure in Solution:

75ml of the relevant solution were put in each of a number of 75ml beakers, as required. The beakers had been pre-marked for identification. Each specimen was then placed diagonally in the corresponding beaker as shown in Figure 1. The clock reading at the instant of exposure was recorded for each specimen. The top of the beaker was then covered with cardboard paper and the beaker rested on a table.

Subsequent clock readings and weighings were taken thereafter. Hence the weight change per unit surface area of specimen was calculated on recorded times of exposure, over a period ranging from 2 to 21 days. Before any such subsequent weight reading, the specimen was washed in distilled water using a piece of cotton wool to scrub off any losse corrosion product. After the reading, the used specimen was discarded.

2.6 Atmospheric Exposure:

After measuring the surface finish and dimensions, degreasing, and weighing, the specimens were placed in a tray which could hold about 15 specimens at a time, as shown in Figure 2. The wooden base support for the specimens were numbered for easy identification. For the atmospheric exposure tests, the specimens were not cleaned to remove the corrosion products before taking subsequent weight readings, and a single specimen was used to obtain several readings.

3. DISCUSSION OF RESULTS

3.1 General:

The corrosion-time graphs for the different exposure environments are shown in Figures 3 to 6 for mild steel and in Figures 7 to 10 for medium carbon steel. The extent of corrosion was measured as weight increase per unit surface area for the atmospheric exposure tests and as weight loss per unit surface area for exposure in liquid environments. The relationship between surface finish and the extent of corrosion may be deduced from graphs drawn at fixed times of exposure (Figures 11 to o18).

3.2 Atmospheric Exposure:

The initial corrosion rate for every specimen of mild steel and medium carbon steel is more rapid than the rates after the lapse of some exposure time. This is depicted by the steep slopes of the graphs at small times of exposure, which become gentle with increased exposure times.

For increasing surface finish values of mild steel up to about 3.7m the extent of corrosion does not change much (Figure 11). Thereafter, there is a marked increase in corrosion extent as depicted by the rapid weight increase. In the case of medium carbon steel (Figure 15) the extent of corrosion increases linearly with surace finish value, for all exposure times.

3.3 Exposure in 0.1M Sodium Chloride:

The initial corrosion rates for both mild steel and medium carbon steel are only slightly steeper than those after some lapse of time: the corrosion-time graphs transform from mild curves to straight lines (Figures 4 and 8).

For exposure times up to 150h the weight loss versus surface finish graphs of mild steel (Figure 12) are curves whereas they are linear beyond 200h. For medium carbon steel, the weight loss versus surface finish graphs are all curves with increasing slopes (Figure 16). This difference in the graphs notwithstanding, there is a general increase in the extent of corrosion (or weight loss) with increase in surface finish value at all exposure times for both mild steel and medium carbon steel.

The corrosion-time graph of medium carbon steel for specimen set 4 (2.01μm surface finish) abnormally coincides with that of specimen set 2 in Figure 8. This discrepancy may be due to some of the reasons mentioned in section 3.6 below.

3.4 Exposure in 0.1M Ammonium Hydroxide:

The corrosion-time graphs are virtually linear for both mild steel and medium carbon steel (Figures 5 and 9). This indicates a constant corrosion rate.

The weight loss versus surface finish graphs for mild steel are curves whose slopes decrease with increasing surface finish values (Figure 13). The graphs for medium carbon steel (Figure 17) are linear.

Although there is an abnormal pattern of weight loss against surface finish between specimen sets 1 (1.74μm) and 2 (1.80μm) for medium carbon steel, as these two sets interchange places in the graphs (Figure 9); the general trend for both mild steel and medium carbon steel is, again, an increase in weight loss with increasing surace finish value.

3.5 Exposure in 0.1M Hydrochloric Acid:

The corrosion-time graphs for both mild steel and medium carbon steel (Figures 6 and 10) initially

have very steep slopes which become gentle as time passes. The steep slopes could be due to the highly corrosive nature of inorganic acids.

There is a general trend of increasing weight loss with surface finish value increase for both mild steel and medium carbon steel (Figure 14 and 18).

3.6 Some Experimental Constraints:

The results of the present investigation might have been influenced by the following shortcomings, among others.

a) The test materials are assumed to be homogenous and of standard composition. However, the inevitable heterogeneity of composition of the test materials could bring about unexpected corrosion patterns.

b) For tests where weight increases were measured (i.e. the atmospheric exposure tests), flaking off of corrosion products from the metal surface in the course of the experiements might erronously lower subsequent weight readings.

c) Conversely, for tests where weight losses were measured (tests involving exposure in solutions) the adherance of some of the corrosion products to the parent metal might have erronously increased weight readings. This might have been a major source of error as it is practically impossible to wash off completely the most minute corrosion products from a surface.

d) Although weight changes have been presented in terms of unit surface area of specimen, there could have been discrepancies due to unequal dimensions within a set of specimens. This has arisen from the difficulty in obtaining exactly equal dimensions during machining.

e) Also, the difficulty in obtaining exact surface finish values on machining made it impossible to directly compare specimens of equal surface finish. Such comparison could only be obtained by means of the graphs.

f) Many of the graphs only show approximate trends as the number of points are not large enough for obtaining accurate plots. This is due to difficulties encountered in obtaining specimens which cover a wide range of surface finish values coupled with the shortness of available times of exposure.

4. CONCLUSIONS

The foregoing constraints notwithstanding, the following conclusions can be made:

a) With the exception of ammonium hydroxide which produced a constant corrosion rate, all the other environments showed rapid initial corrosion rates which decreased with the passage of time. This trend is expected as the initial corrosion product provides some amount of surface protection against further attack.

b) There is a general increase in the extent of corrosion (represented by weight change) with increasing surface finish value, after all exposure times.

c) The graphs of weight change per unit surface area versus surface finish can be used to compare the agressiveness of different environments. For instance, the weight loss of mild steel for a surface finish value of 2.0μm after 200h of exporsure in 0.1M sodium chloride is 11.0 x 10^{-3}mg/mm^2 whereas the corresponding weight losses for 0.1M solutions of ammonium hydroxide and hydrochloric acid are 15.6 x 10^{-3}mg/mm^2 and 52.0 x 10^{-3}mg/mm^2 respectively (see point A in Figures 12, 13 and 14).

d) The graphs can also be used to compare the extents of corrosion of mild steel and medium carbon steel at any fixed surface finish value and exposure time in a particular environment. Thus the weight loss of mild steel of a surface finish value of 2.0μm after 200h of exposure in 0.1M ammonium hydroxide is 15.6 x 10^{-3}mg/mm^2, whereas the corresponding weight loss for medium carbon steel is 8.4 x 10^{-3}mg/mm^2 (see point A in Figures 13 and 17). Such comparisons obtained from results of extended exposure times can aid material selection for engineering applications.

e) From these graphs it is also possible to specify a maximum surface finish value which should not be exceeded for a specified exposure time or service life. For instance, for an expected service life of mild steel of 300h and a maximum corrosion of 17.0 x 10^{-3}mg/mm^2, a surface finish value not exceeding 2.46μm is specified for exposure in 0.1M sodium chloride (see point B in Figure 12).

f) Other metals such as cast iron, copper aluminium, brass, etc, used in everyday application can also be tested in relevant environments such as natural gas and oil, sea water, industrial and domestic waste waters, drinking water, etc. As many metals are usually exposed in fluid environments under flow conditions, experimentation can also be done under such conditiions.

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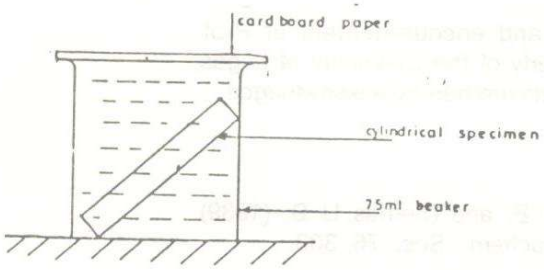


Figure 1 : Exposure in 0.1M solution

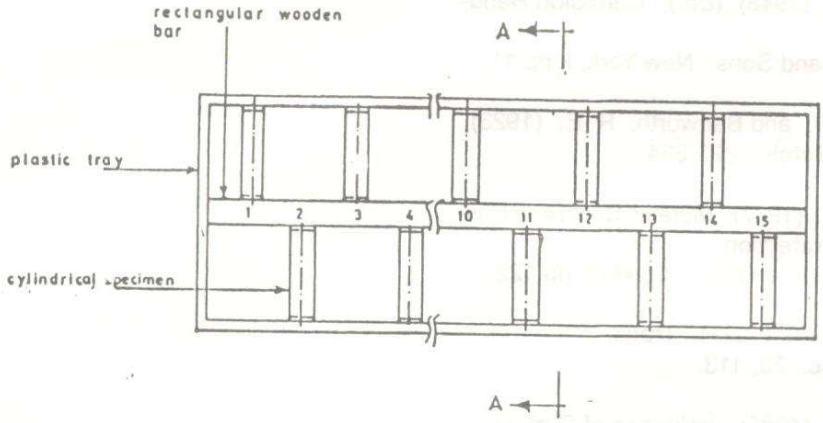


Figure 2a : Plan view of container

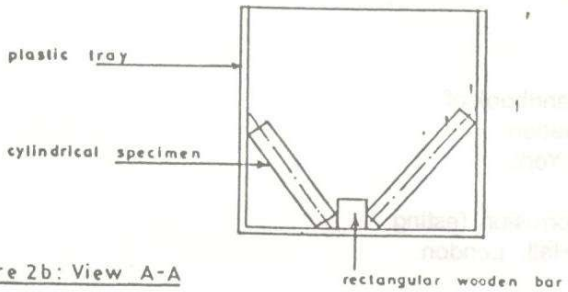


Figure 2b: View A-A

Figure 2 : Atmospheric Exposure

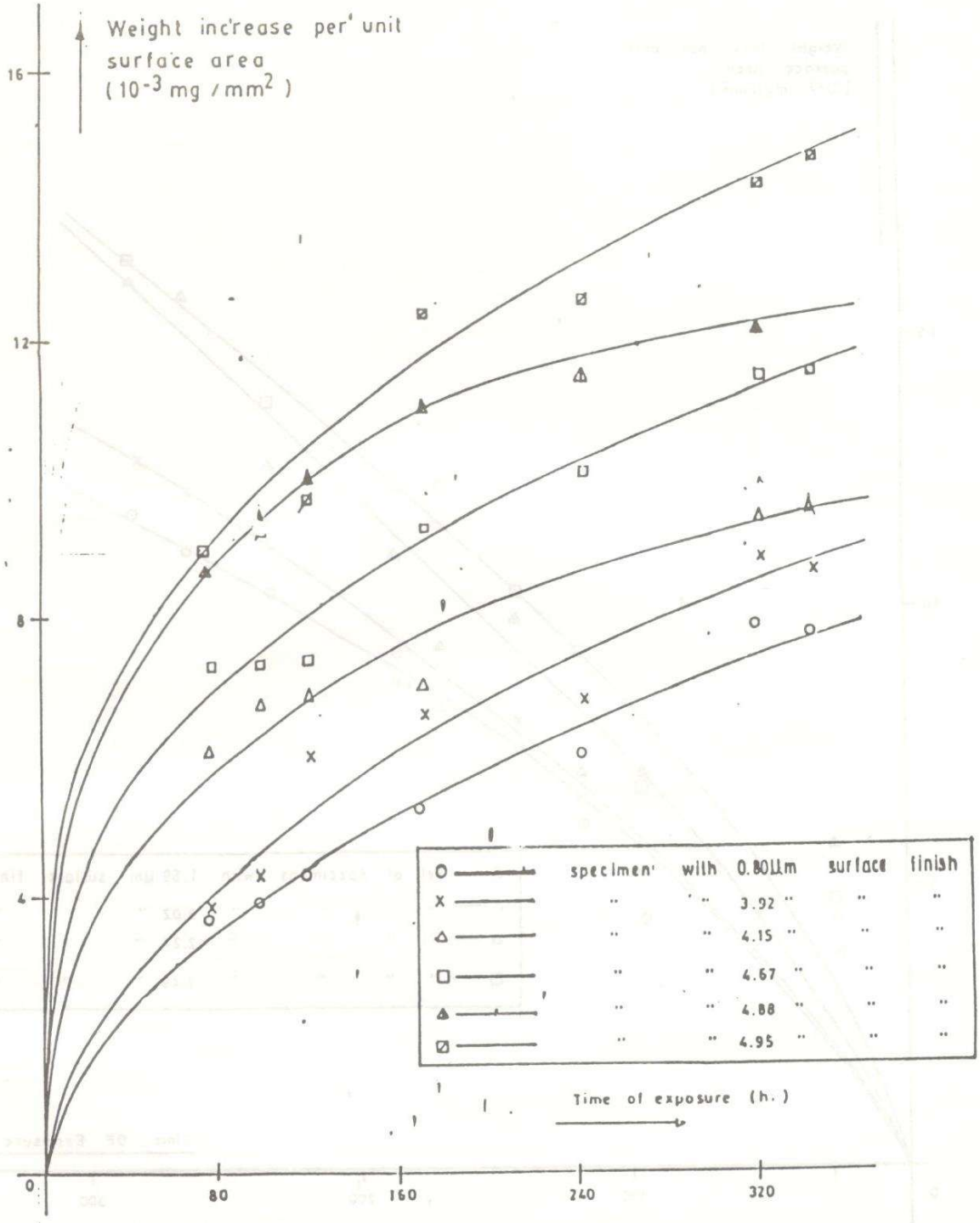


Figure 3: Corrosion/ time graphs of mild steel in the atmosphere

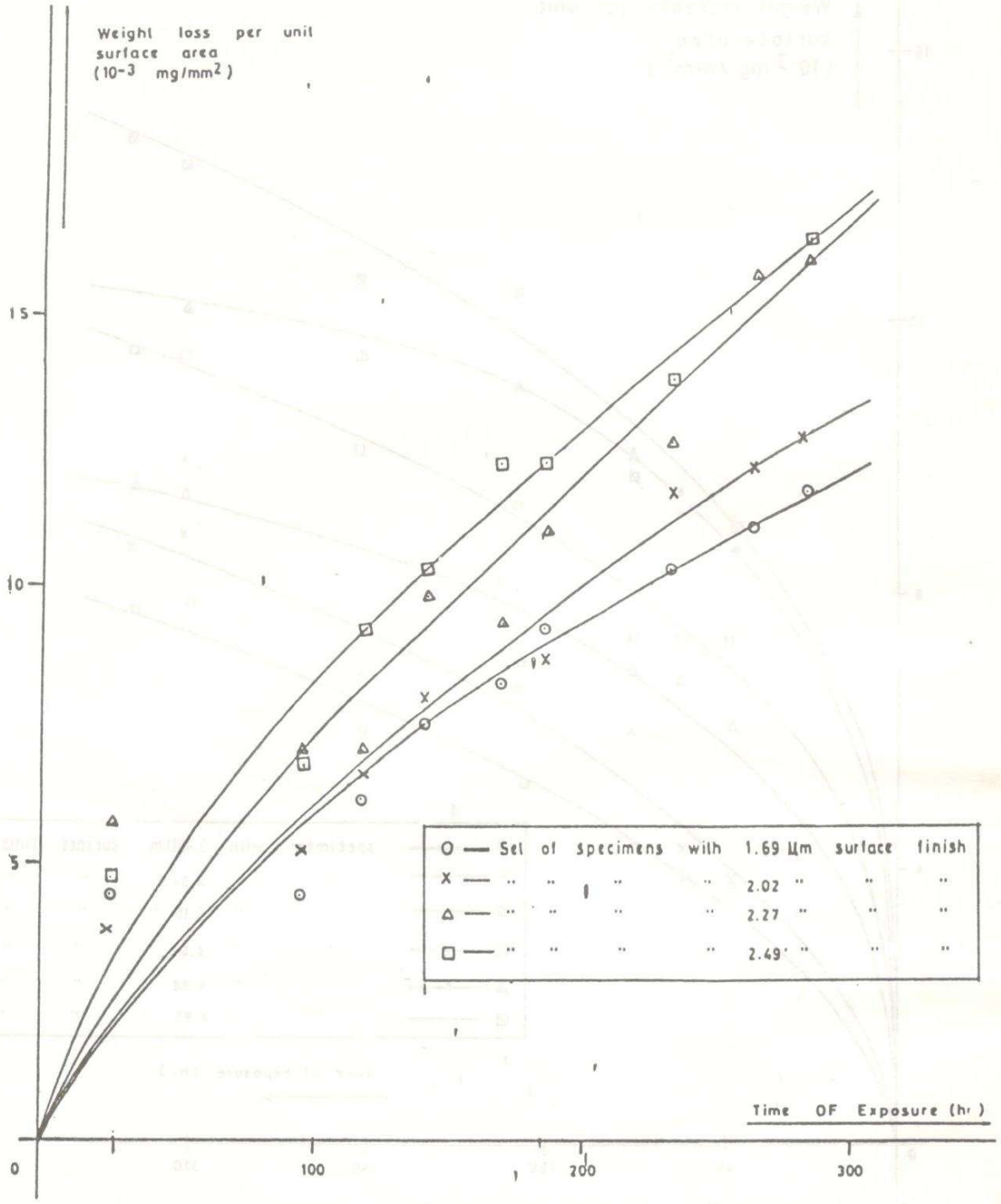


Figure 4: Corrosion/time graphs of mild steel in 0.1M sodium chloride

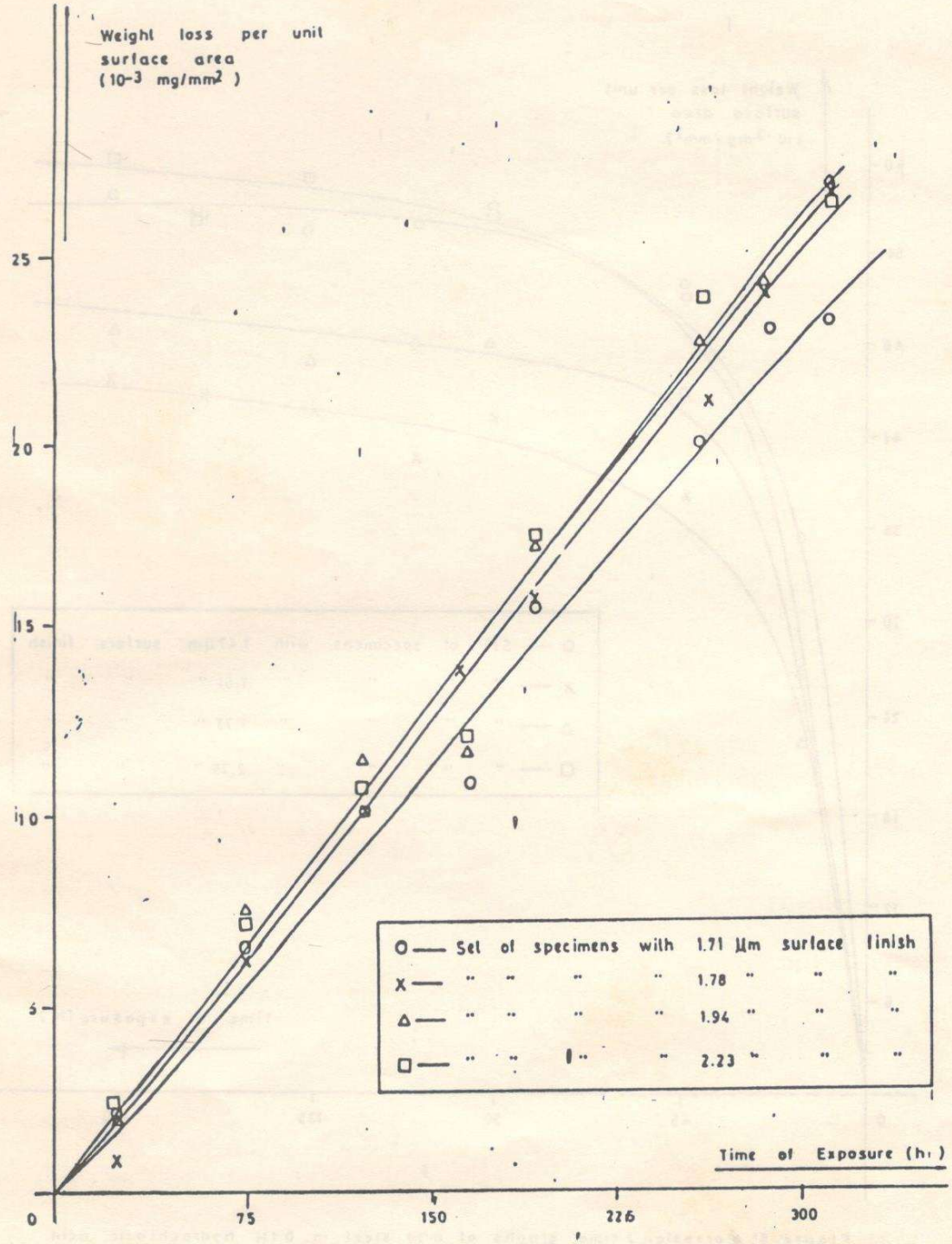


Figure 5: Corrosion/ time graphs of mild steel in 0.1M ammonium hydroxide

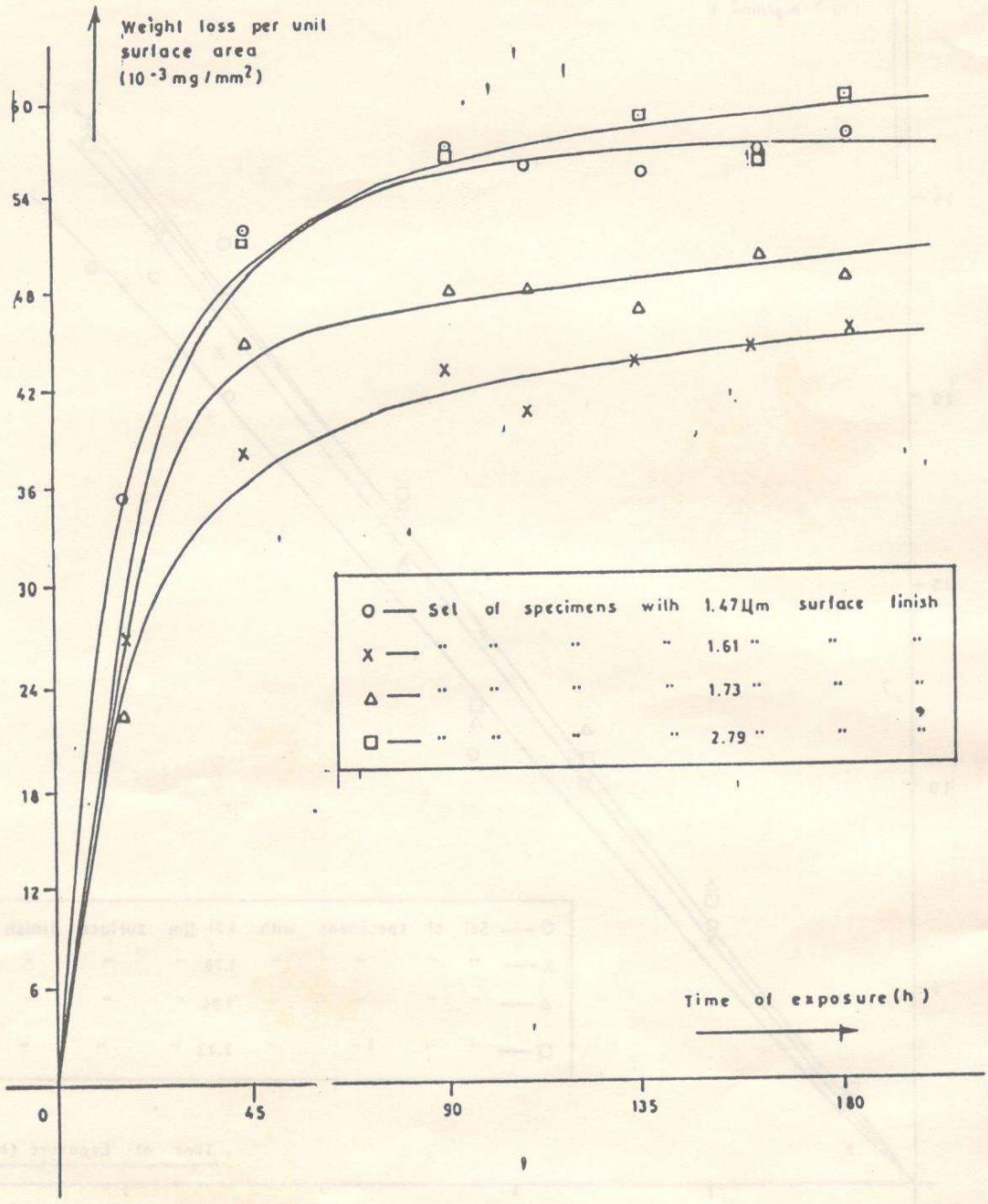


Figure 6: Corrosion / time graphs of mild steel in 0.1M hydrochloric acid

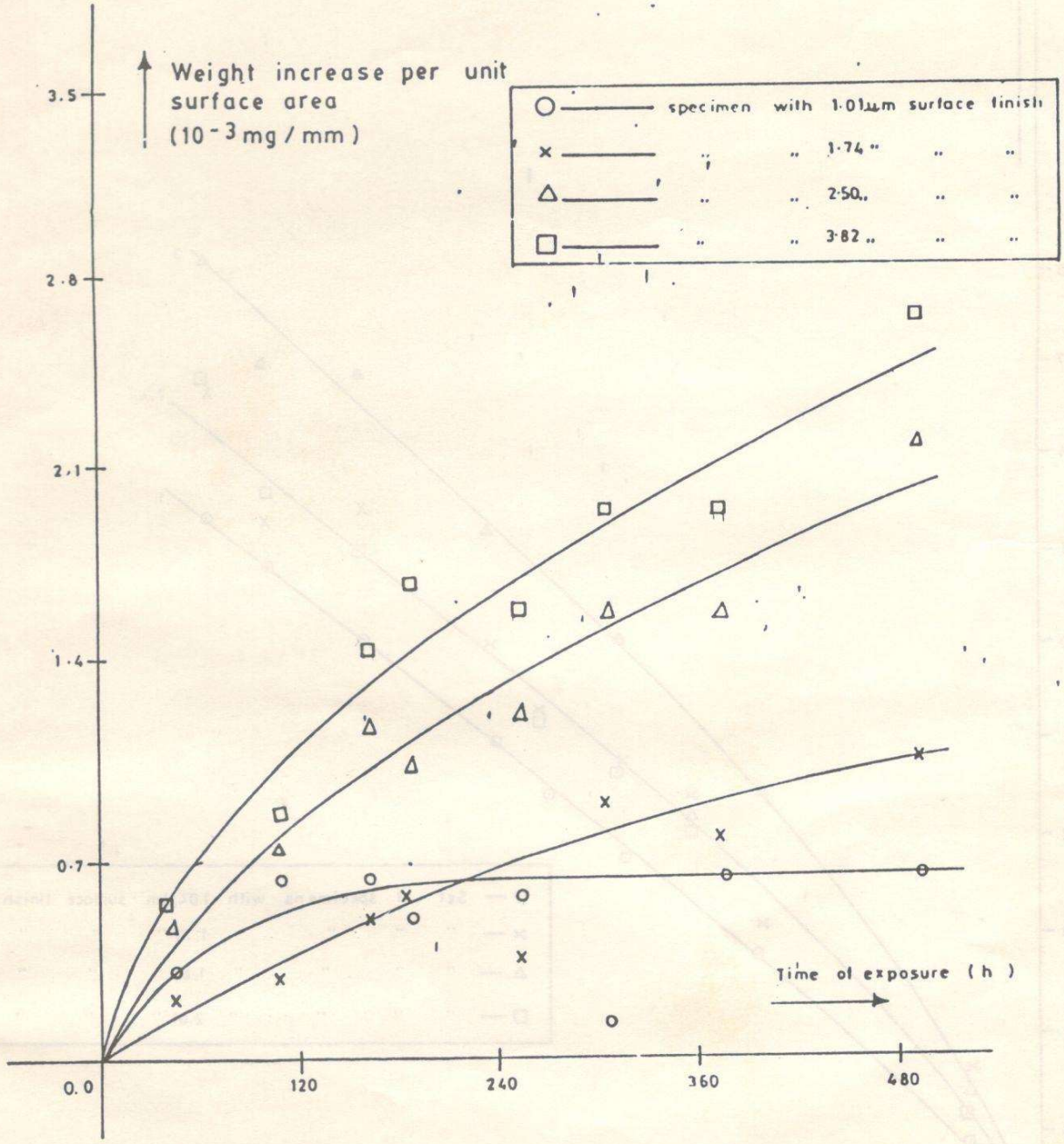


Figure 7: Corrosion / time graphs of medium carbon steel in the atmosphere

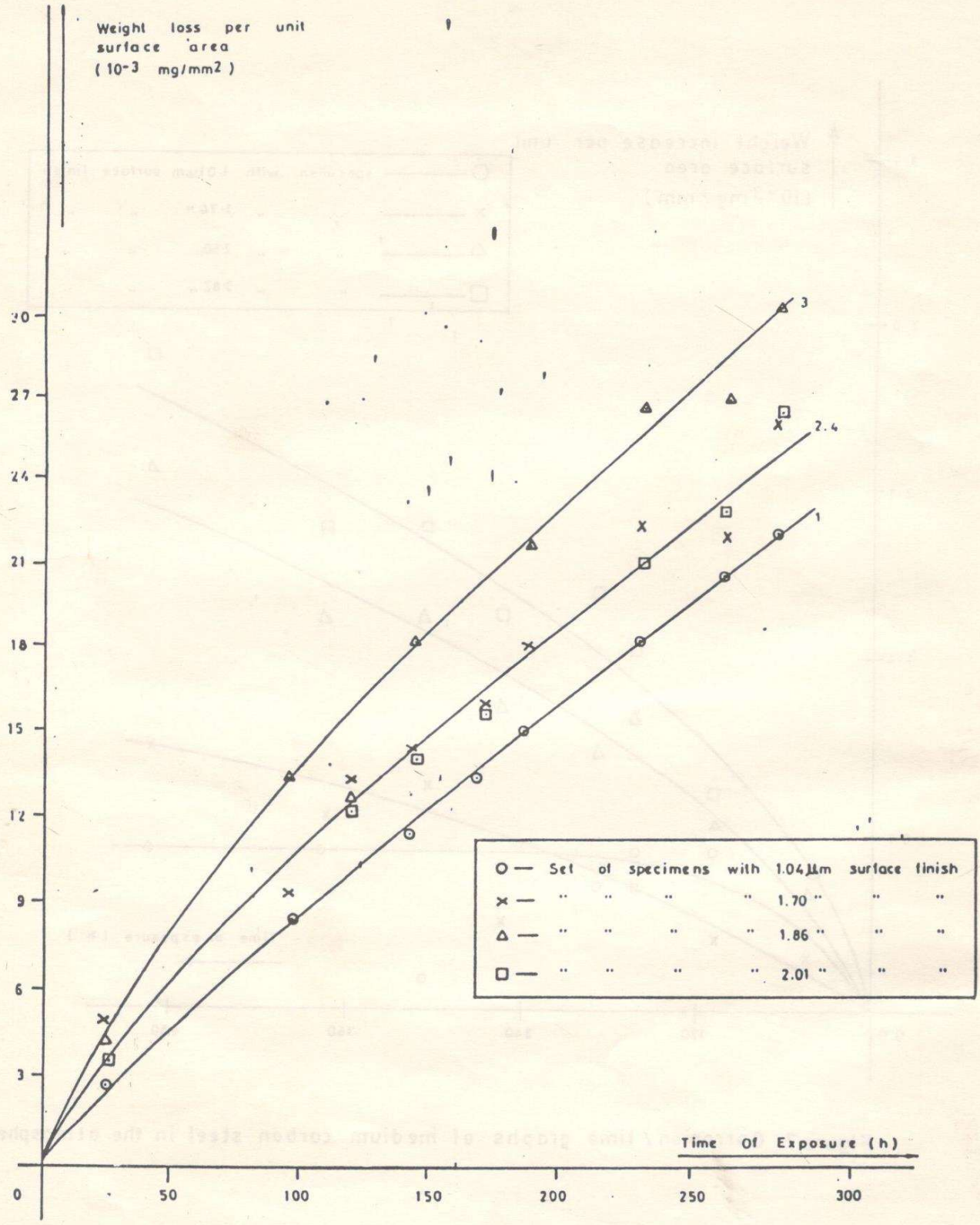


Figure 8: Corrosion/time graphs of medium carbon steel in 0.1M sodium chloride

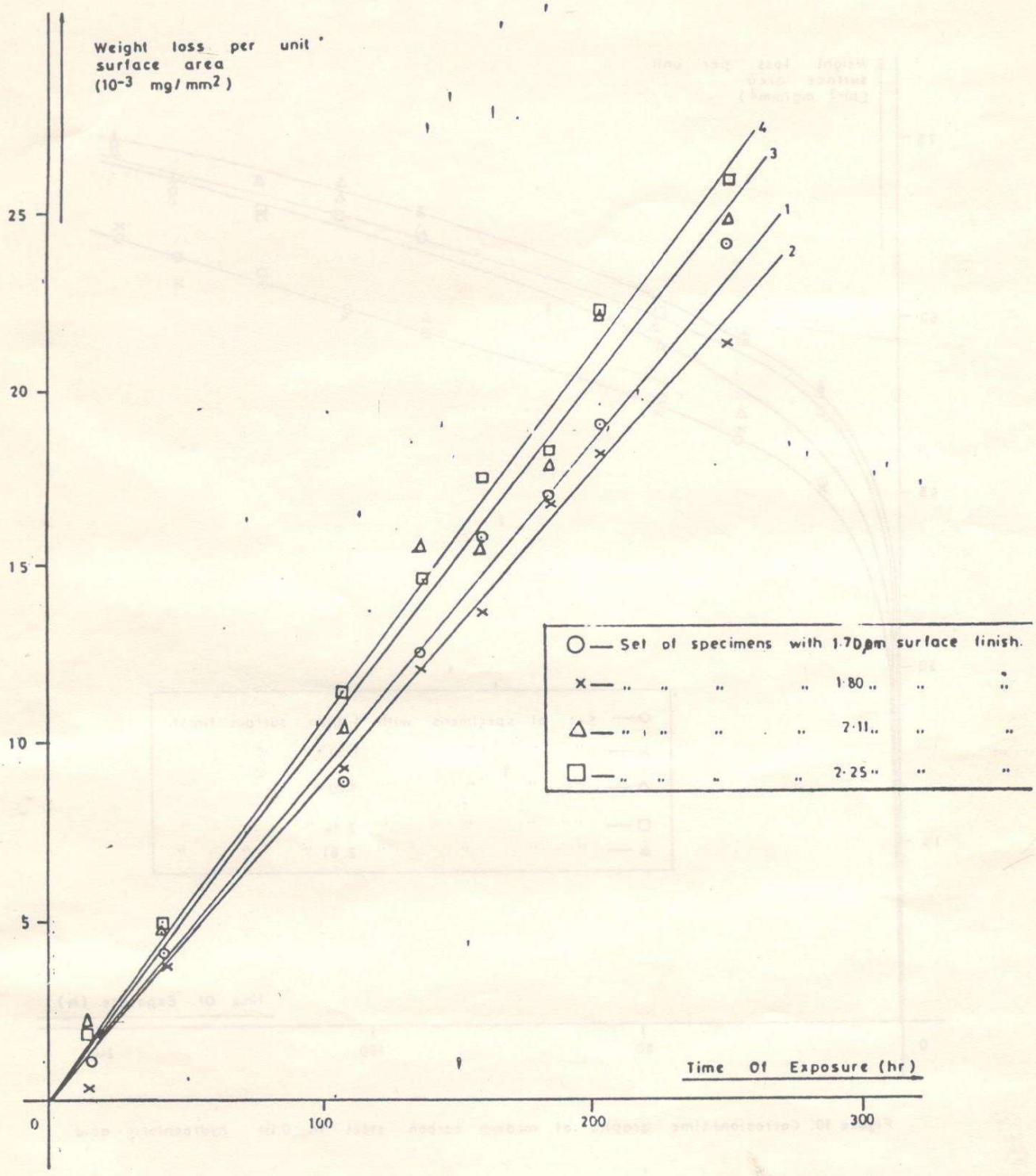


Figure 9: Corrosion/time graphs of medium carbon steel in 0.1M ammonium hydroxide

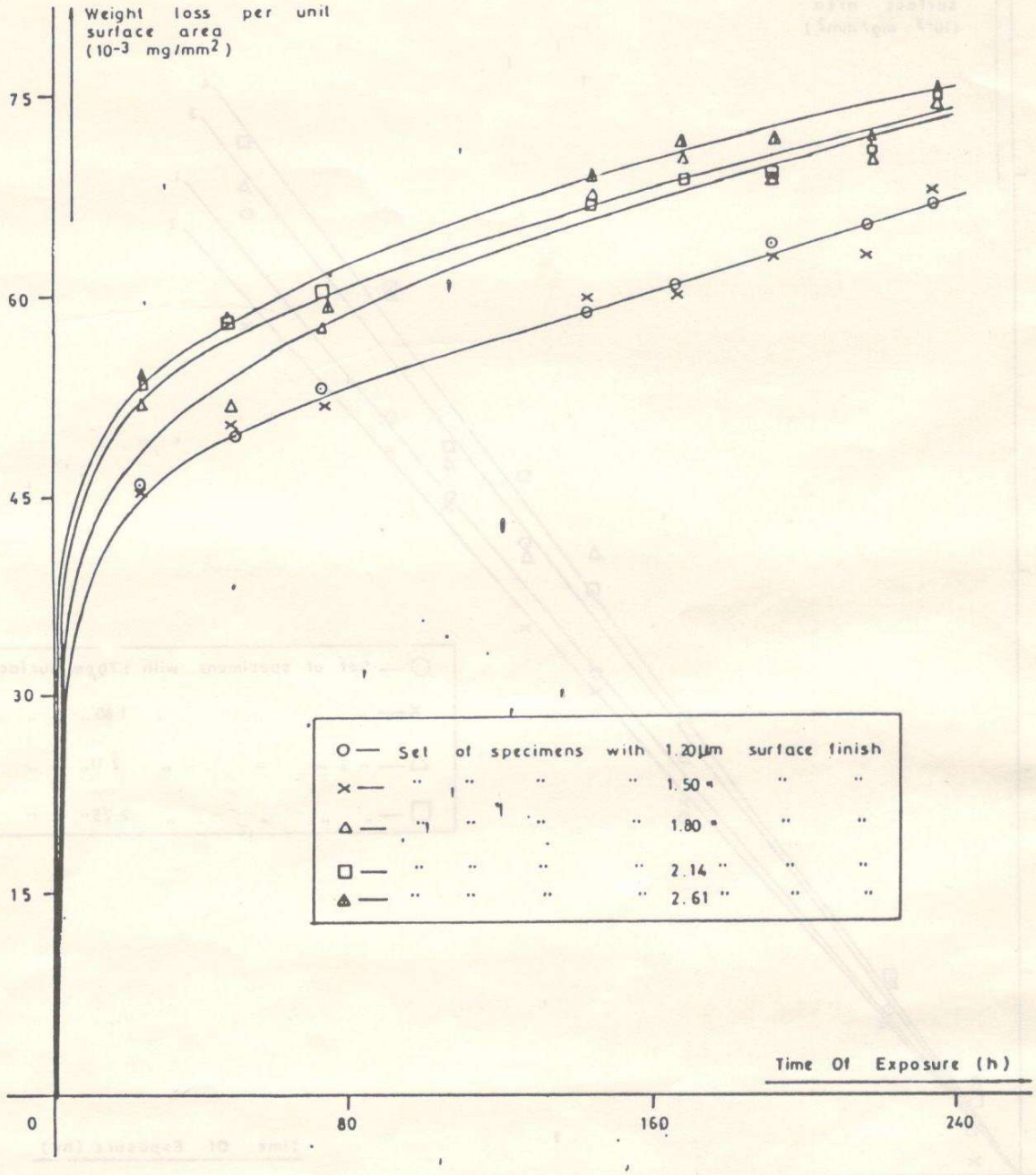


Figure 10: Corrosion/time graphs of medium carbon steel in 0.1M hydrochloric acid

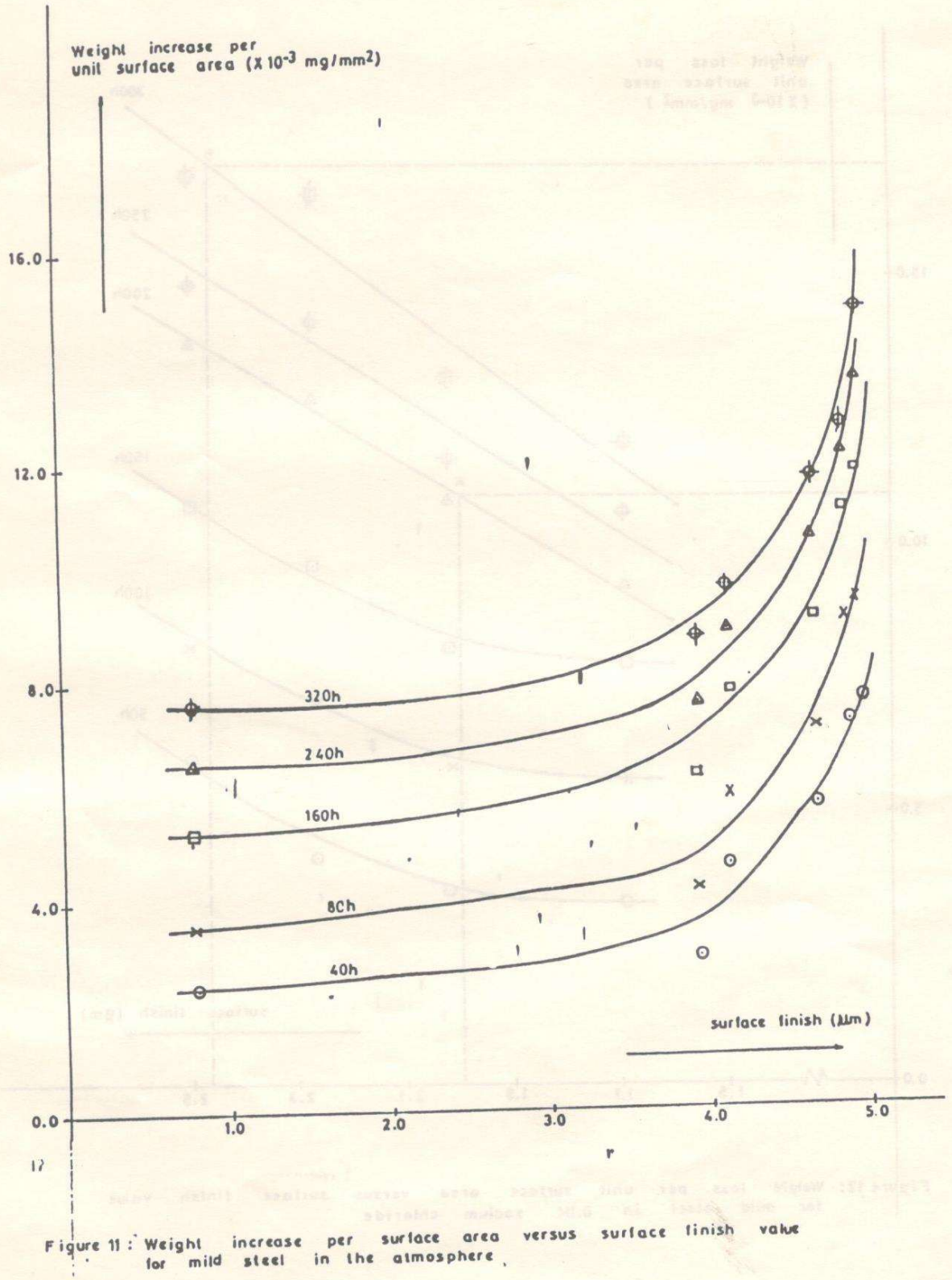


Figure 11 : Weight increase per surface area versus surface finish value for mild steel in the atmosphere.

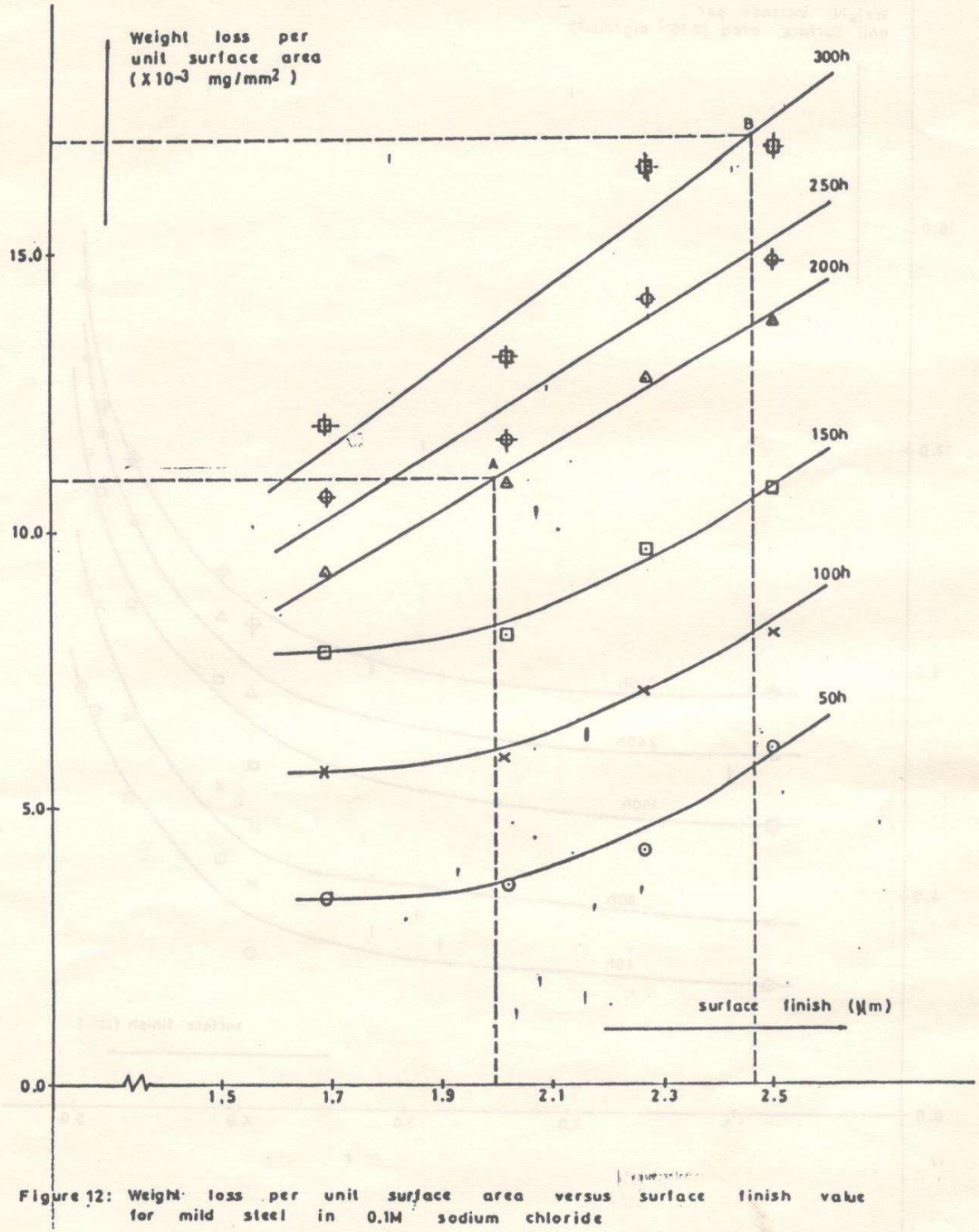


Figure 12: Weight loss per unit surface area versus surface finish value for mild steel in 0.1M sodium chloride

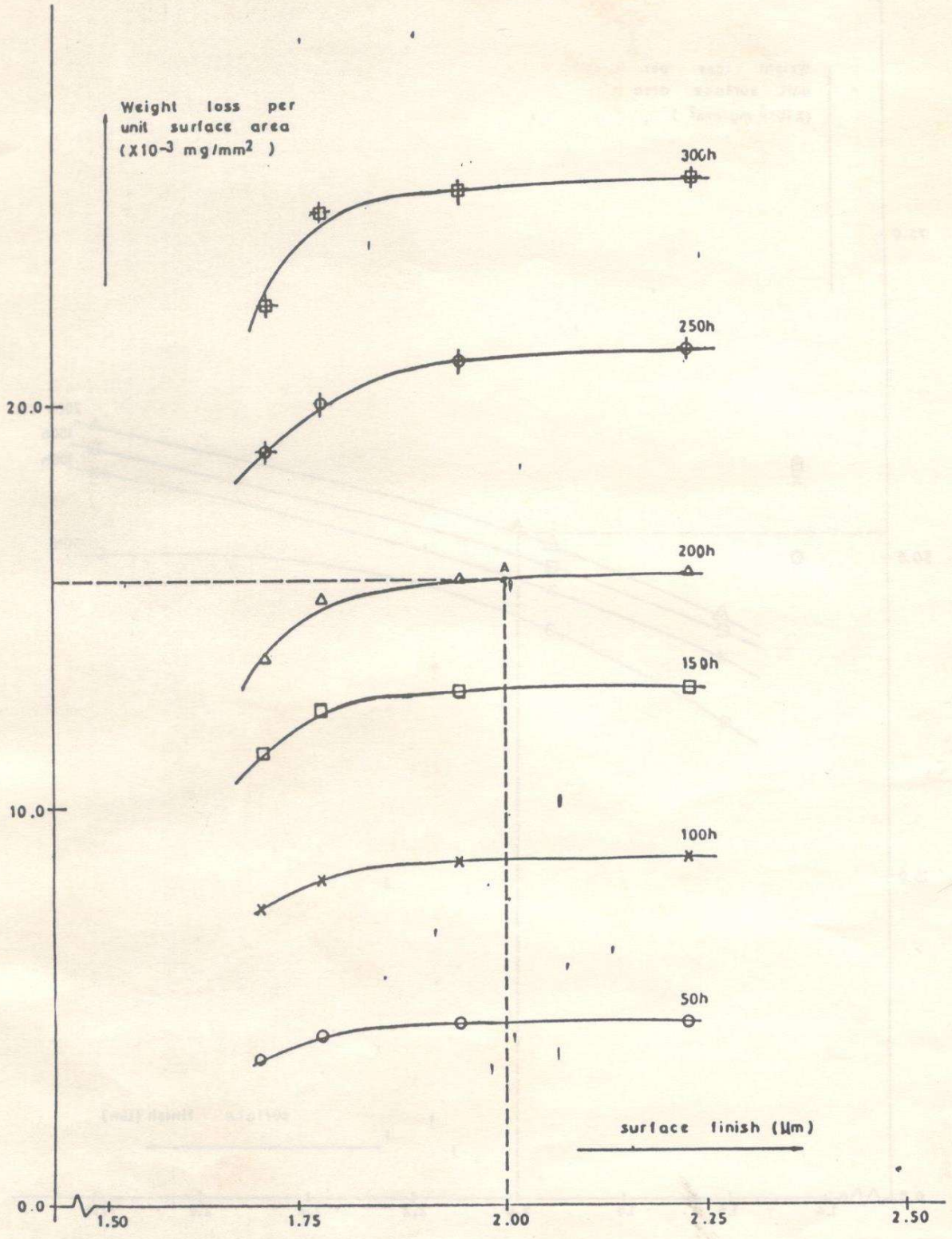


Figure 13 : Weight loss per unit surface area versus surface finish value for mild steel in 0.1M ammonium hydroxide

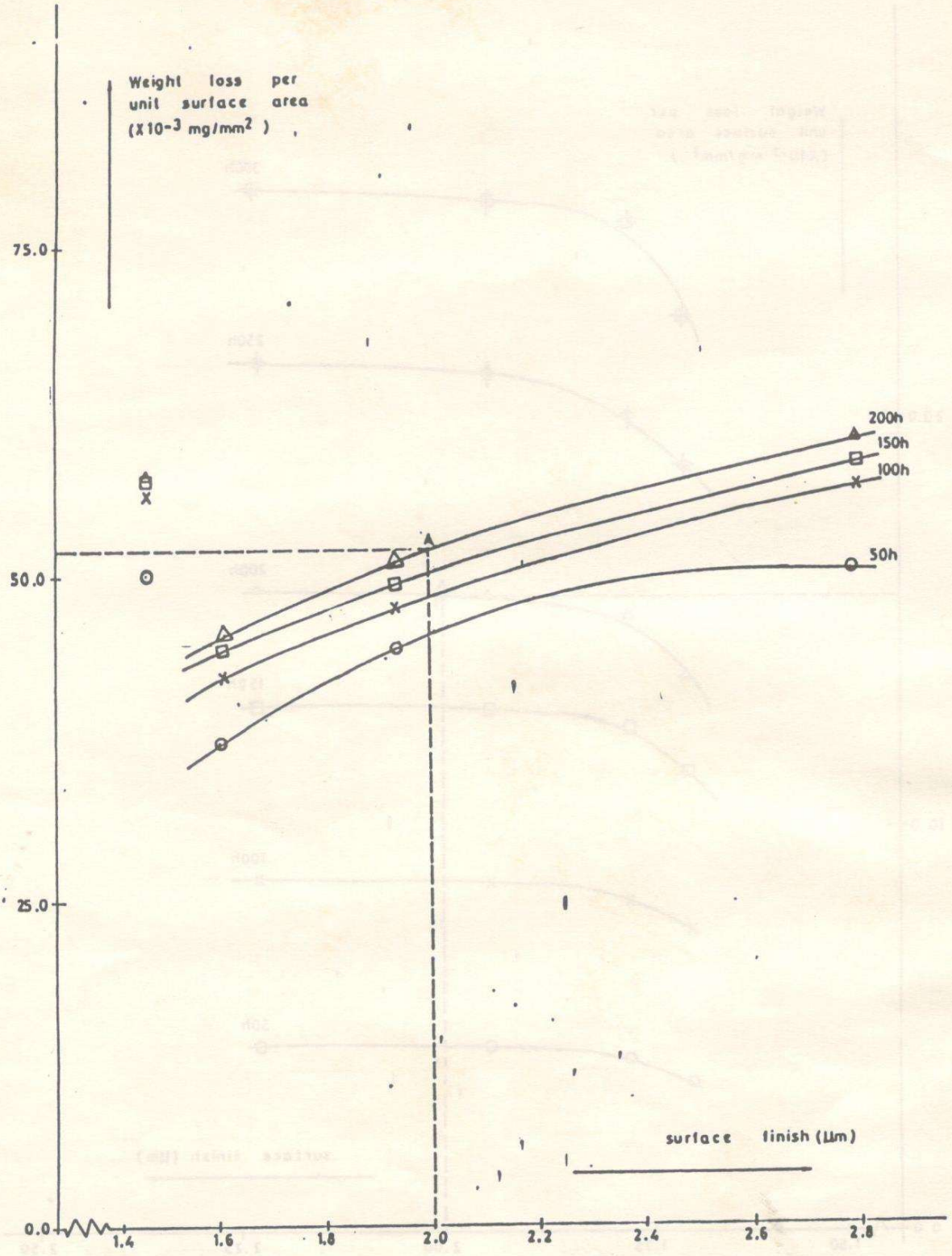


Figure 14: Weight loss per unit surface area versus surface finish value for mild steel in 0.1M hydrochloric acid

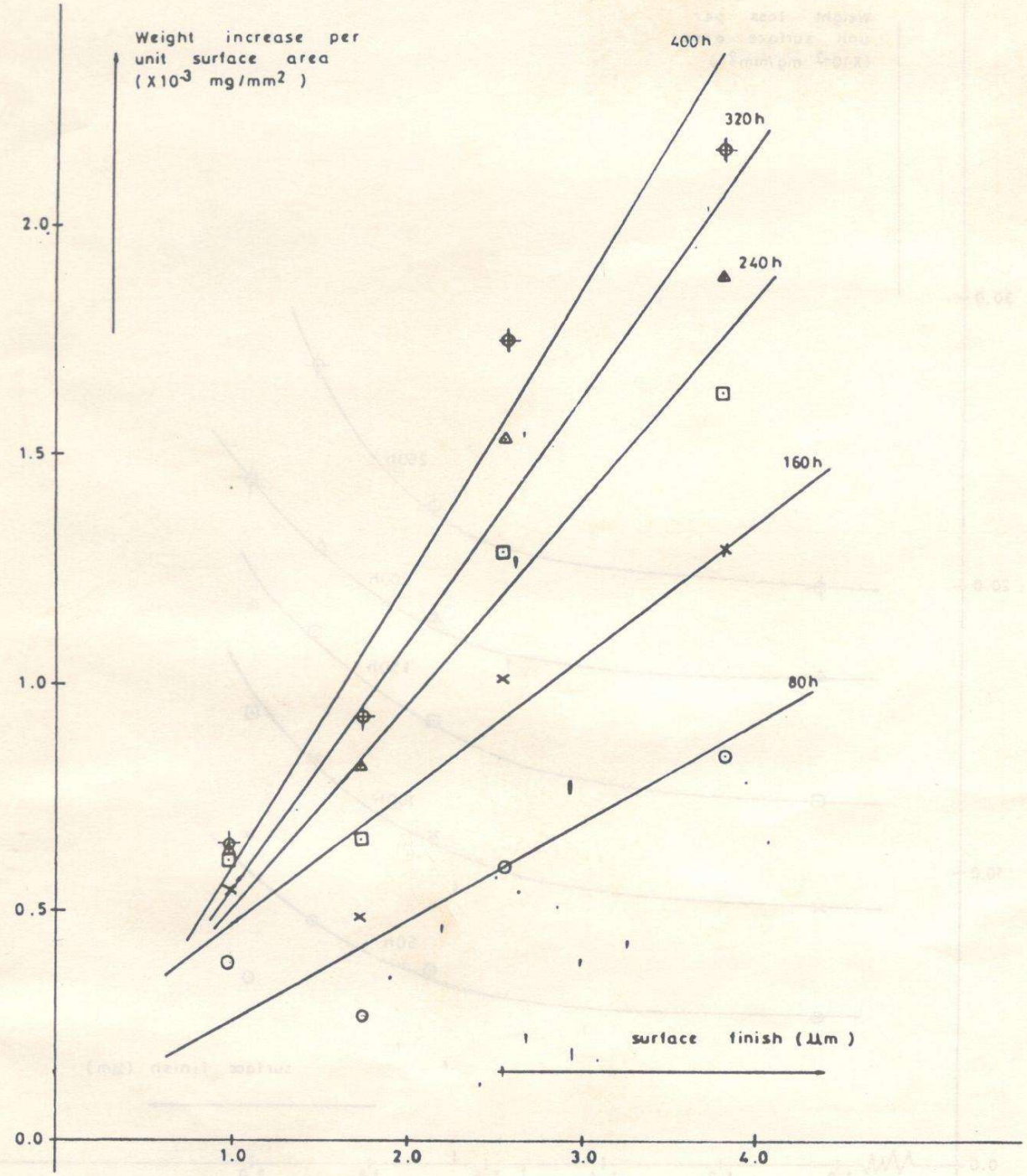


Figure 15: Weight increase per unit surface area versus surface finish value for medium carbon steel in the atmosphere

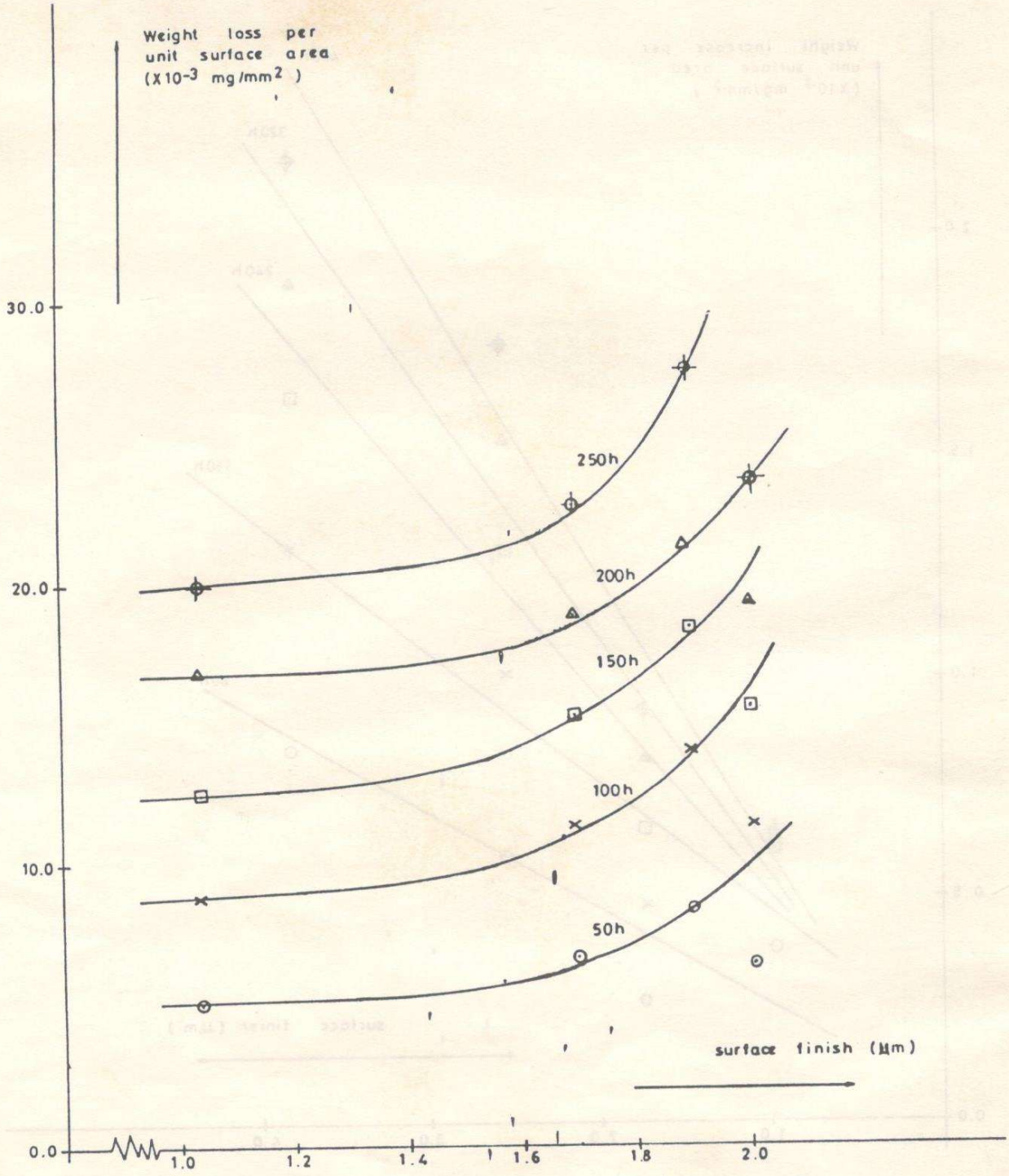


Figure 16 : Weight loss per unit surface area versus surface finish value for medium carbon steel in 0.1M sodium chloride

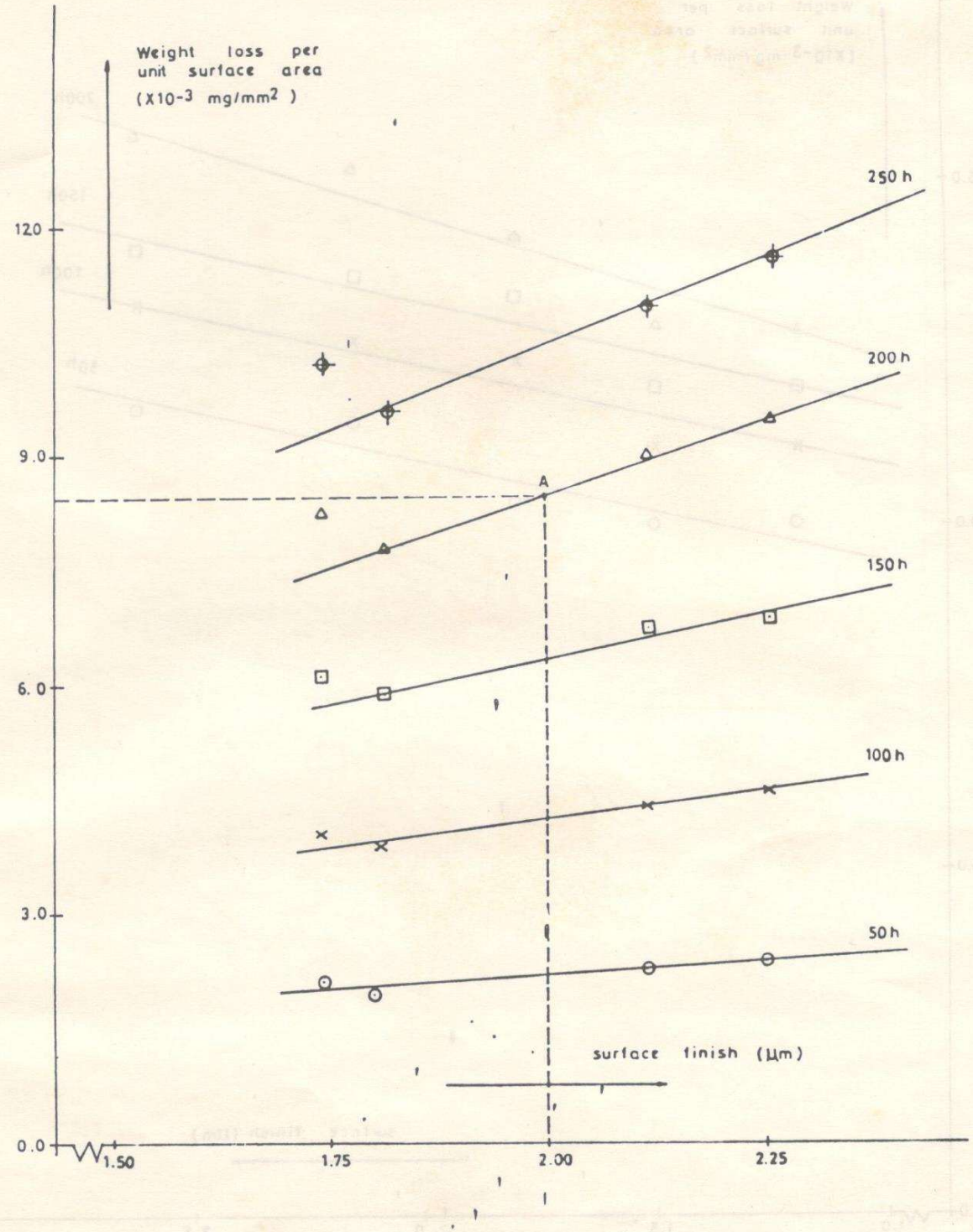


Figure 17 : Weight loss per unit surface area versus surface finish value for medium carbon steel in 0.1M ammonium hydroxide

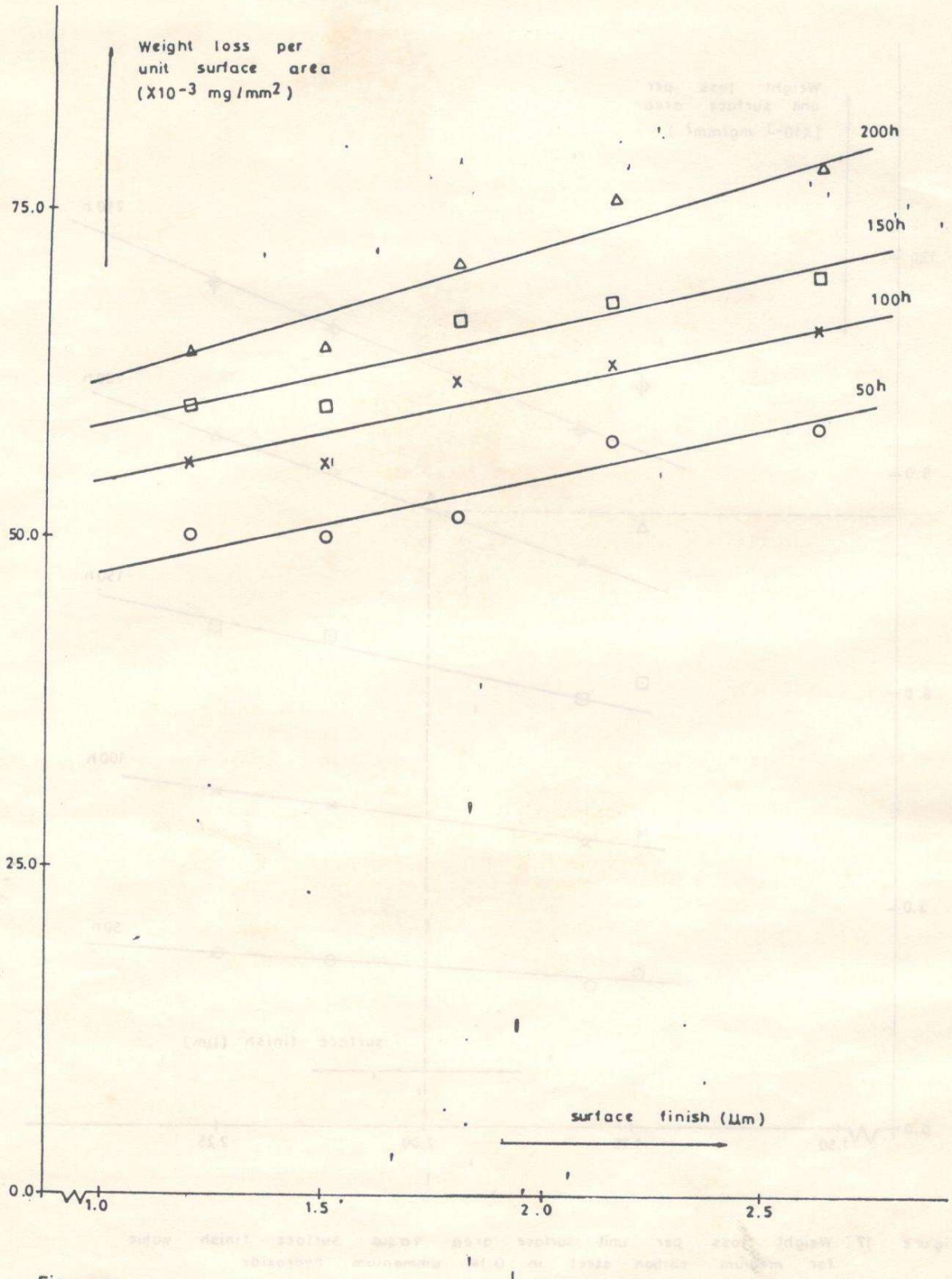


Figure 18: Weight loss per unit surface area versus surface finish value for medium carbon steel in 0.1M hydrochloric acid