AN ANALYTICAL INVESTIGATION OF A FAILED 1120 ALUMINIUM WIRE

By

C. A. Loto
Center for Engineering Research
The Research Institute
King Fahd University of Petroleum & Minerals
Dhahran 31261, Saudi Arabia

ABSTRACT

An analytical investigation was performed on an 1120 aluminum wire which failed under stress test. Scanning electron microscopy (SEM) examination and the energy depressive spectrometer (EDS) analysis were the major analytical methods of investigation used. The failure mode of the alloy was found to be that of brittle failure interspersed with ductile failure. The brittle failure results from the second phase particles contained within the aluminum matrix which rendered the structure in that region weak and hence susceptible to failure under stress tests.

KEY WORDS: Brittle, ductile, aluminium wire, failure, analysis.

INTRODUCTION

Failure analysis is a technique by which facts are gathered and studied to determine the cause of an equipment or part failure so that preventive action may be taken. This technique of analysis has been described as an indispensable problem-solving tool because it focuses on the why of failure [1]. It is important that a satisfactory method be available for the engineering evaluation of an item of equipment that fails prematurely. It is known, that the studies of failure can provide valuable information in meeting future design needs or modifications in usage that can prevent future failures, apart from a primary objective of solving the specific problem at hand [1]. Yet, the lessons that can be learned from failures are usually ignored.

Each failure investigation is unique. However, it has been found that certain basic steps are usually useful in determining the root cause of the failure. Which of the steps are most relevant to a particular failure investigation will depend, of course, on the nature of the failure [2]. Such basic steps include: (1) defining the problem; (2) obtaining background information; (3) field investigation and collection of evidence; (4) examining evidence in the laboratory; (5) evaluating the failure sequence and causes; (6) performing exemplar test; (7) performing calculations (where necessary); (8) risk assessment; (9) drawing conclusions and making recommendations.

There are a number of examination methods used in failure analysis. The type of examination selected depends on the nature of the system, components, or structure; and on the way it failed. Material relevant to physical testing has been documented [3-8].

One of the most promising new techniques in the failure analysis is electron fractography which makes use of the electron microscope. The electron microscope is used as a unique tool for the characterization of the fracture mechanisms associated with complex failures. In addition, the fracture mode and the effect of environment is generally readily identifiable. The relation between the fracture surface structure developed and the type of fracture, effect of environment, type of loading, direction of loading, rate of strain, temperature, twinning, etc., is possible with this technique [9]. The scanning electron microscope (SEM) can magnify surfaces from as low as 5 x and up to 240,000 x. One of the several accessories available for the SEM is the dispersive X-ray spectrometer. The dispersive is a micro-spectro-chemical technique of the same principle as the electron microscope analyzer. The scanning electron microscope and the energy dispersive spectrometer (EDS) are the major tools of analysis used in this work.

Usually, all the different fracture surfaces viewed by the SEM are classified into only six mechanistic and appearance types viz: ductile failure; b cleavage, quasi-cleavage, hydrogen embritt stress corrosion cracking, and fatigue crackin is important to note, however, that a s mechanism is rarely involved. A failure wil by one system but may switch to others. A mi of fracture modes is the common experienc during the crack propagation and crack terminat

A brief description of the fracture modes will be given. ***Ductile failure*** of most alloys o coalescence of voids growing at microscopic of strain discontinuities such as grain bound inclusions when the alloy is in tension over The rounded, "dimple" topography is charac of a ductile failure. The three modes of coalescence that have been reported are a normal rupture, and shear rupture [10]. ***B cleavage*** is a transgranular fracture progressing along well-defined crystallogra planes. The mixed tongue and river patte characteristic of a brittle tension failure mecha According to Garland [11], all metals (and ce have been classified into four groups accordi their brittleness (or ductility). (1) Ductile temperatures, ductile at room temperature, brittle at low temperatures, appreciable duc elevated temperatures, (3) brittle at temperature, ductile at elevated temperatur (4) brittle at all temperatures. The other phenomena include hydrogen embrittlemen

rrosion cracking, and fatigue cracking (mentioned rlier). McCall of Battele has compiled a review of e representative literatures on failure analysis in s MCIC (Metal & Ceramics Information Center) port [12]. Many other recent work [13-15] on failure alysis of metallic components in different nditions had also been reported.

e analyzed aluminium wire samples in this work re obtained from Midal Cables Ltd., Bahrain. e wire had been produced and stored for two ars under normal environmental conditions at rth, Australia. Very recently, the wires were sted mechanically and some portions were found lose ductility and failed.

VESTIGATION PROCEDURE

aterials

e as – received aluminium wire samples (from dal Cables Ltd. Bahrain) were of AAC (all minium conductors) of 1120 grade. The product s of 3.25 mm dia and with the percent chemical mposition of 0.74 Si, 0.332 Fe, 0.729 Cu and the t – 99.48 Al. The aluminium wire can be nsidered to be of almost complete purity.

eparation of specimen

e aluminium wire samples were cut into several gths as test pieces suitable for scanning electron croscopy (SEM) examination. The failed parts were cut, cleaned and mounted in moulding resins (araldite) without any further treatment. The immediate vicinity of the failed area(s) were also cut and separately mounted in the moulding resins. Each of the aluminium wire samples, was further cut in cross-sections, mounted in the moulding resins, ground, polished and etched with the Keller's reagent.

Scanning electron microscopy (SEM) examination and energy dispersive spectrometer (EDS) analyses

Each of the prepared aluminium test pieces was thoroughly examined in the scanning electron microscope. The SEM was used to view, examine and determine the failure morphology/mode, topography and to reveal any available second phase particles (impurities).

Micrographs were made of different representative areas of interest at different locations inside and near the edge of the failed cracks. Similar micrographs were made along the surface lengths of the examined aluminium wire samples. The analyses of the chemical compositions of the examined portions of the failed specimens were made by the energy dispersive spectrometer (EDS).

RESULTS AND DISCUSSION

The various scanning electron microscopy (SEM) micrographs and their corresponding EDS analyses, made for the major failed (cracked) surface; and

other cracked surfaces in the as-received failed aluminium wire sample, are presented in Figs. 1 to 15 and in Figs. 17 and 18.

Fig. 1 shows the micrograph made for the largest open microscopic failure. It presents no details for further analysis at that magnification of 130 x. However, at the inside center of the crack failure, Fig. 2, at a magnification of 2000 x, there are located many distinct grains or particles with well-defined grain boundaries. The phenomenal appearance is different from that of the matrix. The mode of failure was apparently that of brittle failure, while the surrounding matrix presents a feature of mixed brittle and ductile failure.

Fig. 3 shows the particles located at the center of the crack described above in Fig. 2, but at a higher magnification of 7000 x. The EDS analysis of the apparent, widely separated particles is presented in Fig. 5. Fig. 4 shows the internal feature of the open crack failure at a magnification of 600 x.

The EDS analysis shows clearly the peak of elemental oxygen in addition to the base aluminium. Also apparent in Fig. 5 is the peak for chlorine (Cl) – an indication of the presence of chloride ions. Oxygen in combination with aluminium inside the matrix is an indication of the presence of alumina (Al_2O_3). This is a deleterious impurity inside the aluminium matrix that weakens the structure. Under the application of high stress, such as used in testing of the aluminium wire, it will yield embrittlement. The presence of chloride as inclusion of the grain within the matrix is diffi to explain.

The micrograph of another open crack failure presented in Fig. 6. A magnified feature (2000 x its edge failure mode, is shown in Fig. 7. Fig shows the inside and the edge (near) features of crack. The upper middle right portion of Fig. 8 magnified form (4000 x) is presented in Fig. 9. F 6 and 7 show brittle failure appearance at the ed In Fig. 8, a brittle failure mixed with ductile fai is clearly shown. The feature in Fig.9 is a fur evidence of this phenomenon where the sec phase particles are distinctly shown. The g boundaries are widely separated. Some of particles could be observed in the micrograph t fragmented. The failure mode here was that brittleness. These second-phase particles created a region of weakness and stress within aluminium matrix. Under applied stress suc used in the test, an unexpected failure could oc The EDS analysis of the particles in Fig. presented in Fig. 10. The peaks show the prese of copper with the constituent elem composition of 19.16%, and oxygen, 5.07% addition to the base aluminium.

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g. 11 shows the SEM micrograph mode of failure
ar the edge of the crack in Fig. 6. A higher
gnification of Fig. 11 (4000 x) is presented in
g. 12. The observed second phase particles here
as described earlier. The striking difference,
wever, is the dark particle within the grains and
matrix. An analysis of the dark particle, Fig. 13,
the EDS , confirms the presence of iron (Fe), the
nstituent composition which amounts to 1.90%.
e presence of oxygen at 7.94% also confirms the
ains to be alumina. It can thus be inferred that the
uminium matrix consists of alumina, which also
ntains iron. The overall effect, therefore, will be
t of weakening the aluminium structure, raising
stress, and hence rendering it susceptible to
ess cracking failure under test.

esented in Fig. 14, is the failed surface and the
elding crack steps that led to the failure. The only
iking things examined are the particles that were
cated on the crack steps. The EDS analysis of a
presentative particle is presented in Fig. 16. It
nsisted of various chemical constituents which
clude C, O, Cu and Ca. These particles are known
be detrimental to the desired ductility of
uminium particularly when in compound form
ch as observed in this aluminium wire with the
cond phase particles.

he last observation made from the examinations of
e surface of aluminium wire specimen that failed
under test is that of an irregular shallow pit-like corrosive degradation in the vicinity of the failed portion. This feature is presented in Fig. 15. The EDS analysis made of the pit confirmed the presence of C, O, Na, Cl, K and Al (Fig. 17). At another site of the pit, Fig. 18, the presence of Si, O, and C are confirmed in addition to Al. This phenomenon is an evidence of corrosive degradation that resulted due to the long-time exposure of the aluminium wire in storage, to the atmosphere laden with sodium chloride contained in the atmospheric moisture. While the presence of chloride ion is recognized here, it is not considered strong enough to be the cause or major cause of the failure of the tested metal. It could, however, make a contribution to the failure, especially in the region that has already been weakened by the second phase particle impurities such as observed in this failure analysis. While the presence of oxygen can be associated with alumina, the high percentage of carbon present can be associated with aluminium carbide. The presence of these elements and Si, are harmful to the mechanical strength of the metal.

Metallographic studies

The purity of the 1120 aluminium wire (99.50%), rendered the metallographic studies difficult. It did not respond well to all the etchants used. However, the etched surface obtained is shown in Fig.19. It contained dark patches and no grain boundary was discernible in spite of the high magnification of the

SEM (1,600 x) used. The EDS analysis of the dark patches, Fig. 20, shows it to contain Cu, Si, C, O, and little Ca. The presence of these elements is in agreement with what was obtained when the surface corrosion pit and some particles were analysed by the EDS.

CONCLUSION

From the results/observations, it could be inferred that the failure of the aluminium wire was that of the brittle failure interspersed with ductile failure. The brittle failure results from the second phase particles contained within the aluminium matrix which rendered the structure in that region weak and hence susceptible to failure under stress tests.

There was evidence of surface corrosive pit-like formation and the presence of chloride. However, these can not be considered to be serious enough to cause the failure. It could make a contribution to such a failure if located within the area where the second phase particles are located. Intergranular failure was visible only within the location of the second phase particles.

The failure of the aluminium wire under test could be attributed to the presence of impurities such as alumina, silicon, copper, carbon (alumina carbide) present in the wire.

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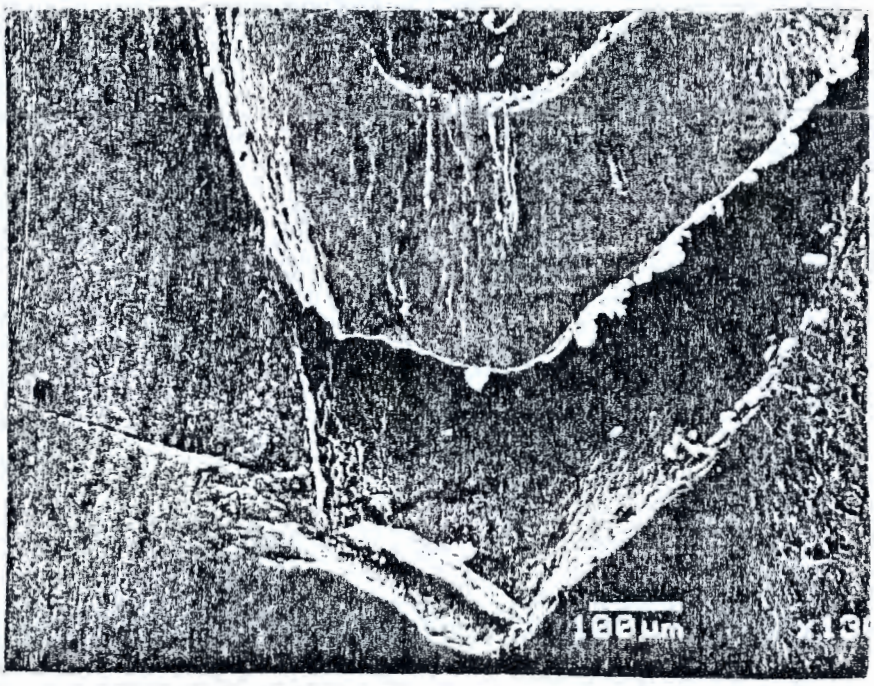

Fig. 1. Failed surface of as-received aluminium wire

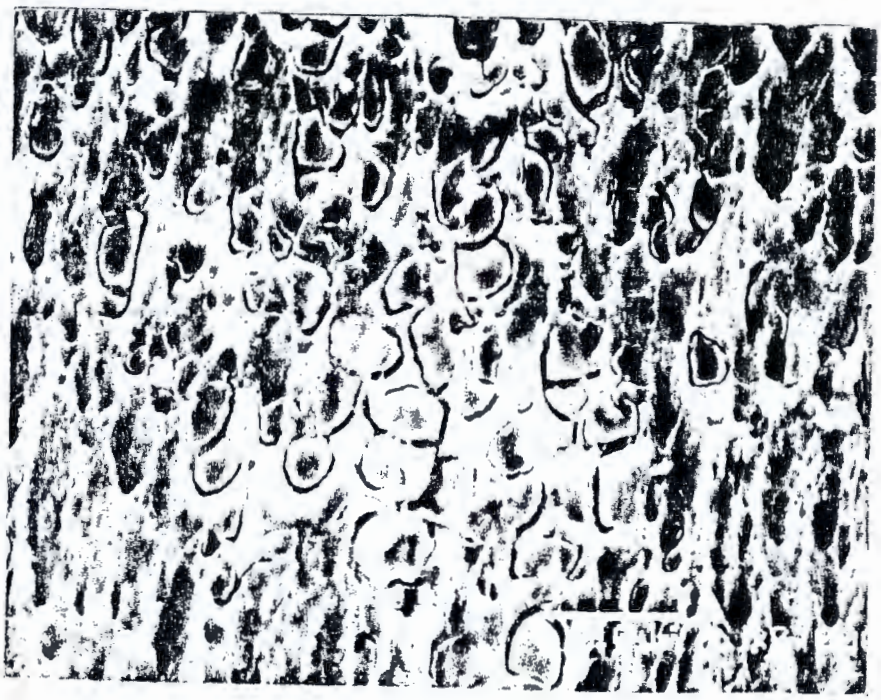

Fig. 2. Inside surface feature of the failed aluminium wire.

Fig. 3. Second-phase particles inside the failed surface matrix.

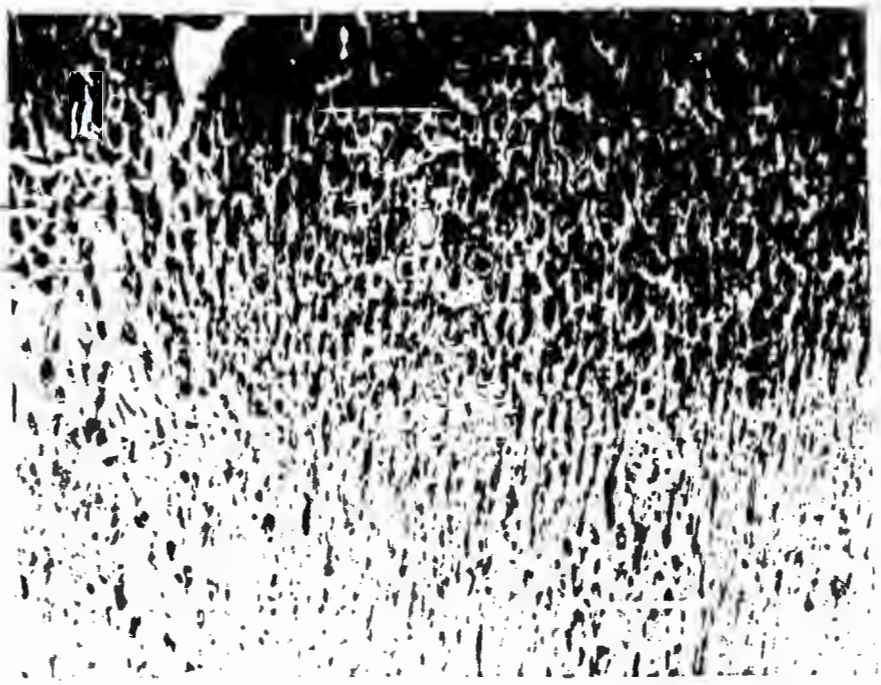

Fig. 4. Failed aluminium surface topography at a lower magnification (600 x)

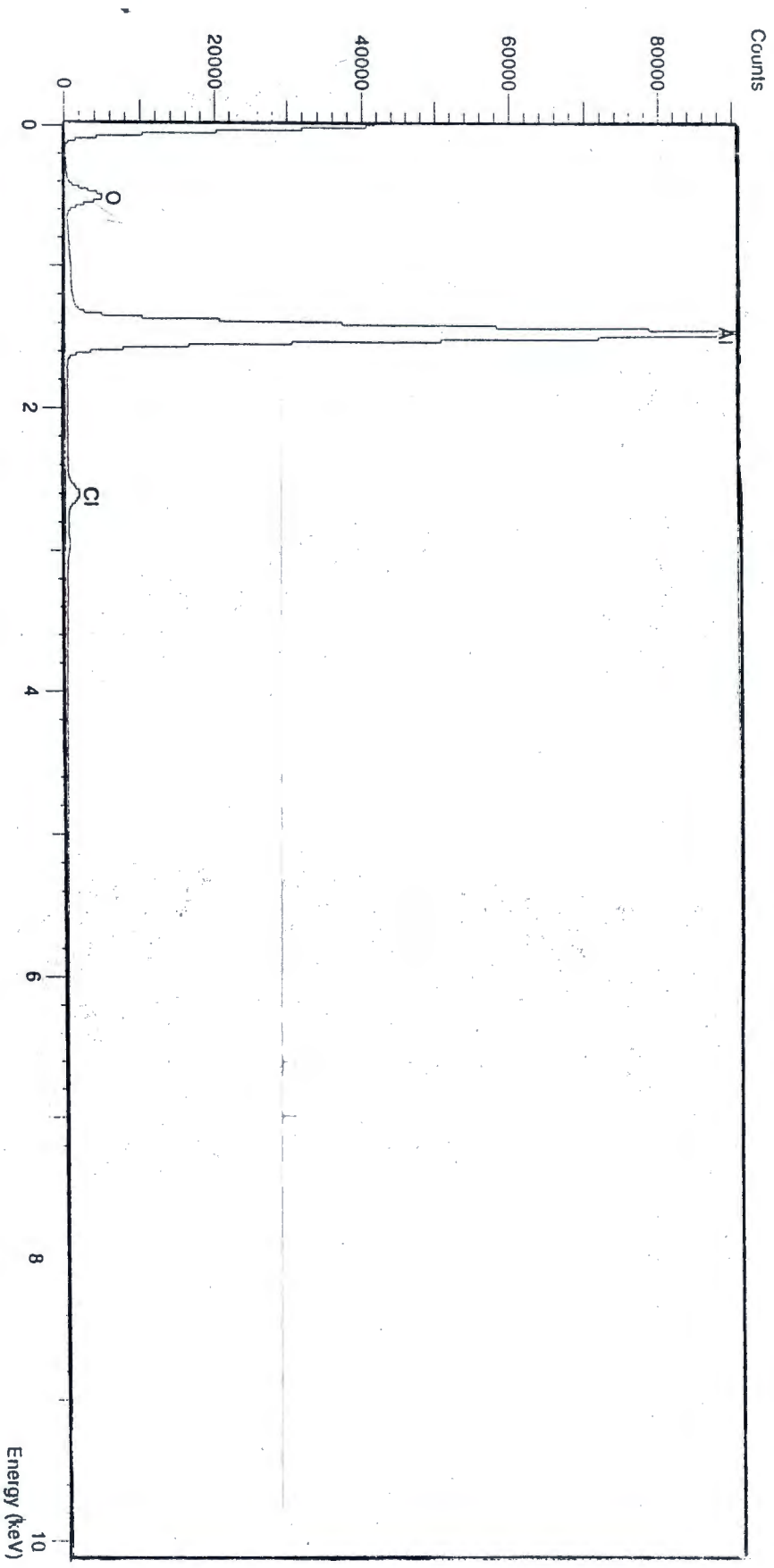

Fig. 5. EDS analysis of center grain of failed surface

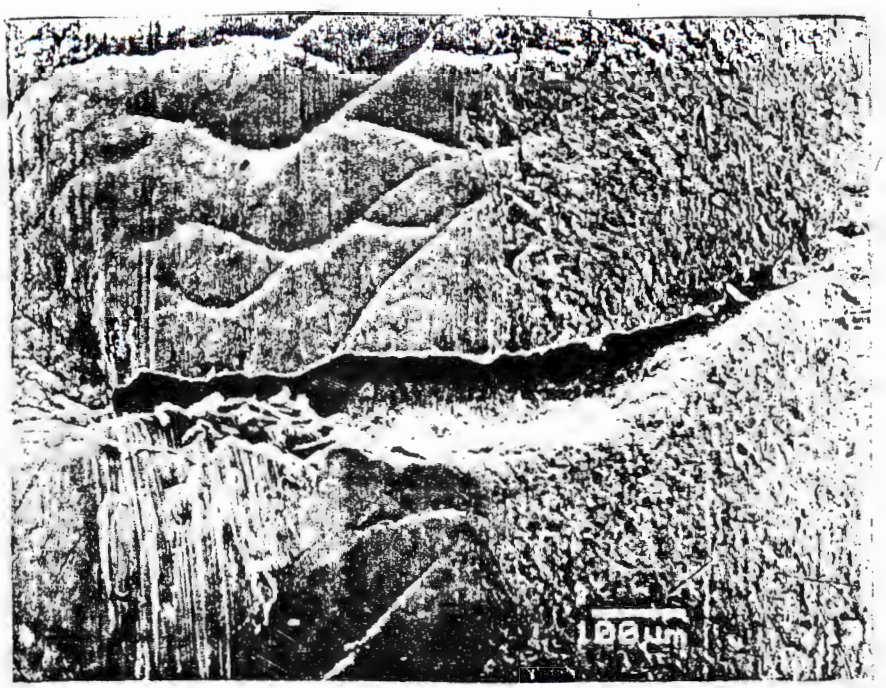

Fig. 6. Failed surface of as-received tested aluminium wire.

Fig, 7. Edge and near the edge feature of the failed sample (from Fig. 6)

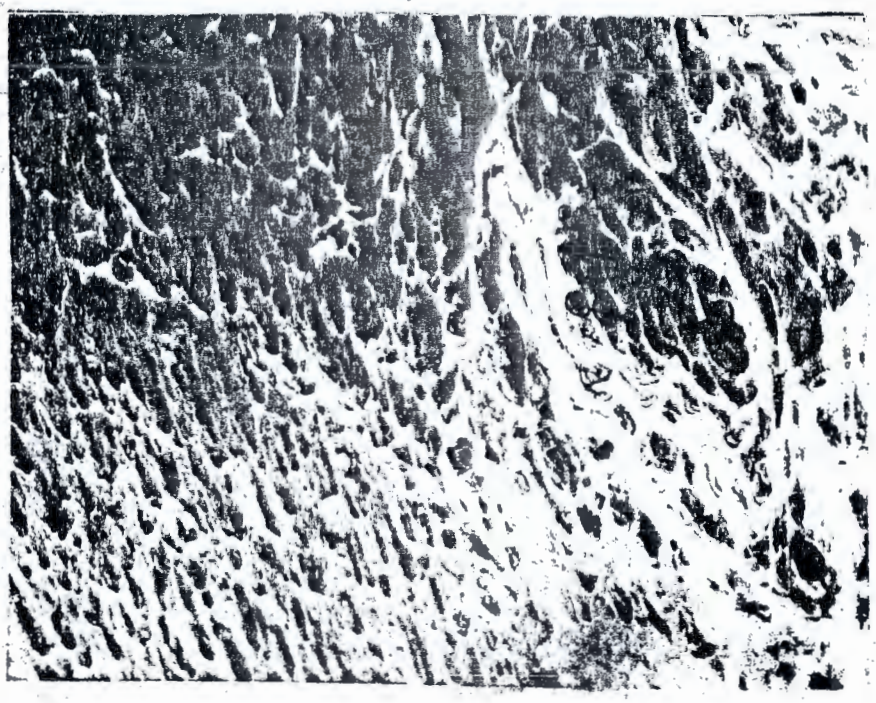

Fig. 8. Failed surface feature inside and near the edge of the open crack.

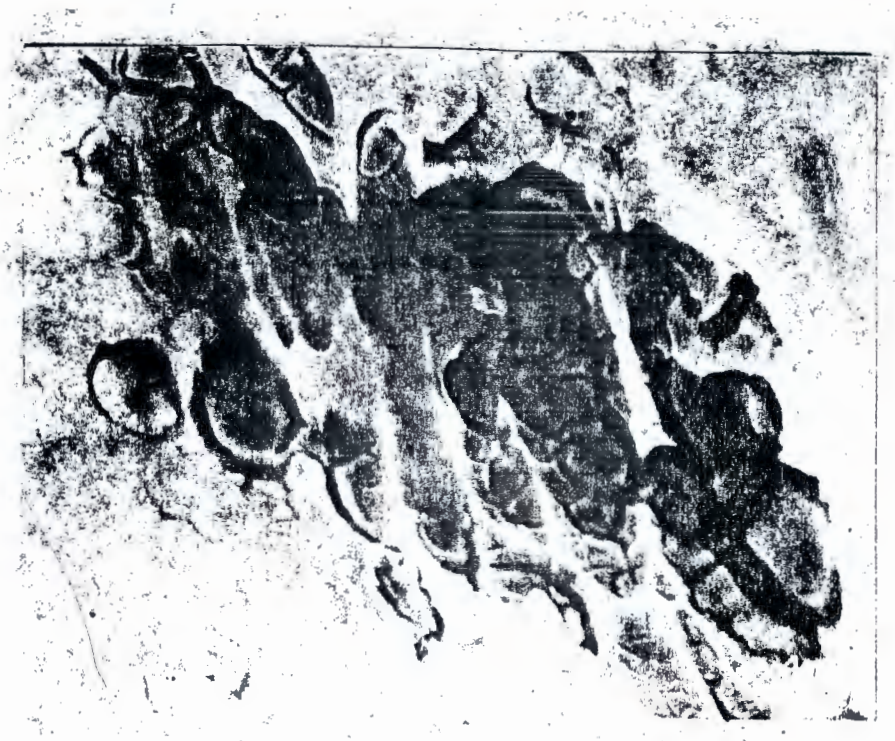

Fig. 9. Second phase particles as in Fig. 8. at higher magnification (4000 x).

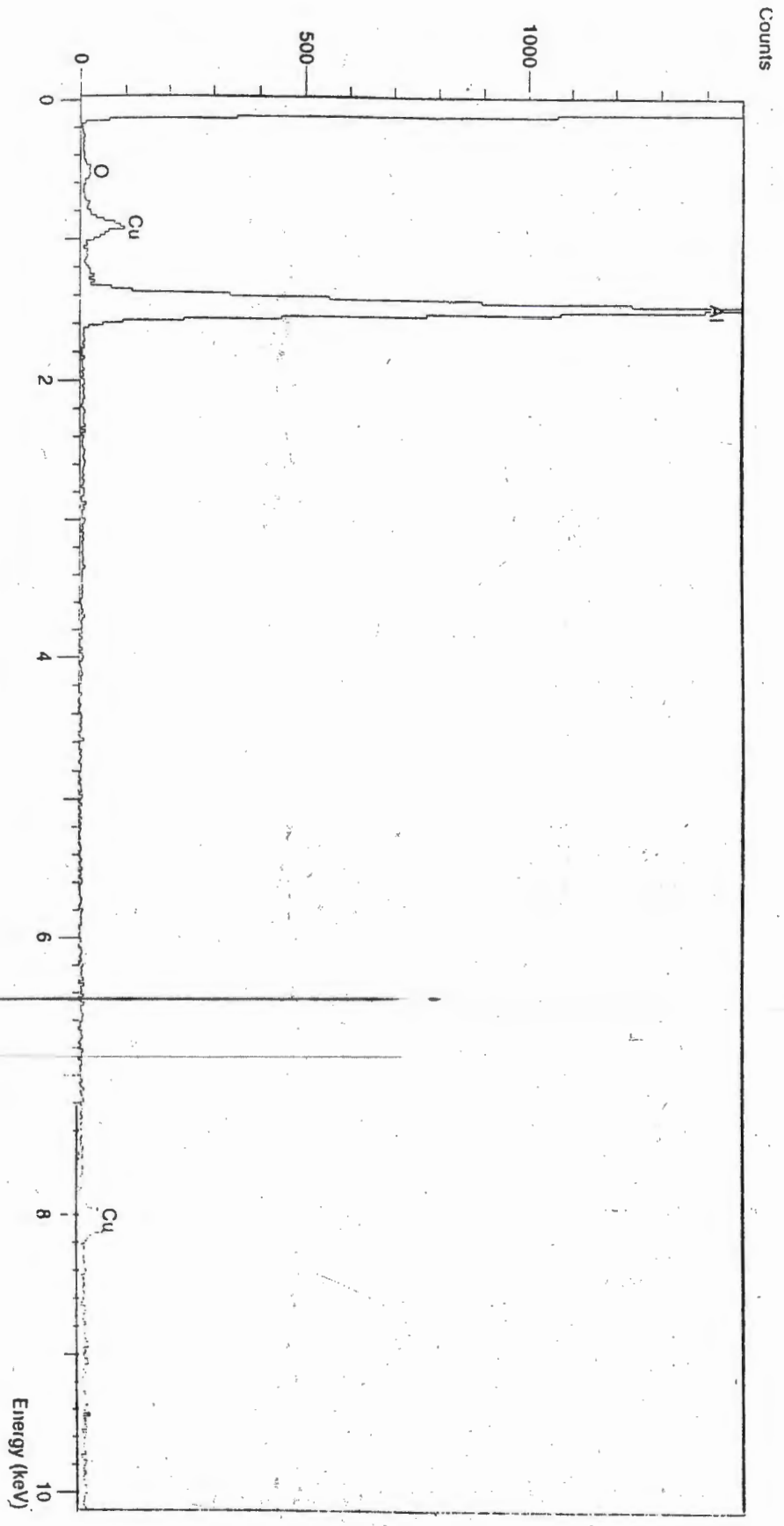

Fig. 10. EDS analysis of second phase particles in Fig. 9

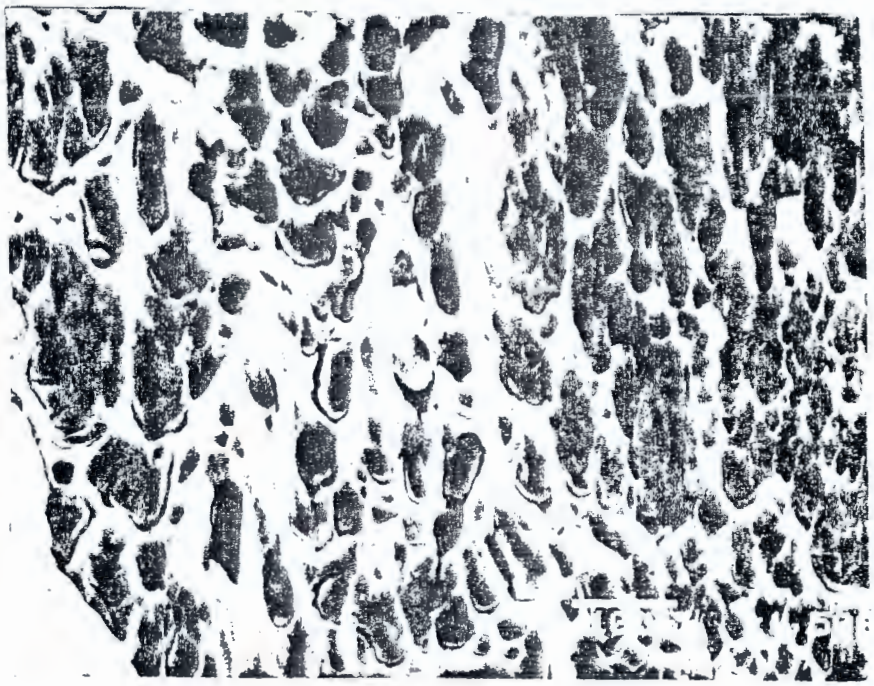

Fig. 11. Surface feature of failed samples as in Fig. 6 near the edge of crack.

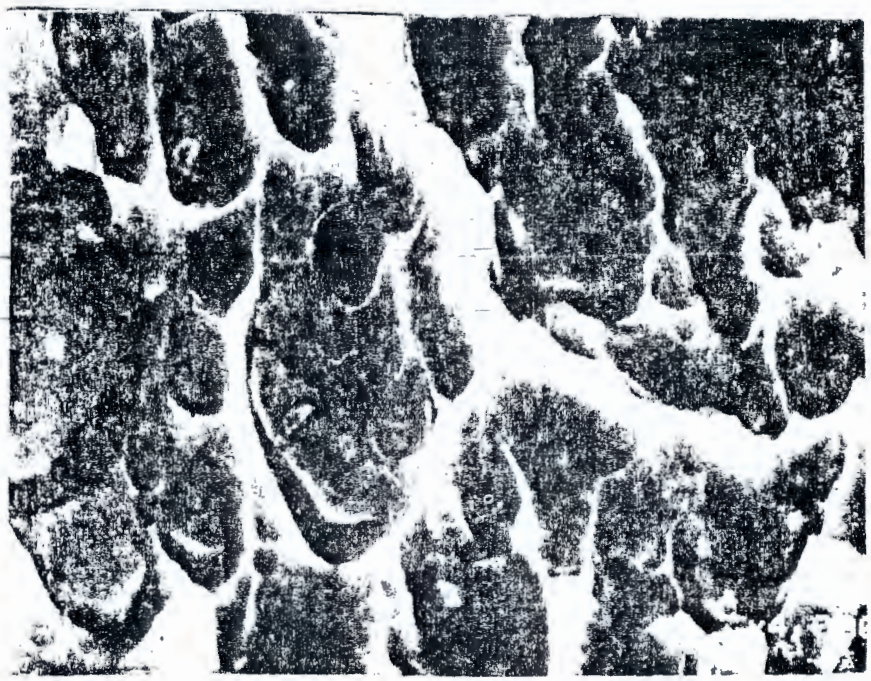

Fig. 12. Surface feature as in Fig. 11 but at a higher magnification showing second phase particles within the matrix.

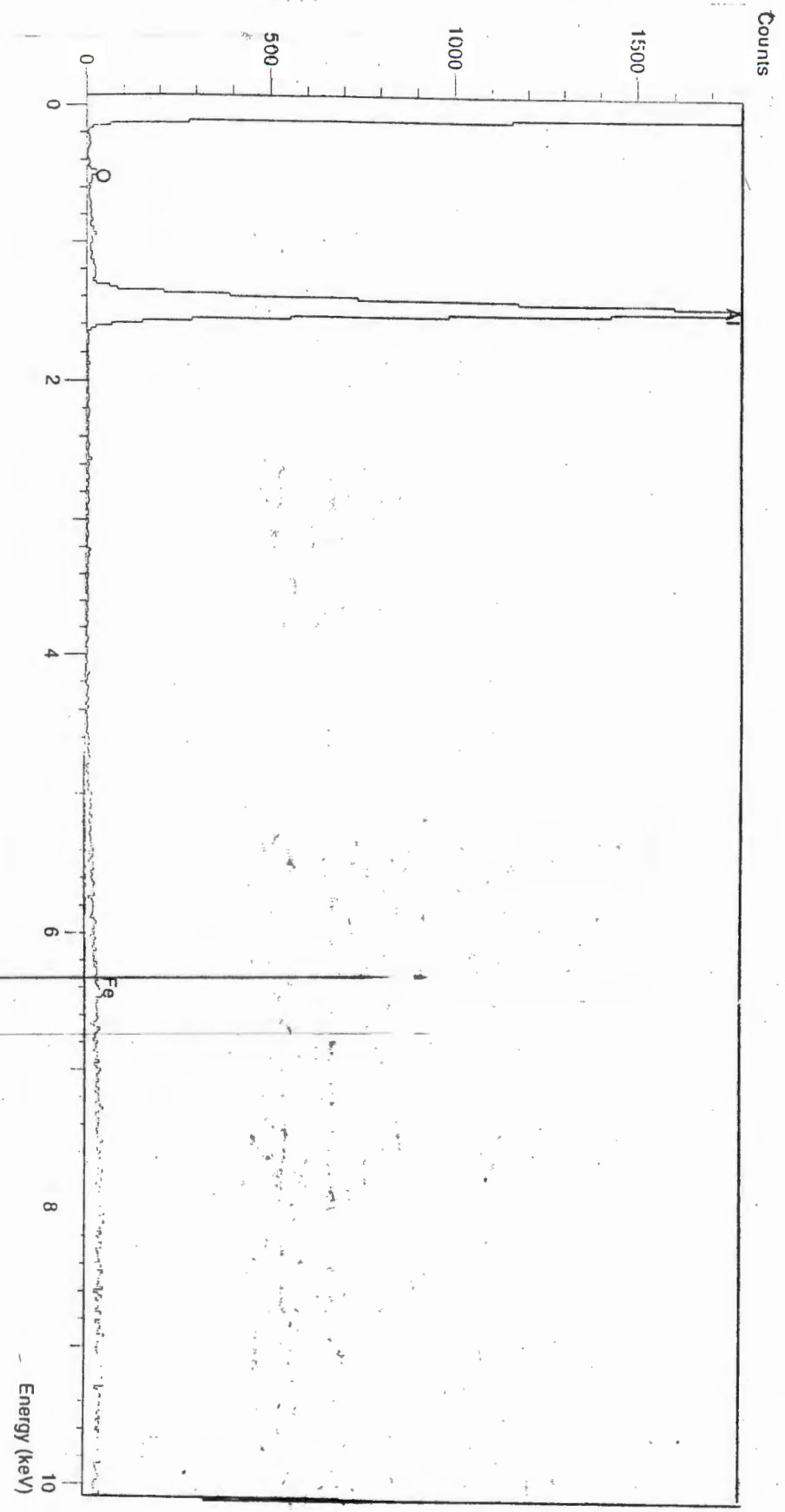

Fig. 13. EDS analysis of dark substance at the center of a large particle in Fig. 12

Fig. 14. Failed surface and crack defect steps leading to failure.

Fig. 15. Irregular pit-like formation on the aluminium wire sample of the Failed surface.

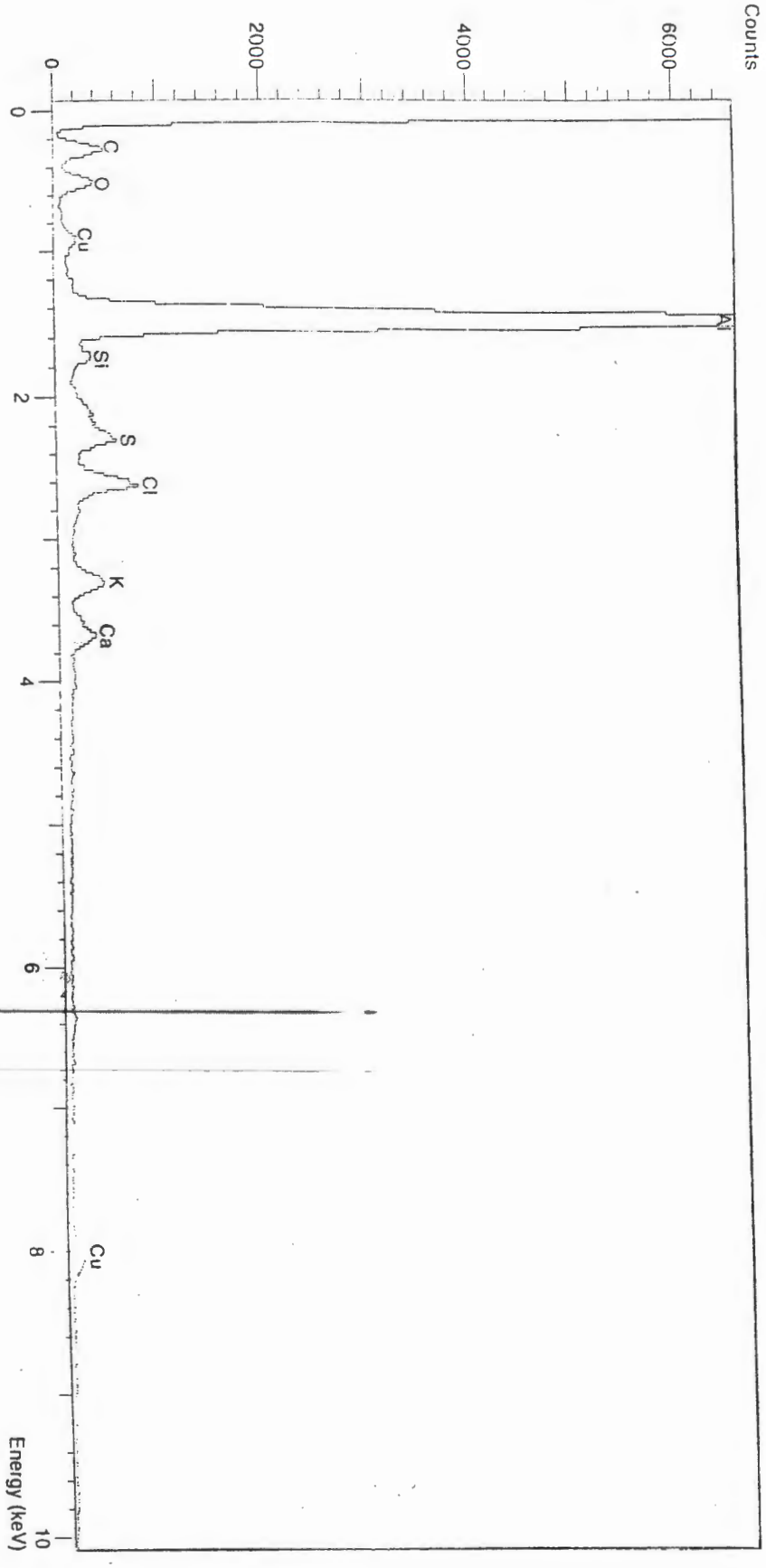

Fig.16. EDS analysis of a particle on cracked surface detect in Fig. 14

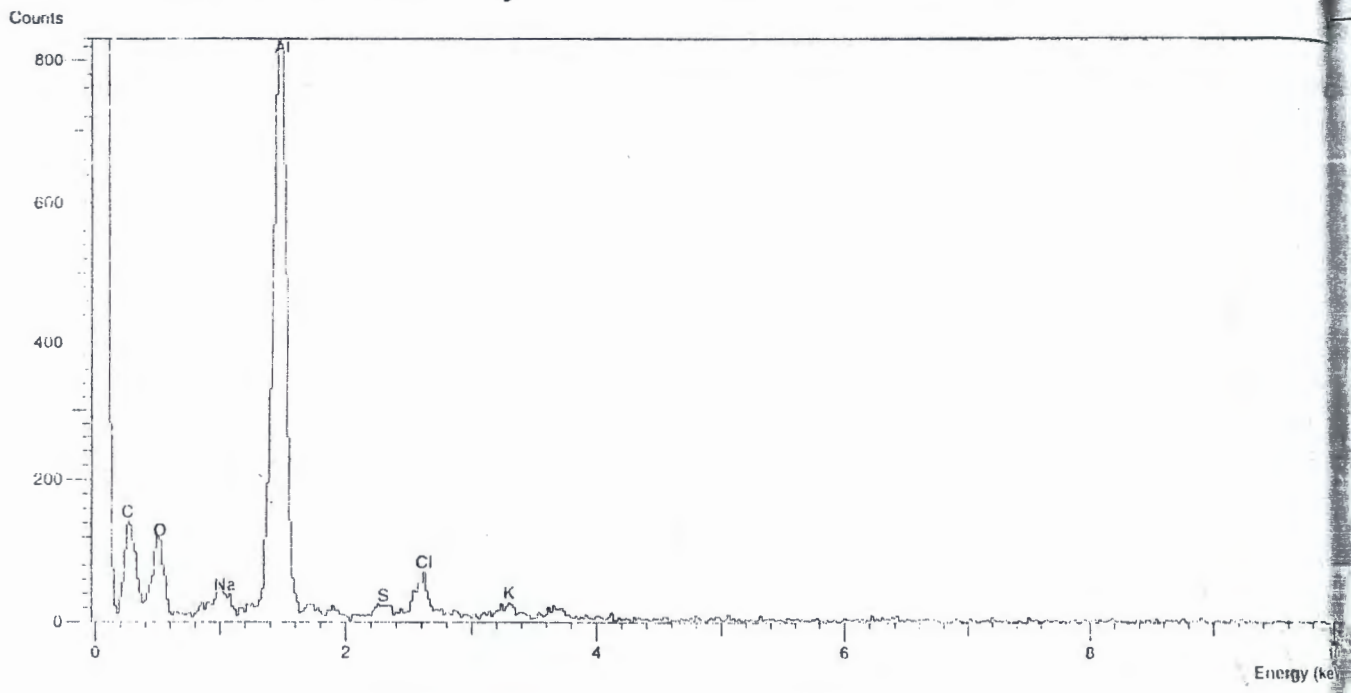

Fig.17. EDS analysis of the corroded pit-like formation in Fig. 15

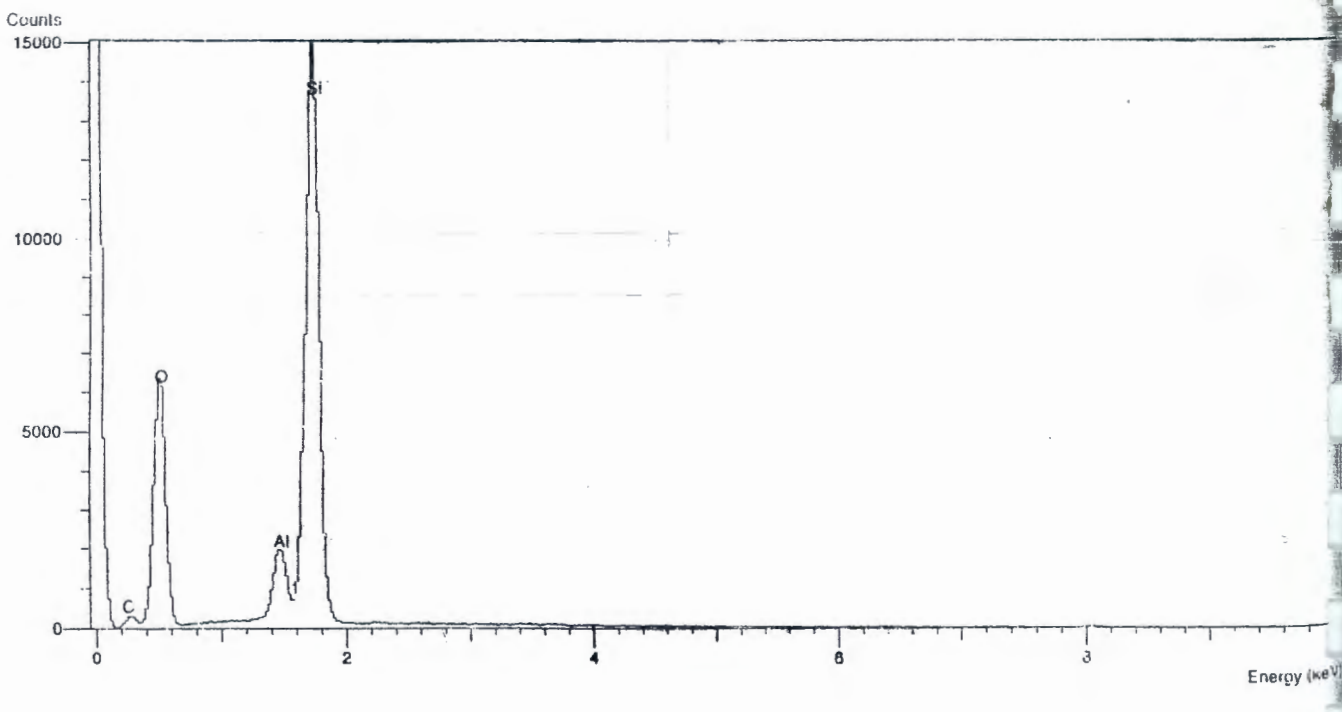

Fig.18. EDS analysis of a particle inside the corrosion pit in Fig. 15

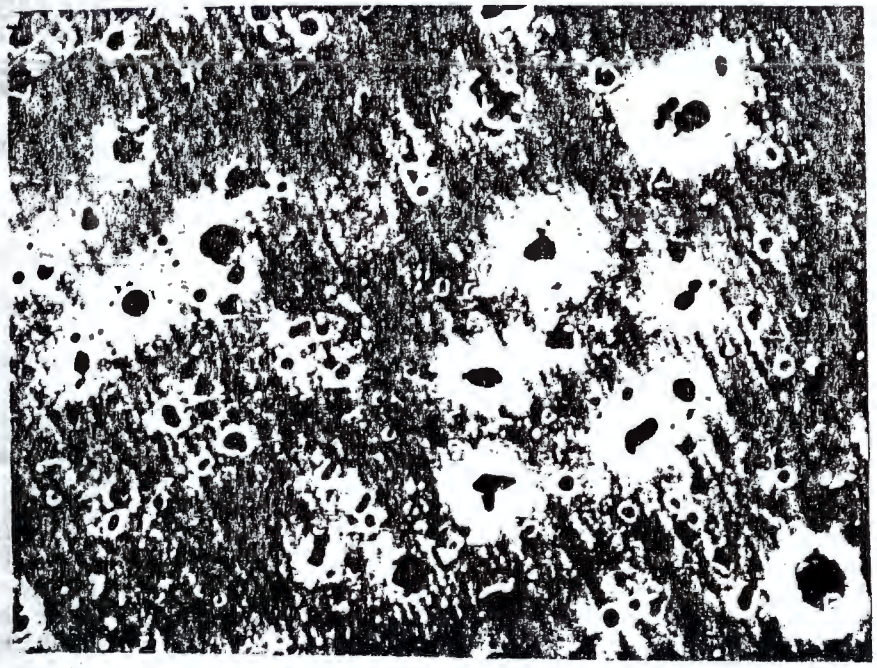

Fig. 19 Etched surface of the failed aluminium wire sample.

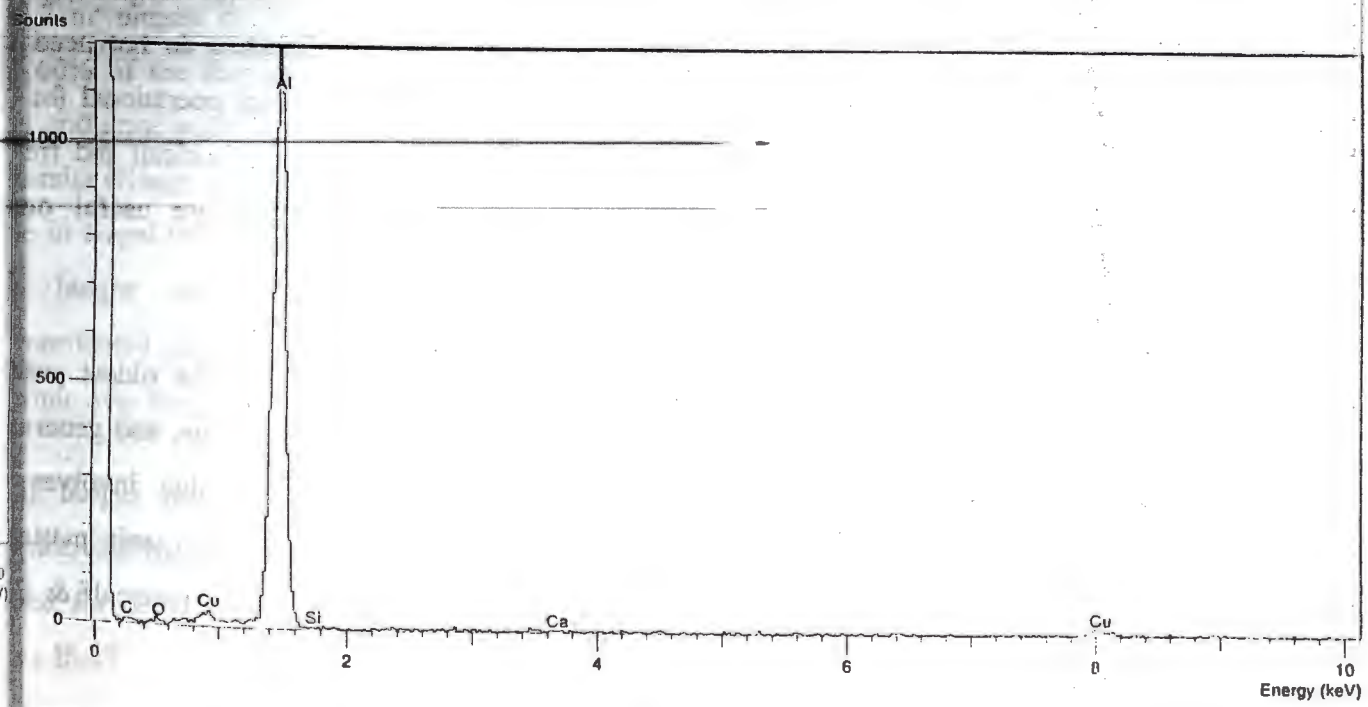

Fig. 20 . EDS analysis of the black patches on the etched surface of aluminium sample as in Fig. 19