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The Initial Stages of Deformation in Metals Subjected to Repeated Liquid Impact

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VIII. The initial stages of deformation in metals subjected to repeated liquid impact

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[Plates 22 and 23]

Experiments have been carried out to investigate the initial stages in the deformation of metals due to repeated liquid impacts. The initiation of damage is discussed and a comparison made with the initial stages of deformation in metals subjected to similar hydrodynamic loading conditions due to the action of shock waves in a liquid. The destructive role played by the rapid flow of liquid across the surface of a specimen after impact is also described.

INTRODUCTION

Many authors, including von Schwarz & Mantel (1936) and Hancox & Brunton (this volume, p. 121), have reported that the first stage in the deformation of most metals when subjected to repeated liquid impact takes the form of small plastic depressions randomly distributed throughout the area of impact.

These depressions, which appear very early in the erosion history of a specimen, are formed at an impact pressure which is several times smaller than that at which yielding would first be expected in a particular material. The discrepancy factor varies from about 4 for softer metals such as copper, to at least 10 for a high strength steel.

OBSERVATIONS OF INITIAL STAGES OF DEFORMATION

Experiments have been carried out in an apparatus in which specimens, projecting from the rim of a rapidly rotating disk, impact many times the side of a continuous jet of liquid (Honegger 1924). These experiments have confirmed the above findings and depressions as described have been observed in copper, aluminium, brasses and many steels, at impact pressures lower than would be expected.

Explanations for the occurrence of these depressions include: (i) inhomogeneity of the pressure profile over the impact area—due to turbulence on the jet; and (ii) the presence of weak areas in the material at points where the depressions originate.

It is important to note the way in which the surface is loaded in the liquid impact process. In most methods of loading a surface, as, for example, in the case of a rigid indenter being pressed into a surface, the load is taken mainly by the strongest points in the indented area, and the resistance to deformation is then a measure mainly of the strength of these stronger regions. However, under liquid impact conditions the load is applied equally over the whole surface, and any weaker points present are now vulnerable to the applied stress, and if this is high enough, will yield under it.

Attempts have been made at locating possible weak areas in a newly prepared surface, by microhardness and scratch-hardness testing of many points in a given area of the surface.

These tests have not indicated localized differences in surface hardness sufficiently large to explain the formation of the depressions from 'soft' spots. It is thought, however, that the scale on which the hardness was measured was too great, i.e. since any weaker areas could originally be of diameter less than 5 μm the ratio of indentation area/area of possible soft region was too great to show any significant difference in hardness from place to place.

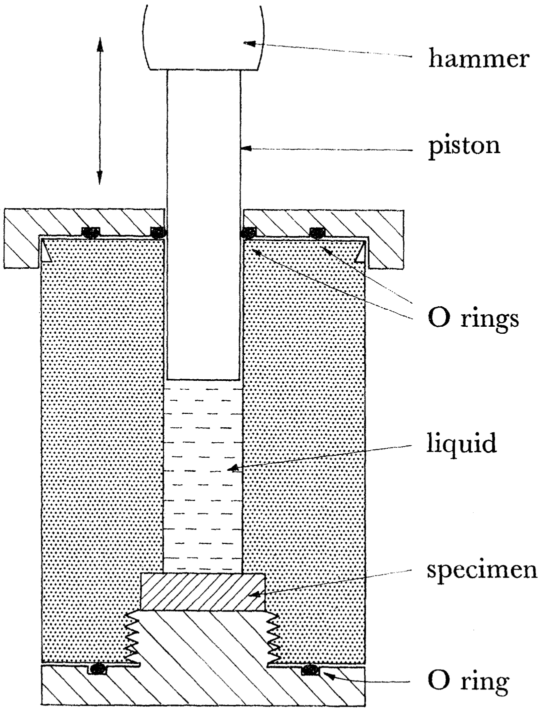

FIGURE 1. Diagram of shockwave apparatus. The specimen is placed at the bottom of the $\frac{1}{2}$ in. diameter liquid column contained in the hardened steel chamber. The piston is sealed in the cylinder and kept under a static load throughout. The pneumatic hammer strikes the piston at rates of up to 200 blows/min.

In order to investigate further the behaviour of a material loaded hydrodynamically, experiments were carried out using the apparatus shown in figure 1, in which specimens were placed in the path of shock waves moving through a liquid. Specimens are placed at the bottom of the enclosed column of liquid down which shockwaves are transmitted, by the action of a 60 lb. air hammer striking the piston. The liquid is kept under a constant static load throughout to eliminate cavitation effects. In this way hydrodynamic loading is achieved as in the liquid impact process, but the tangential flow of the liquid across the surface is avoided.

It is found that specimens subjected to this form of loading yield in the same way as specimens subjected to repeated liquid impacts. The depressions thus formed are identical in characteristics and appearance in both cases.

Figures 2 (*a*) and (*b*), plate 22, are photographs of depressions formed in copper specimens (*a*) as a result of repeated liquid impact, and (*b*) as a result of the action of plane shockwaves produced in the apparatus of figure 1. In figure 2 (*a*) the specimen has received about 4000 impacts at a velocity of 50 m/s and in figure 2 (*b*) the specimen has received about 500 blows in the shockwave apparatus. The depressions in the photographs vary in diameter from less than 5 μm to more than 20 μm.

Both photographs were taken by means of the Nomarski interference contrast technique which has the effect of showing up even slight differences in surface contour in great contrast (Nomarski & Weill 1955).

This would then suggest that the formation of the depressions in the liquid impact process is due to the yielding of the material at weaker sites under the action of the relatively low impact pressures. The physical nature of these points of weakness is not fully known, but it is obvious that at these points the dislocation structure of the crystal is favourable for slip under the very low stresses obtaining. Once a depression is formed, the effect of work hardening can be more than counteracted by the stress concentrating profile of the depression. This means that the applied stress may then always be greater than the local yield stress, and that the depression will increase in size with subsequent impacts.

High speed liquid flow across the impacted surface

When one considers the other mechanism by which damage is produced in the impact process—the effect of the high velocity flow of the impacted liquid across the surface of the specimen (Bowden & Brunton 1961), it has been predicted that the shear forces thus produced will only be large enough to cause damage when the surface itself contains discontinuities, the form of changes of contour which impede the flow of the liquid (Engel 1953).

This has been investigated with the use of water jets with velocities of over 300 m/s in the apparatus described by Leach & Walker (this volume, p. 295). Such a jet was directed at glancing incidence ($< 5°$) on to the surface of a polished specimen, so that the main component of the flow velocity was along the surface of the specimen, and the component normal to the surface was very small, thus simulating the action of the liquid flow in the impact process, but in the absence of the usual high normal pressures.

It is found that a surface which is well polished and free from flaws will withstand the action of the flowing liquid for a given time with no discernible damage, while a surface containing flaws or discontinuities will exhibit significant loss of material under the same conditions.

Figure 3, plate 23, shows part of the surface of a copper specimen subjected to the action of a 300 m/s 1 mm water jet for 1 min striking the surface at an angle of 4° 40′. The surface was initially marked with a groove lying at right angles to the direction of the liquid flow and, as can be seen, material has been removed from the edge of the groove facing the flow. A well polished surface showed no discernible damage after the same treatment.

Discussion

The experimental observations indicate that the first stages in the deformation under repeated liquid impact of soft ductile metals such as copper originate from small defects in the metal itself. These could be inherent in the metal or arise in the preparation and polishing of specimens prior to the impacts by the liquid. The latter, however, is unlikely since electropolished specimens exhibit the same behaviour as those polished mechanically.

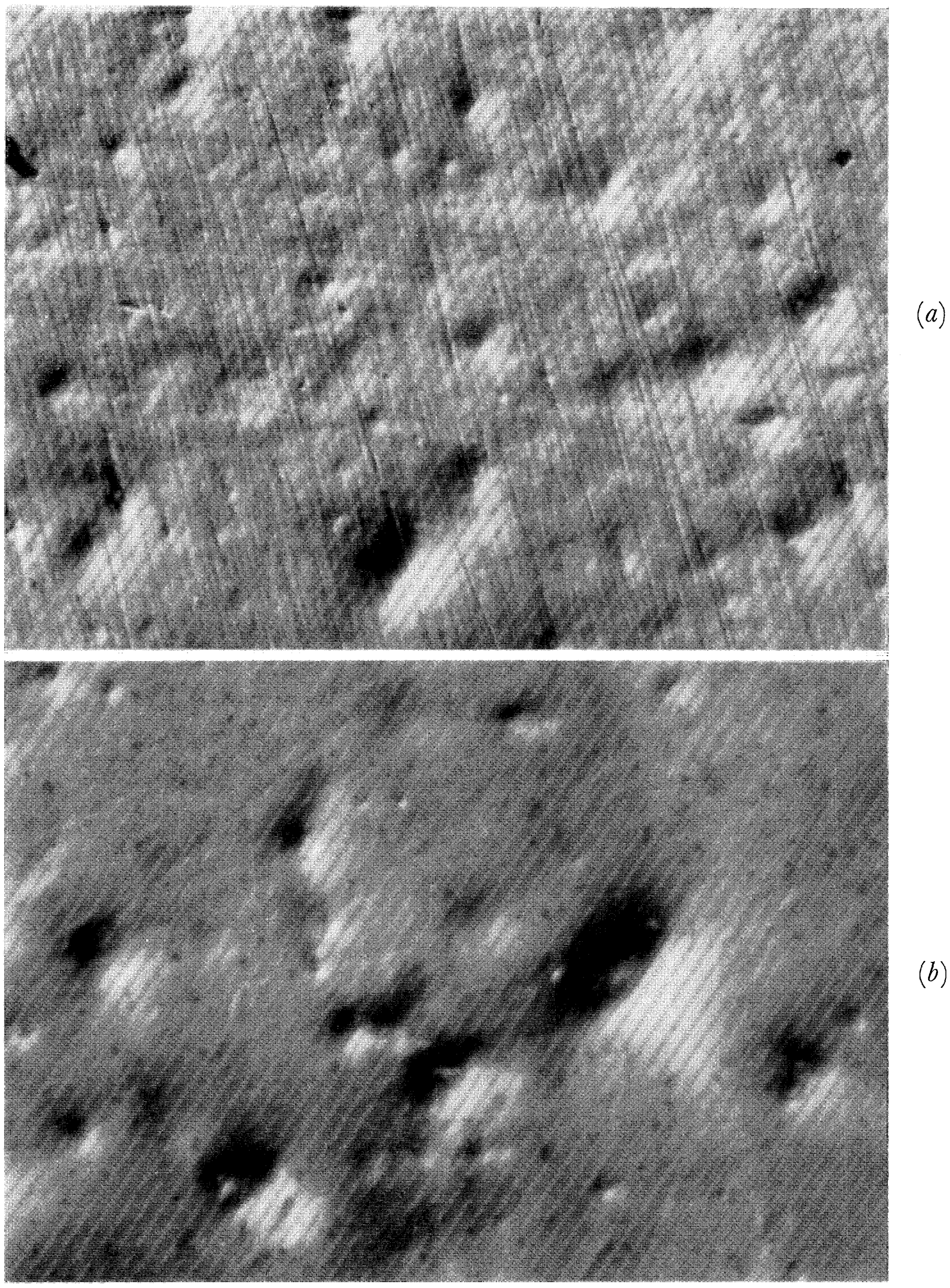

Figure 2. (*a*) Surface depressions in a copper specimen which has received about 4000 impacts at a velocity of 50 m/s from a water jet of diameter 1·3 mm. (*b*) Surface depressions in a copper specimen as a result of the action of plane shockwaves produces in the apparatus of figure 1. The specimen has received about 500 blows. Both photographs were taken by means of the Nomarski interference contrast technique, and the side of the frame in each case represents 300 μm.

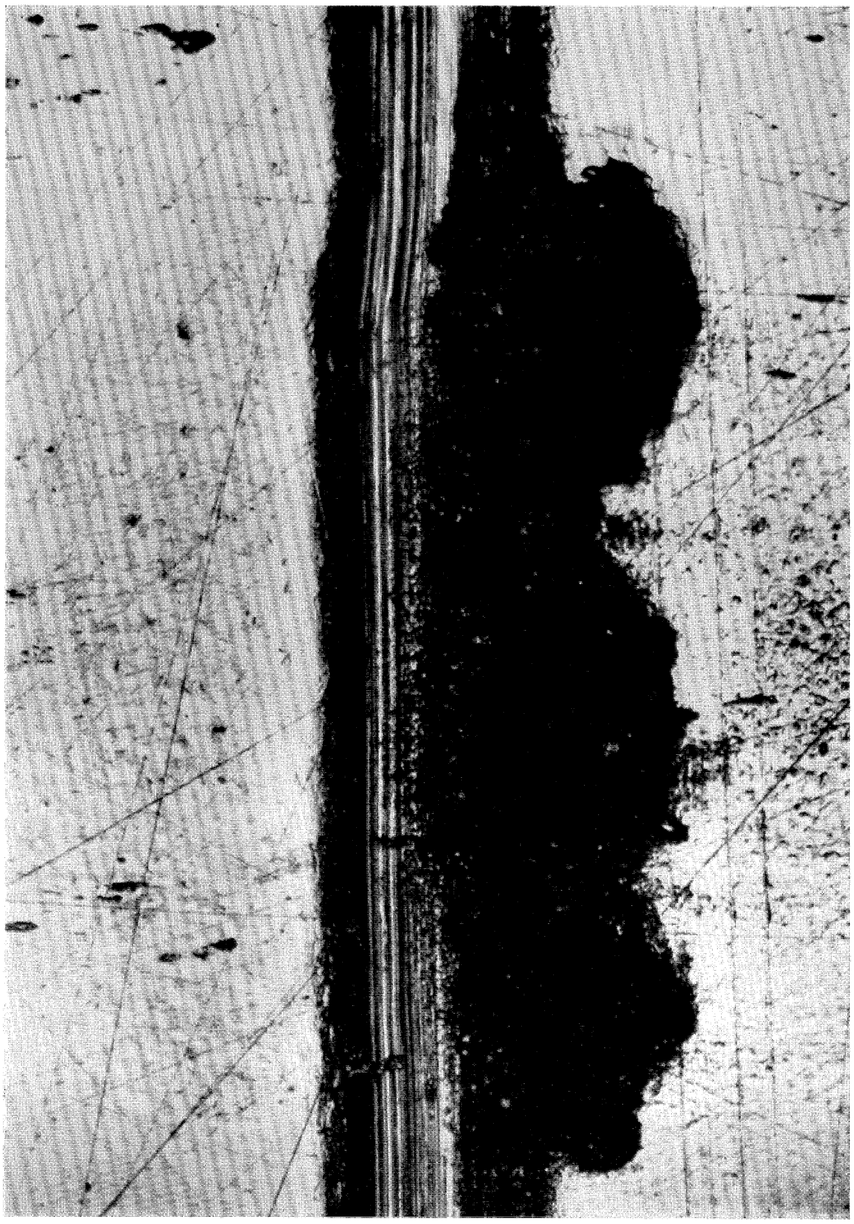

FIGURE 3. The surface of the copper specimen, containing a groove lying at right angles to the direction of liquid flow, after subjection to the action of a 1 mm water jet of velocity 300 m/s striking the surface at glancing incidence. The direction of flow was from left to right in the photograph; material has been removed from the edge of the groove facing the direction flow. The length of the frame represents 2 mm.

It would be reasonable, therefore, to assume that the microweaknesses are inherent and are exploited by the manner of stress application which is peculiar to this hydrodynamic loading. Further, the destructive influence of the rapid flow of liquid across the surface of a metal after impact is dependent on the existence of irregularities of surface contour—these are generally introduced by the normal pressure applied to a surface on impact.

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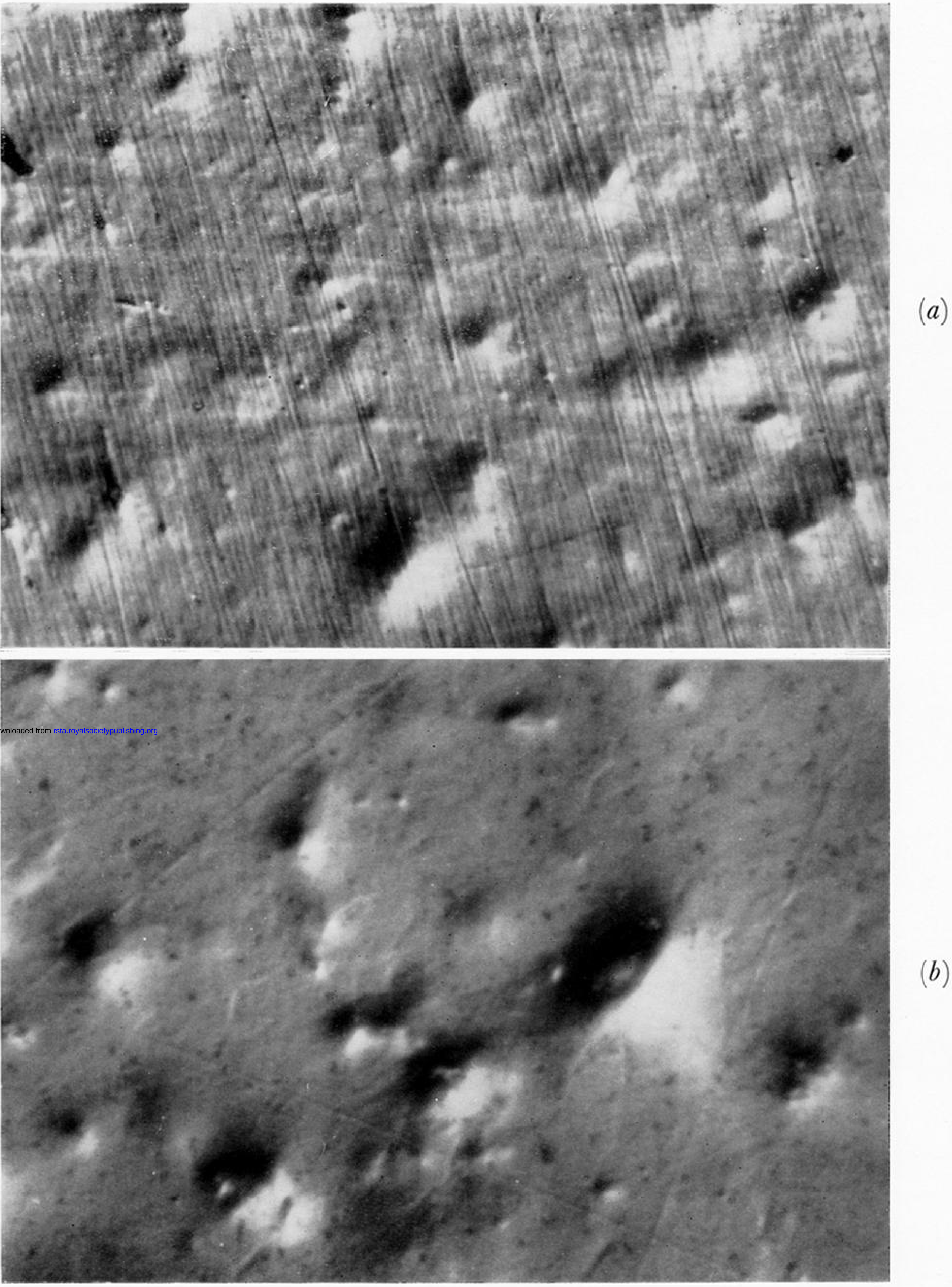

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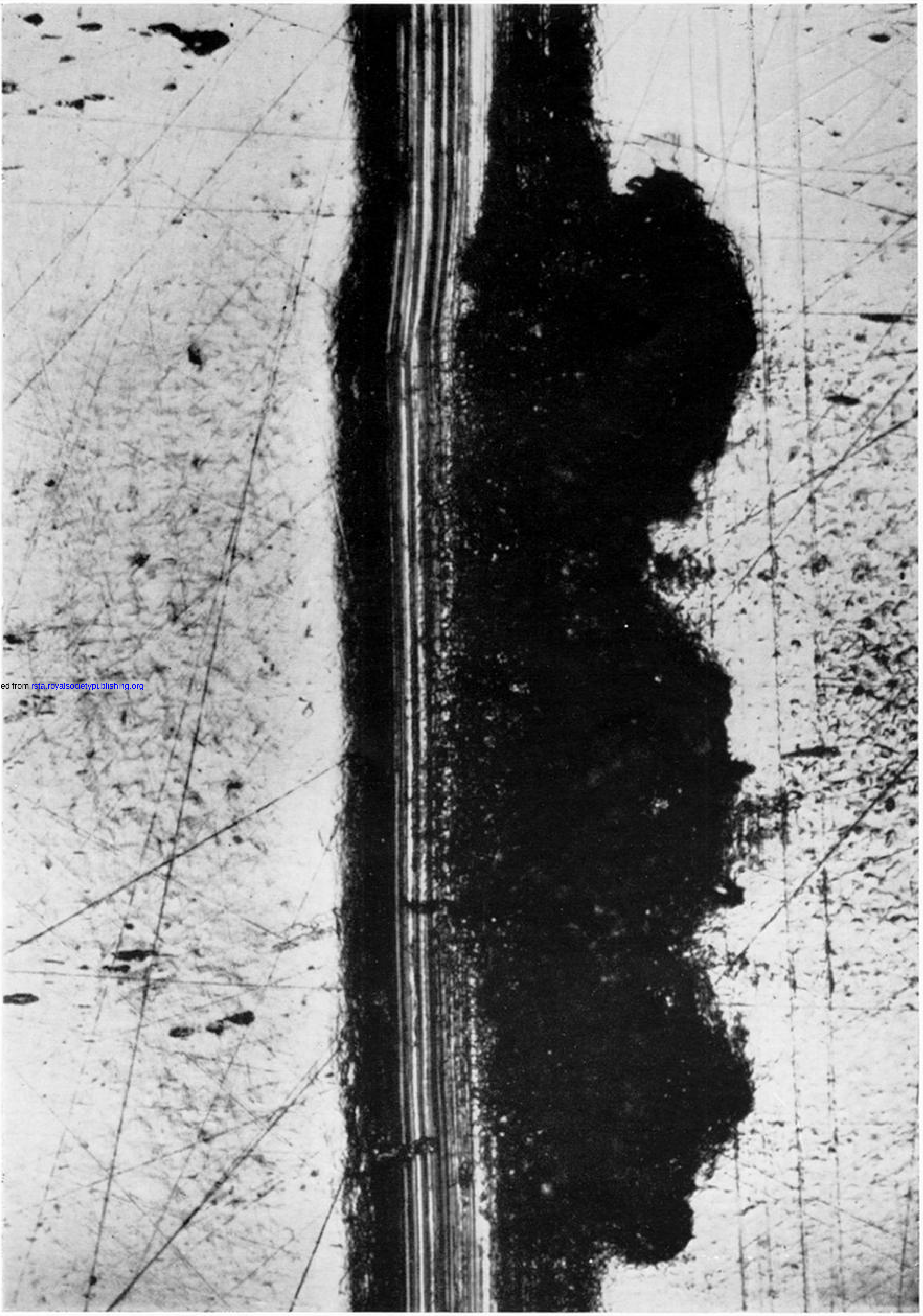

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