EXOELECTRON EMISSION AS A METHOD OF INVESTIGATING PLASTICALLY DEFORMED METAL SURFACES

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In studies of problems of deformation and strength of metals and alloys it is necessary to bear in mind that fracture of metal surface layers takes place as a result of the combined action of mechanical and physico-chemical factors. Experiment shows that physico-chemical processes are substantially intensified by plastic deformation, this being particularly so in the case of various electrical phenomena.

One of the electrical effects of deformation is the emission of low-temperature electrons from deformed metal surfaces (Kramer effect [1]). At first, there was a tendency to regard this emission as chemical in origin [2]; it was considered that the energy required to expel electrons is generated by chemisorption processes which take place on metal surfaces that are freshly exposed as a result of plastic deformation [3, 4].

The results of many experimental studies cannot be explained in the framework of the chemisorption hypothesis, however; they indicate that electron emission is to a large extent determined by the structure of metal surface layers (the number of structural defects in particular) and depends on the kind, extent, and other parameters of deformation. In the present article the results of investigations which point to a relation between the Kramer effect and deformation characteristics are reviewed, and the possibilities of utilizing this effect in studies of the structure of, and structural defects in, deformed metal surface layers are evaluated.

Exoelectron Emission from Deformed Metal Surfaces

The term “exoelectron emission” first appeared in 1950 in Kramer’s paper [1] which reported the results of the first systematic study of this new kind of emission. Emission from the surface of pure metals deformed as a result of polishing, emerying, or sand-blasting was studied in the first experiments. These methods of producing plastic deformation were chosen because the first manifestation of electron emission was in the form of an abnormally high level of noise in Geiger counters with cathodes which had highly polished internal walls [5, 6]. This manner of deforming metal surfaces is convenient and requires no special equipment; moreover, high emission currents, which are readily recorded even by low-sensitivity counters, are produced by polished or emeryed surfaces.

Kramer found that polishing Al, Pt, Sn, Ni and Fe surfaces with emery paper immediately produces electron emission which decays in time. The decay time varies within wide limits (from a few minutes to several days [7]). A study of the decay of emission current I from polished metals showed that the process is described by

\[ I = c \cdot t^{-a}, \]

where c and a are constants which depend on the character of the metal and on the deformation conditions [8].

It was found in [3] that the decay of exoelectron emission obeys a hyperbolic law, i.e., that the product of the emission current I and emission time t is constant: \( I \cdot t = \text{const} \). It was suggested that this constant value can be regarded as a measure of the emissive power of a given metal. Assessed in this manner, the emissive power of the metals studied in [3] increases in the following order: Pb, In, Al, Au, Cu, Mo, Fe. The emission decay rate is strongly dependent on the method of deforming the metal surface. A more intense and more rapidly decaying electron current is emitted from surfaces polished with fine abrasives than those polished with coarse materials; this difference is even more pronounced in the case of sandblasted surfaces [3].

![Fig. 1. Exoelectron emission from a single zinc crystal extended by a step-by-step method [11].](image1)

![Fig. 2. Kinetics of exoelectron emission during and after deformation [10].](image2)
Since similar results were obtained by other workers, it may be taken as an established fact that surface deformation of pure metals (Be, Al, Zn, Mg, Fe, Ni, Mo, Cu, Pt, Pd, Au, Cr, W, Sn) causes electron emission.

Investigations which had led to this conclusion had some serious shortcomings. In the first place, the emission was studied after, and not during, the deformation process; secondly, the duration of the emerying and polishing operations and the abrasives used varied from case to case so that the degree of deformation of the surfaces studied was unknown. These shortcomings were eliminated in subsequent studies which made it possible to relate exoelectronic emission to the deformation parameters.

For instance, Lohff [4] constructed an apparatus which enabled him to study the electron emission from Zn, Al, and Pb specimens while their surfaces were being abraded with a steel brush. Measurements of emission currents immediately after deformation revealed that the emission curve passes through a maximum; this effect, called emission inertia, was later observed by other workers [9, 10].

In his subsequent investigation, Lohff studied electron emission from single zinc crystals which were undergoing deformation in tension under controlled conditions [11]. Each specimen was extended in stages, the length of the specimen being increased in each stage by 1% (Fig. 1). Under these conditions, the emission current increased with increasing degree of deformation, reached a maximum at 8% strain, and then decreased. A similar effect was observed by Kramer on copper specimens deformed in tension and torsion: The number of pulses initially increased with increasing load, after which it decreased as the applied stress approached the breaking stress [7].

The most detailed study of the relationship between exoelectron emission and mechanical properties was carried out on aluminum. It was shown by Grunberg and Wright [12] in 1957 that the emission from polycrystalline aluminum plastically deformed in tension is negligible below 5% deformation, then increases sharply and falls again in the later deformation stages.

Voos and Brotzen [10], who studied the behavior of high purity aluminum in tension, confirmed the existence of the emission inertia effect, i.e., the continuation of the emission current beyond the end of the deformation stage (Fig. 2). In their experiments the specimens were extended at a rate of 1.6 mm/min for 480 sec, after which deformation was discontinued; the emission current, which increased with increasing strain, continued to increase when the deformation ceased, reached a maximum, and then decreased.

A detailed study of the dependence of exoelectron emission on the applied load was carried out in [13], in which aluminum specimens were extended at a constant rate and the number of pulses measured at one minute intervals. When the applied stress reached 2 kg/mm² (corresponding to 1% strain), there was a noticeable increase in the number of pulses, which increased by several orders of magnitude when the strain reached 2.5%. In [14] it was shown that uniform bending of technical purity aluminum also causes an increase in emission current.

It was established by these investigations that uniform deformation in tension, bending and torsion is accompanied by the appearance of emission currents whose intensity depends on the degree of deformation, increasing in the low strain range and decreasing at higher strains.

Subsequent researches were directed towards elucidating the effect of deformation under more complex loading conditions and the influence of the deformation rate on the kinetics of exoelectron emission. It was found that electron emission takes place from metals deformed by cyclic loads; in the case of aluminum fatigued in bending, electron emission was observed at stresses as low as 4 kg/mm² [15].

The emission from aluminum specimens undergoing tests on a vibrating machine was studied in [13]. In this case, a cyclic stress of 5 kg/mm² was applied to the specimen for 35 min; the results (Fig. 3) showed that the application of stress causes an immediate increase in emission current, which after 10–15 min reaches a constant level of approximately 13 000 pulses/min and which begins to decay when the stress is removed.

Some interesting experiments on the effect of deformation rate on the kinetics of exoelectron emission were carried out in [10]. As shown in Fig. 4 (curves 1 and 2), the emission current measured 240 sec after the commencement of deformation at a rate of 4 mm/min is 7 times larger than that recorded for a specimen deformed at 2.5 mm/min, no emission taking place at this stage from a specimen deformed at 1.6 mm/min.

Supporting evidence showing that exoelectron emission is substantially affected by deformation rate was obtained by Sujak [14] who used impact bending tests. Each application of the impact load