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Internal friction peculiarities in metals subjected to a single weak magnetic field pulse

O.I.Datsko, V.S.Abramov, V.Yu Dmitrenko, V.V.Chishko

A.Galkin Donetsk Institute for Physics and Engineering,
National Academy of Sciences of Ukraine,
72 R.Luxembourg St., 83114 Donetsk, Ukraine

Behavior of low-frequency internal friction level in various metals during first few minutes after exposure to weak magnetic field pulse has been studied. The time dependence of internal friction during the first 10 to 15 min has been found to exhibit a maximum in some cases and a minimum in other ones. This fact is related to differences in irregular distributions of tensile and compressive internal stresses in the samples under investigation along their axes.

Исследовалось поведение уровня низкочастотного внутреннего трения в различных металлах в первые минуты после воздействия на них импульса слабого магнитного поля. Установлено, что временная зависимость внутреннего трения на протяжении 10–15 минут обнаруживает в одних случаях максимум, а в других — минимум. Этот результат связывается с различным неравномерным распределением сжимающих и растягивающих внутренних напряжений в материалах исследуемых образцов вдоль их оси.

This work is a continuation of investigations into behavior of low-frequency dislocation internal friction (IF) level in materials subjected to weak ($H \approx 10^5$ A/m) magnetic field (WMF) pulses. The fact of WMF pulse effect on the IF level was observed in [1–3] while in [4], a long-time kinetics of the IF level variation after action of a WMF pulse on a material was revealed. The kinetics was observed by measuring the IF level at 0.5 day intervals during 10 days, the material was subjected to multiple (about a hundred) WMF pulses. It is of interest to reveal the IF level variation character during first few minutes after action of a single WMF pulse on a material.

Various metals were selected as the study objects, namely, technical purity grade aluminum, tin bronze (Br 012), 70, U-8, 40Ch13, and 30ChN2MFA steels. The materials were in non-equilibrium metastable state due to deformation (drawing and rolling), hardening, or continuous casting. The specimens were of 40 mm working length and 60 mm total length. The specimen cross-section was either circle of 2.6 mm in dia. or 3×3 mm^2 square. The "upper" and "lower" sides were conditionally fixed for each specimen.

An IF setup of reverse torsion pendulum type was used having the free damped vibration frequency about 1 Hz. The setup comprised a magnetic coil of 40 mm internal diameter and 60 mm length. The specimen under study was mounted in the setup so that its axis was coincident with the coil one, the "upper" butt being free and the "lower" one fixed. In this position, the specimen was subjected to a single WMF pulse of $3\cdot(3\cdot10^5)$ A/m amplitude and 10^{-4} s leading edge duration. Immediately after the magnetic action, the IF level was measured during 30 min in 5 min intervals. The IF value was determined by calculation of the free damped vibration number as the specimen strain amplitude was decreased from $6\cdot10^{-5}$ to $3.2\cdot10^{-5}$. The logarithm of the free damped vibration amplitude was a linear function of the vibration number, that is, there was no residual microplastic strain of the specimen. The IF level was measured to within 3 %. To eliminate un-

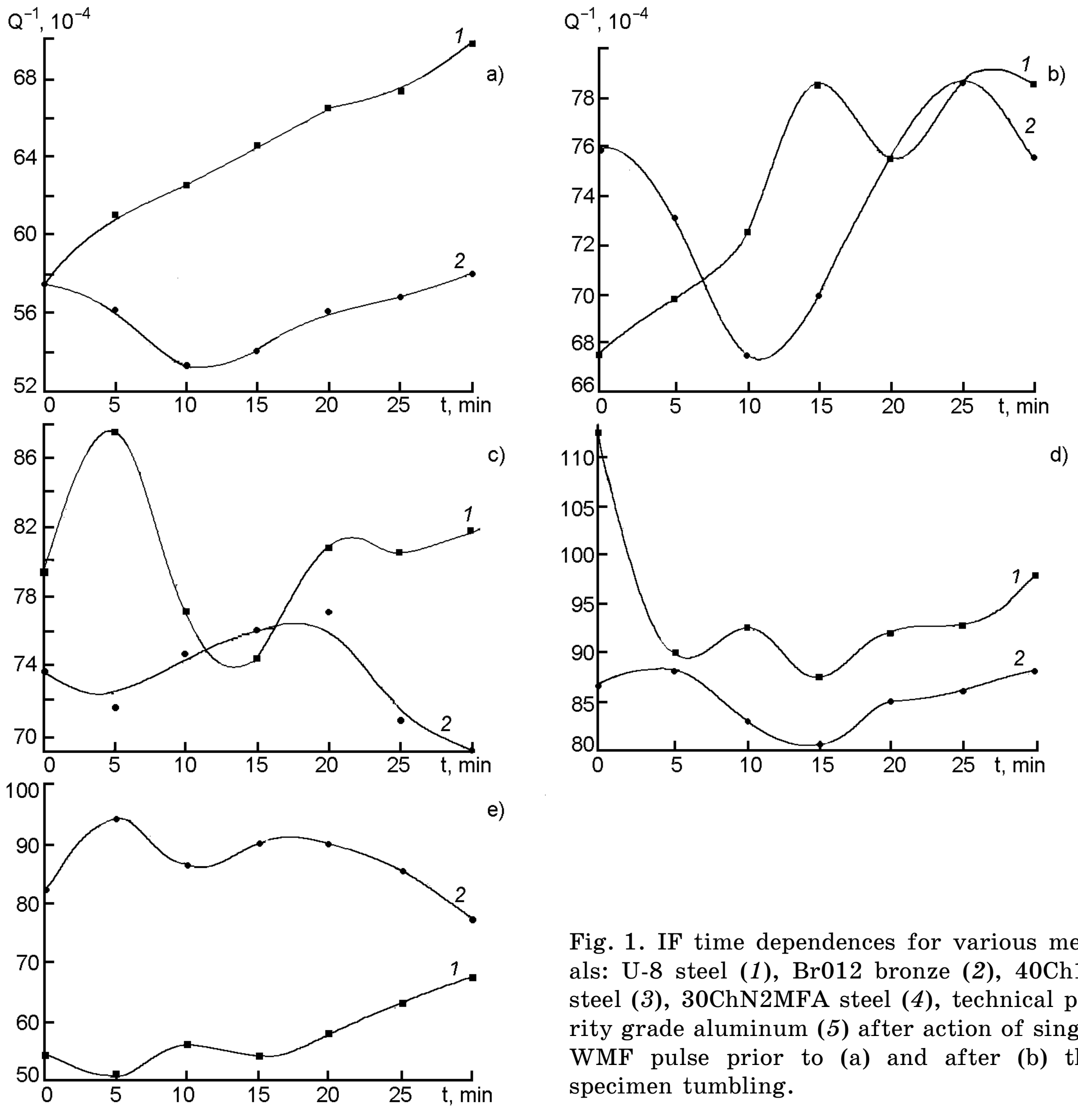

Fig. 1. IF time dependences for various metals: U-8 steel (*1*), Br012 bronze (*2*), 40Ch13 steel (*3*), 30ChN2MFA steel (*4*), technical purity grade aluminum (*5*) after action of single WMF pulse prior to (a) and after (b) the specimen tumbling.

controllable structure changes arising in the specimen during its mounting into the setup, the measurements were done several days after the mounting.

Fig. 1 (Curve a) presents the time dependences of IF level for the materials selected (except for 70 steel) after a single WMF pulse. The results obtained show that the IF level is changed (by 10 to 20 %) during first few minutes after the WMF pulse action. In some cases, the IF level first increases and then decreases during 10 to 20 min, thus exhibiting a maximum (Specimens 1, 2, 3), while in others cases, it decreases first and then increases, exhibiting a minimum often followed by a maximum (Specimens 4, 5). The reasons for such distinctions in the IF level behavior are unclear. Basing on the existing concepts [1–8], the following suggestions can be made.

1. The IF level change under consideration may be related most probably to differences in aftereffect character of the material structure changes as a response to relaxation of impurity-defect complexes (IDC) of dislocation-point defect type due to WMF pulse. So it is believed that the magnetic action causes changes in atomic interaction of point defects belonging to IDC as well as of the matrix atoms with broken bonds (due to changes in their atomic systems). This results in distortion of equilibrium between IDC and the material matrix. Thus, prepositions arise for IDC rearrangement under action of internal stresses in the material. Such a rearrangement should obviously be of different character depending on the internal stress character in the material. It is likely, for example, when the internal stresses are compressive, the IDC will first be decomposed in time and then their ele-

ments will form new IDC more close to equilibrium. At tensile internal stresses, the IDS will be first completed, then decay and then form new complexes. The dislocations involved in the IDC will be either unlocked or locked with the point defect complexes, respectively, or locked-unlocked-relocked, respectively. The IF level will behave in time in respective manner, exhibiting either a maximum or a minimum followed by a maximum. Real materials contain obviously various IDC types with different parameters of the structure response to WMF pulse and subsequent relaxation due to internal stresses. Changes in some IDC types seem to cause long-time variations in the IF level observed in [4] while others, short-time variations revealed in this work (Fig. 1, curves a).

2. The material manufacturing and treatment by melting, deforming, hardening, etc. is accompanied by formation of structure inhomogeneities and internal stresses therein. Such inhomogeneity may be especially pronounced along the axis of a drawn wire. In this case, tensile and compressive internal stresses (and probably IDC accumulations) may alternate along the wire axis at certain periodicity. The IDC where the impurity atoms are smaller in radius than the matrix ones will be concentrated in domains of maximum compressive internal stresses, while those where the impurity atoms exceed in radius the matrix ones, in domains of maximum tensile internal stresses. In this connection, the internal stresses along the specimen axis may vary in character depending on the alternation period, the specimen cutting site and its length. The stresses may be tensile only, or compressive only, or be tensile at one specimen end and compressive at another. In other words, the tensile and compressive internal stresses (and probably the IDC accumulations) may be distributed non-uniformly either within a wire segment defined by the above-mentioned alternation period, or along the specimen axis (if its length is close to the alternation half-period and the specimen is cut out in the wire section where this half-period exists).

3. When low-frequency IF is studied by reverse torsion pendulum method, the material relative strain is set as the vibrations are excited by external action. This strain is the same along the whole specimen axis, both at the upper end and at the lower (fixed) one. If, however, the tensile and compressive stresses are distributed non-uniformly along the specimen axis, the resulting stress distribution is also inhomogeneous. In this connection, the propagation regularities of sound wave, strain, or structure rearrangement along the specimen axis are defined by the above-mentioned stress distribution character. Thus, if the internal stress distribution character varies along the wire axis (when moving downwards) or along the specimen axis (when moving downwards and upwards), the structure rearrangement character is also different. Most probably, if a maximum is observed in the time dependence of IF after a WMF pulse action, the material in the specimen upper part is under compressive internal stresses while in the case of a minimum, under tensile ones.

The set of above statements allows us to suppose what follows.

(a) The different behavior of IF level (a maximum or a minimum) in various materials (being in initial non-equilibrium metastable state) observed during the first 10 or 15 min after a single WMF pulse is caused by non-uniform distribution of compressive and tensile internal stresses and IDC accumulations in the material along a length section of the wire or along the axis of the single specimen.

(b) The effect of non-uniform distribution of compressive and tensile internal stresses and IDC accumulations in the material can be revealed by measuring the IF level after a single WMF pulse action either on several specimens cut out of the deformed wire (or strip) or on the same specimen using the upside-down tumbling.

To check those suppositions, a 70 steel wire was used drawn with 70 % squeezing. Four specimens (Nos. 1, 2, 3, 4) were consecutively cut off from the wire with conventionally fixed "upper" and "lower" ends (according to the wire drawing direction). Fig. 2 (curves a) presents the study results obtained for the four specimens. It is seen that the IF time dependences exhibit different behavior that is characterized by a maximum (Specimens 1, 2, 4) or by a minimum followed by a maximum (Specimen 3). The IF time dependences after the specimen tumbling are also different. Where a maximum was observed prior to tumbling, a minimum or a minimum followed by a maximum is now found (Specimens 1, 2, 4; small shifts in time are possible); in contrast, where a a minimum followed by a maximum (Specimen 3) was observed before, a maximum is found after the tumbling (see Fig. 2, curves b). Similar results were obtained for other materials (Fig. 1,

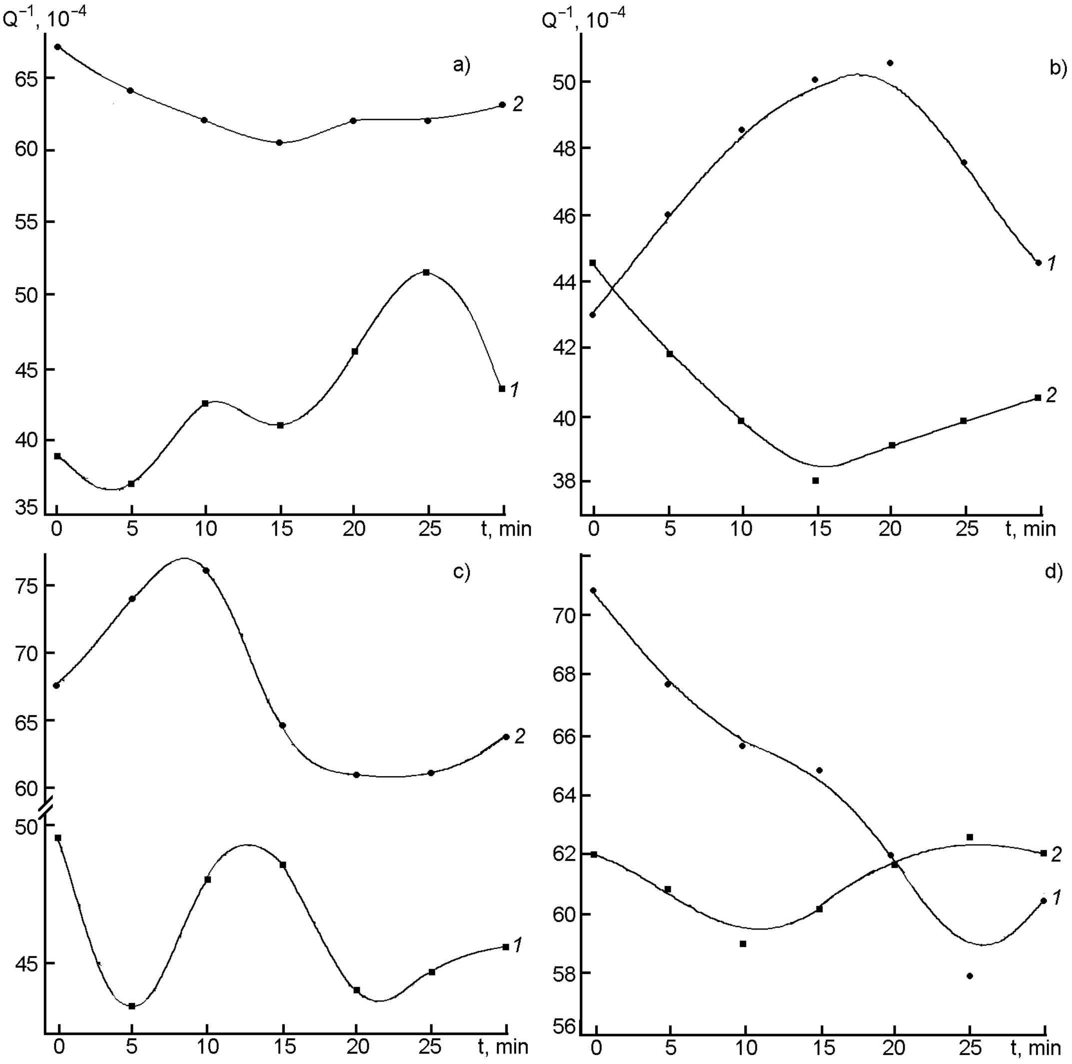

Fig. 2. IF time dependences for specimens cut off sequentially from a drawn 70 steel wire (Specimens *1*, *2*, *3*, *4*) after action of single WMF pulse prior to (a) and after (b) the specimen tumbling (the specimen "upper" and "lower" ends, respectively).

curves a and b). The observed IF maxima and minima are more or less pronounced in different cases. It can be supposed that those are due to compressive and tensile internal stresses, respectively, that are higher or lower in different cases.

Using the data on time dependences of IF for four specimens of steel 70 (Fig. 2), we attempted to construct an approximated diagram of distribution or coexistence of compressive and tensile internal stresses along the wire axis. After background subtraction, the maximum height ($+\Delta Q^{-1}$) and minimum depth ($-\Delta Q^{-1}$) in the IF time dependences was supposed to be in proportion to the compressive and tensile internal stress level, respectively, at the specimen end. After these values (ΔQ^{-1}) were determined at the upper and lower specimen ends, taking into account the specimen cutting sequence as well as the working and total specimen length, the ΔQ^{-1} variation character over the wire length, l, was determined (Fig. 3). The comparison of data presented in Figs. 2 and 3 evidences that the pronounced maxima and minima in the IF time dependence observed prior and after the specimen tumbling take place in the case when the maximum stress (and the IDC accumulation) values fall on the opposite specimen ends. In contrast, if the maximum stress (and the IDC accumulation) values fall on the specimen middle part, the IF maxima and minima are much less pronounced.

According to the obtained ΔQ^{-1}~(l) dependence, within a 240 mm long wire section, the compressive and tensile internal stress alternate in the material with a half-period of 45 mm, almost equal to the working length of test specimens.

Those experimental data on the alternation half-period of internal stresses, d = 45 mm (Fig. 3) and typical time τ values (5 and 15 min) in extreme points of the IF level time dependence (Fig. 2) make it possible to estimate the velocity ($v = d/\tau$) of structure rearrangement wave arising due structure relaxation of internal stresses; the corresponding values are $1.5 \cdot 10^{-2}$ and $5 \cdot 10^{-3}$ cm/s.

To conclude, the low-frequency dislocation IF level in metals during first 10 to 15 min after a single weak magnetic field pulse action varies showing a maximum in some cases and a minimum in other ones. The data obtained evidence that these differences in the IF variation character are caused by non-uniform distribution of compressive and tensile internal stresses as well as of IDC accumulations in the material along the test specimen axis. In a 70 steel wire prepared by drawing down to 2.6 mm diameter with 70 % squeezing along the deforming axis, a non-uniform periodical distribution of compressive and tensile internal stresses as well as of IDC accumulations takes place at the half-period of 45 mm. The study procedure used in the work can be applied to reveal the coexistence character of compressive and tensile internal stresses as well as of IDC accumulations along the axis of wire (or strip) and specimens of materials being initially in a non-equilibrium metastable state.

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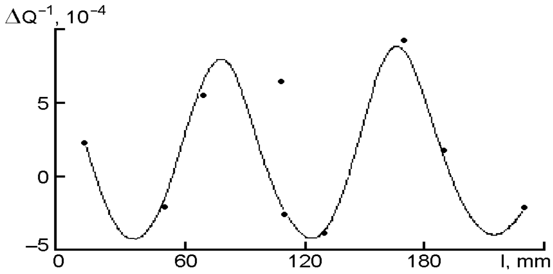

Fig. 3. Approximated (possible) character of the IF level behavior after background subtraction (ΔQ^{-1}) along the axis of drawn 70 steel wire (after the data obtained for the above Specimens *1*, *2*, *3*, *4*).

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Особливості внутрішнього тертя у металах після впливу одиночним імпульсом слабкого магнітного поля

О.І.Дацко, В.С.Абрамов, В.Ю.Дмитренко, В.В.Чишко

Досліджено поведінку рівня низькочастотного внутрішнього тертя у різних металах у перші хвилини після впливу на них імпульсу слабкого магнітного поля. Встановлено, що часова залежність внутрішнього тертя на протязі 10–15 хвилин має в одних випадках максимум, а в інших — мінімум. Цей результат пов'язується з різним нерівномірним розподілом стискаючих та розтягуючих внутрішніх напружень у матеріалах зразків, що досліджувалися, впродовж їх осі.