Slow solitary elastic waves respond for the solitonic heat transfer and registered by the acoustic method in the metallic sample having defects

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Abstract. Soliton heat transfer can play an important role under certain conditions. The work shows that the metallic sample defects number increasing may be helpful. It leads to more efficient acoustic-pass detection of soliton-like components of the Slow Solitary Elastic Wave (SSEW). These components have discrete velocities and provide additional "solitonic" heat transfer to the usual one. In the Al samples of 11 cm and 7.5 cm long (with the 2x3 mm² cross section), the laser pulse excites the SSEW components. The number of acoustic events due to reflections of the SSEW components from the sample ends was calculated. At first, the sample had few defects, since it was "annealed" at T_0 for more than 30 years. In 4 consecutive experiments, a laser pulse (λ=10.6 μm, 0.3 seconds, 10 kW/cm²) caused 21 to 6 acoustic events in 40 minutes. This is the result of going back and forth on the sample of two SSEW components with velocities 0.062 and 0.0307 cm/sec. Then, to increase the defects number, the sample was deformed on an Instron 3382 unit and irradiated with a neodymium laser of λ=1.06 μm (42 laser pulses of 10nsec, 1J each, with 0.1sec intervals). For 140 minutes, 106 acoustic events were recorded. By intervals between them, it was possible to identify the SSEW components with velocities of 0.298; 0.0170; 0.00938 and 0.00615 cm/sec.

1. Introduction
In the Al sample, a laser pulse (LP) excites soliton-like waves - the components of the Slow Solitary Elastic Wave (SSEW), having discrete velocities. These waves provide an additional, solitonic mechanism for the transfer of thermal energy, predicted by M. Toda [1]. Note that in some cases and for a limited time such heat transfer can become the main factor of energy transfer from the source. V.L.Ginzburg considered the soliton as one of the most promising objects of modern physics research [2]. As for the discreteness of the velocities of soliton-like waves (in our case, SSEW components), this statement can be considered recognized and proved as a result of a series of works of theorists [3÷5] (each with the first reference to the previous one from the series). It was published by employees of LPI of RAS in 1992 the report about the soliton-like waves observation in the experiments [6], and by the year 2000 there were a lot of their reports about the unsteady energy transfer by soliton-like waves in a solid states samples [7].
Head of Axelerator Laboratory (Dubna) A.M.Baldin invited us to give an article in their journal on the experimental study of solitons. These formations are of great interest in nuclear physics but they were mainly studied by theorists. The corresponding article was presented and published [8]. It was carried out jointly by the scientists of LPI of RAS and MEI. It was used there a new unique e-beam source for the excitation of SSEW type waves (developed at MEI). We are able to observe experimentally some ordered and predictable system from the acoustic events (AE). It appears regularly at one of the ends of the specimen. This confirms that waves of the SSEW type propagate along the sample. They cause the formation of the AE. But it is known that such waves carry energy. In the described experiments, in our opinion, it is the waves of the SSEW type that are responsible for the soliton heat transfer.

A further confirmation of this was found in the IMET of RAS experiments to observe the acoustic emission of metal samples, which were rapidly heated in a vacuum furnace [9]. The analysis of these and many other new results in the framework of the LPI of RAS IMET of RAS cooperation repeatedly confirms the presence of heat transfer by soliton-like waves. They are well detected by the acoustic method, since they lead to the formation of Acoustic Events (AE). The results of these works were repeatedly reported at various conferences, including international ones, but so far it has not been possible to publish it in the form of a journal article.

The purpose of this particular study is the desire to obtain yet another confirmation of the appearance of the above picture from a number of AEs. They should appear in experiments regularly at one of the ends of the sample. If our assumptions are correct, then the picture should be more clearly observed with an increase in the number of defects in the sample under study. And the increase in the number of defects can be achieved artificially in the same sample. At present, the results of our experiments do not yet have repetitions in the world literature.

A comparison was made between two samples (in this case, Al) with different defect content. The number of AE is related to the reflections of the SSEW components from the ends of the Al-sample. But with a small defect content in the sample, not every reflection causes the appearance of "one's own" AE. With an increase in the concentration of defects in the same sample (which the authors achieved in the second part of the work), the number of AEs registered should also increase. The fact is that now it is easier for the wave to accumulate the number of defects necessary for the AE formation. To reliably compare the results, it is desirable to have close velocities of solitary waves in experiments. The calculated velocity of the $i$-th SSEW component, $U_{i\text{calc}}$, at constant temperature is expressed in terms of its number, $i$, and the longitudinal sound velocity in the material under study, $v_l$, as

$$U_{i\text{calc}} = \frac{v_l}{(2.05)^i}. \quad (1)$$

2. Experiment with an aluminum sample containing few defects

2.1. Method of the experiment [10].

The test sample was in the form of a rod 11.1 cm in length, cross-section 2.4x3.0 mm$^2$. One of the sample ends was irradiated through a NaCl lens (f 20 mm) by an ~ 0.3 sec IR CW Gas Discharge CO$_2$ Laser pulse. Laser power was ~ 5 W (λ 10.6 μm) and an electro-mechanical interrupter was used. The spot size in the focus was ~ 0.2mm. To reduce the reflection coefficient, the Al-sample end was covered with a heat-resistant paint. The paint held one irradiation pulse, after which the place of irradiation changed.

2.2. What was observed on the records?

The records show AE series, which were investigated in the present experiments. The number of AEs due to the reflections of the SSEW components from the sample end faces was calculated. In these experiments, the Al-sample had few defects, since it was "annealed" at room temperature for more than 30 years. The effect of 1-fold LP caused the formation of a number of AE, the appearance of which was recorded for 40 minutes. Fig. 1 shows AE energy records (in dB) for the first four experiments performed using the same sample. By the way, the same results look very different in
[10]). There they are given in the form of time dependencies - for AE energy also, but in mV. The experiments were carried out for one day, with ~30 min intervals and with the laser intensity changing within ~ 5%.

2.3. Conclusions.

What features can be pointed on the presented AE-records?

2.3.1. The amount of AE decreased in each subsequent experiment (with the same 40 minutes of recording duration). At first, this amount decreased sharply (after the first experiment), and then slowly: 21; 8; 8 and 6 AE on one record. It is interesting and important that a sharp decrease of the AE amount (to the second experiment) touched those AE, intervals between which are small. You can think that the reason is that the corresponding SSEW components are faster. Then it was these fast components that stopped appearing. One of the possibilities of this is as follows. These SSEW components cleared the sample of "their" defects quickly, during the first experiment. The reason could be in some kind of resonance between defect movements and wave velocity.

2.3.2. The main intervals found between AE in the four experiments are the following:

369.6 sec (experiment No. 1); 340.4 and 364.8 sec (No. 2); 371.4 sec (No. 3); 359.3 sec (No. 4).

The average arithmetic is 361.1 sec. From this one can obtain the average value of the experimentally determined velocity: 11.1cm / 361.1sec = 0.0307 cm/sec. This experimental value of the velocity is rather close (73%) to the calculated velocity value of the 23rd SSEW component.

2.3.3. The SSEW component velocity higher than the 23rd component velocity could be calculate using some time intervals on the records of No. 1 and No. 2 experiments. These intervals are in good agreement with each other and are represented by short dashed lines a), b), c), d) - in Fig. 1a) and e), f) - in Fig. 1b). These time intervals are slightly shorter than half of the main time interval observed on all 4 records. This corresponds, approximately, to the doubled velocity of the studied SSEW component. The obtained experimental values of the velocity is also rather close (71%) to the calculated by equation (1) velocity values of the 22nd SSEW component.
Figure 1 a)b)c)d). Acoustic events (AE) in 4 consecutive experiments with an Al-sample containing very few defects. (The time intervals on part a) between AE4 and AE21 are close each another and the average arithmetic is 369.6 sec)
3. Experiments with an aluminum sample containing an increased number of defects
Here we briefly discuss the results of a series of 6 experiments and present in detail the result of the first one.

3.1. Experimental method.
A heat-resistant paint was applied to the irradiated end of the sample.

3.1.1. To increase the number of defects, the sample was deformed on the Instron 3382 installation in the experiments of this section.

3.1.2. The sample was irradiated by neodymium laser having generation in the spectral region $\lambda = 1.06 \mu m$. It was one of the differences from the experiments of the first part of this article. The number of LP (with a duration of 10 nsec, energy of 1 J each), which followed one after another in 0.1 sec, were amounted to several dozen in each experiment. In the first experiment, which is discussed here in detail, there were 42 of LP.

3.2. Results.
106 AE were recorded for 140 minutes of registration in the experiment No. 1. Fig. 2 shows the results of AE recording.

3.2.1. How was the registered AE number changed in a series of 6 experiments?
We have the following AE number per time unit in 2 (03z, 04z) control experiments: 2 AE / 50 min or ~ 2 AE / hours.
In the experiments No. 1 and No. 2, 62 and 1195 AE were registered for 2.24 and 43.1 hours, respectively. This corresponds, in practice, to the same rates of AE occurrence, namely, 27.6 and 27.7 AE / hr.
In experiments No. 5 and No. 6, the threshold for the AE appearance was raised (from 33 dB to 34 dB), which made their appearance more difficult. This fact must be taken into account when comparing with the results of previous experiments. In the experiments No. 5, No. 6 we have: 11 AE and 315 AE; Their registration time was 2.2 and 83.5 hours. Hence, we obtain the rates of events occurrence, respectively, 5.00 and 3.77 AE / hour. Thus, although AE began to appear much less frequently, but still their appearance rate is 2.5 times higher (2.2 hours, experiment No. 5) and 1.9 times higher (for 83.5 hours, experiment No. 6 ) than in the control experiments.

3.2.2. What SSEW components are shown in Fig. 2?
As data related to the results of the work, presented on the Fig. 2, the following 4 (repeating) time intervals found in this experiment are shown:

252; 440; 800; (1220 - 1270) sec.

Since the length of the sample in these experiments was reduced to 7.5 cm, then the values of the velocity $U_{exp}$ corresponding to the above time intervals are:

0.0298; 0.0170; 0.00938; (0.00615 - 0.00591) cm / sec.

If we assign these values to the calculated values according to formula (1) at $A = 2.05$, we find rather good agreement. This quantities, which are in satisfactory agreement with the calculated values, are in very good agreement also with values measured in previous part of this work:

$0.71 \ U_{calc, 23}; 0.83 \ U_{calc, 24}; 0.93 \ U_{calc, 25}; (0.61-0.59) \ U_{calc, 25}$. 
4. Discussion of the results common to the 2 parts of the work and conclusions.
As for the sample of the material "almost without defects" as for the sample with a small number of defects there is a rather good agreement between the measured velocity of the SSEW components with the calculated values. Deformation on the Instron 3382 installation increased quantity of defects, but not enough to see the SSEW components better.

Only the first results are processed here, the work will be continued. Already there are samples with an increased number of defects. Work is planned on their investigation.

Returning to what was said at the beginning of the article, we can state the following. In metallic samples that are opaque to optical radiation, it is not possible to "see" (for example, by help of the Schlieren method) - the displacement of soliton-like solitary waves along the sample. But their research is important because they provide "their own" part of the heat transfer. It is in such cases that the primary role of the acoustic method becomes paramount, with the help of which, as once again shown here, it is possible to reliably register the occurrence and movement of soliton-like solitary waves in metallic samples.

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