Piezonuclear Reactions:

Neutrons and Transmutations by Ultrasonic Stress of Iron Bars

Cardone Fabio [1,2,3], Mignani Roberto [2,3] and Petrucci Andrea [3,*]

[1] Istituto per lo Studio dei Materiali Nanostrutturati (ISMN-CNR) Via dei Taurini − 00185 Roma, Italy
[2] Istituto Nazionale di Alta Matematica F. Severi Città Univ., P.le Aldo Moro 2 − 00185 Roma, Italy
[3] Dipartimento di Fisica, Università Roma Tre Via della Vasca Navale, 84 − 00146 Roma, Italy
[*] petruccia@fis.uniroma3.it

Keywords: Ultrasounds, micro-fracture, piezonuclear reactions, neutron emission, transmutations

Abstract. We report the results of neutron measurements during the application of ultrasounds to bars of Iron and Steel. As it happened in our previous works with cavitated solutions of Iron and in the works of brittle fracture by Professor Carpinteri, neutrons were emitted in bursts without any concomitant or following gamma emission. The spectrum of these peculiar neutron emission was measured for the first time. A further outcome of these experiments were the macroscopical damages that appeared on the surface of the bars which was not directly in contact with the sonotrode. The elemental microanalysis of these spots on the surface of the bars showed some interesting and macroscopical variations of the concentration of elements obtained on the undamaged surface. A morphological inspection of the interior of the bars near the damages showed the presence of micro-cavities whose walls or content presented variations of the concentration of elements similar to that found on the surface.

Introduction

In the last six years we carried out experiments about piezonuclear reactions [1, 2] in which we applied ultrasounds to solutions of water containing atoms of Iron and from which, thanks to cavitation, that brings about a violent bubble collapse, we obtained neutron emission. In the wake of these experiments we hypothesised that a similar process to bubble collapse in liquids might take place in solids too, thanks to the presence of microcavities and/or inhomogeneities and/or anisotropies which would play the role embodied by bubbles. This conjecture had its positive verification by some experiments carried out, by a research team led by Professor Carpinteri, at the Polytechnical University of Turin [3, 4, 5]. They applied pressure onto specimens of Iron-rich rocks (granite, basalt) both by continuously compressing them up to their catastrophic collapse (brittle fracture) and by cyclic fatigue tests at low (2 Hz) and high (20 kHz) frequency. The specimens were surrounded by neutron detectors both passive (bubble detectors) and active (^3He). At fracture and during the fatigue tests both types of detectors always recorded a burst of neutrons many times higher than the measured neutron background. On the basis of these evidences, we decided to move a step forward and to apply ultrasounds to man made bars of Iron in order to increase the concentration of Iron which, so far, has turned out to be the key element. As it happens with collapsing bubbles where iron atoms entrapped on their surface get accelerated towards each other, we conjectured that the atoms of iron, surrounding the inhomogeneities (gas porosity) in the lattice of a bar, would be subjected to the same kind of processes. According to the theory proposed by two of us (F. C. and R. M.) [9, 10, 11], that predicts these phenomena, if the collapse of a bubble or of a micro-cavity succeeds in concentrating the Iron atoms in a certain region of space, within a certain time interval and with an amount of energy greater than 367.5 *GeV* , these atoms undergo a new type of nuclear reactions which we baptised piezonuclear reactions. On the basis of this heuristic conjecture, we designed our experimental set-up by taking advantage of the experience gained in the

experiments with ultrasounds and solutions [1, 2, 12, 13, 14], but aware of the big differences between iron in a solution and solid iron.

Experimental set-up

The experimental set-up was made of an ultrasonic machine, called reactor R-1-S, pretty much similar to that one used in our previous experiments [1, 2, 12, 13, 14]. This reactor was suitably designed and assembled by Startec Ltd. It had a converter unit with piezoelectric ceramics and a truncated conical sonotrode mechanically connected to it. A suitably designed metallic frame held the converter-sonotrode unit aligned with the cylindrical iron bar to be treated by ultrasounds (Fig.1). Moreover this frame could be shifted vertically and a pneumatic system allowed one to vary the contact strength between the sonotrode and the bar and hence vary the transmitted power. The bar was held in the upright position by a dielectric cylinder through which the bar was inserted. The shaping of the top and bottom tip of the bar was studied and made in order to have within it both a direct and a reflected wave. Since these two waves are longitudinal waves moving along the same direction but in opposite verses, the transverse planes of the bar with respect to its length find themselves squeezed between these two waves (patent pending on the experimental equipment [15]).

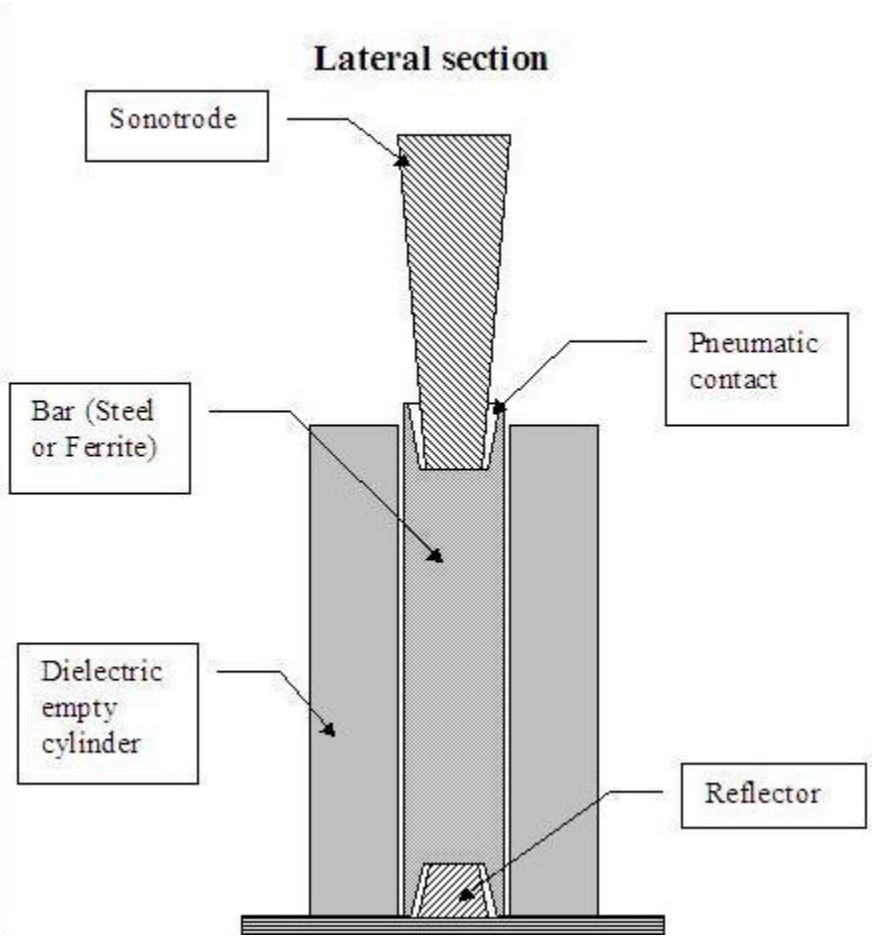

Fig 1: Experimental set-up. Lateral section.

Neutron measurements

The experiments that we carried out had three main targets: check whether neutrons would be actually emitted by such a different device with respect to solutions of water and Iron; obtain for the first time the neutron spectrum of these emissions; check the time of the beginning of neutron emission. This last information had to be correlated with that of the previous experiments [1, 2], where neutrons began to be emitted after 40-50 minutes. We will come back to this point later on. We used two types of neutron detectors: a neutron counter HDS-100GN by Mirion™ [6] and a neutron spectrometer ™MICROSPEC2 Neutron Probe by BTI [7, 8]. The former is a gamma detector and spectrometer with CsI(Tl) scintillator for low energy gamma rays and silicon diode for the high-energy ones. Besides, it contained also a neutron detector with a LiI(Eu) scintillator. The latter is made up of two parts: the multichannel MICROSPEC2™ and the neutron detector Neutron Probe with an *He*3 counter for thermal neutrons up to 800 *KeV* and a liquid scintillator for neutrons from 500 *KeV* to 5 *MeV*. In each measurement, these detectors were placed at 20 cm from the external surface of the dielectric cylinder containing the bar. We put in contact the sonotrode and the tip of the bar like in Fig.1 and applied a pressing force on it, so that the transferred ultrasonic power into the bar was 19 *W*[1]. The frequency of ultrasounds was 20 *KHz* like in the previous experiments with solutions, and the amplitude of the vibration of the sonotrode tip was 15 μm. We treated two different types of cylindrical bars: bars made of sintered Ferrite (α-Iron) and bars made of steel with hardened surface by carbon steel. Both types had the same dimensions: circular cross section of 20 mm of diameter and a length of 200 mm. All of them were treated with the same ultrasonic parameters just mentioned. The two instruments, HSD-100GN and MICROSPEC Neutron Probe were brand new and had their own calibration certificates. By a standard source of AmBe at the Euratom Laboratory Ispra it was verified the compatibility of the readings of the two instruments with the certification. First of all, we carried out prolonged measurements by the HDS-100GN with ultrasounds turned off, in order to get a fairly long history of the neutron background variations. In all of the measurements of neutrons with ultrasounds turned on, several neutron bursts were detected. The height of these bursts were 25% higher than the maximum value of the neutron background. This was the first evidence that we meant to obtain by the HDS-100GN. The second information, that could be obtained by this instrument, had to do with the instant of time when the first neutron burst would appear. In the previous experiments [1, 2], as we stated above, neutron emission began about 40-50 minutes after ultrasounds had been turned on. In this case, conversely, the first burst appeared always within about 5 minutes after the turning on of ultrasounds. Let us make the meaning of this evidence more explicit. In the experiments with solutions of Iron the density of the liquid was about 1 g/cm^3, the first burst appeared after about 40-50 minutes of ultrasounds and the transferred ultrasonic power was about 130 W. Conversely, always working at the same frequency, in the solid case the mass density is that of the Iron, 7.8 g/cm^3, the first bursts appeared after about 5 minutes and the transferred ultrasonic power was about 19 *W*. We report these numbers in Table 1. Very interestingly, we see that when the density of the material increases of 8 times, the interval of time and the power to obtain neutrons decreases with the same factor. This evidence is interestingly in agreement with the prediction of the theory as to the relation existing between the occurrence of piezonuclear reactions and the amount of energy present in the system

[1] This value of 19 *W* was chosen having in mind the power of ultrasounds used in the experiments of cavitation of solutions of Iron (130 *W*), the density of the solutions and the density of solid iron. As we will show and explain in the following of this article, our theory suggests the existence of an inverse proportionality between the density of the material and the ultrasonic power. In this sense, we chose a value of the ultrasonic power which was about 1/8*th* of 130 *W*, since the same but inverse proportion exists between the density of Iron and that of the solutions.

Table 1: Comparison between liquids and solids - Density of the material, Minutes for the first bursts of neutrons to appear, Power of ultrasounds

-	Density	Minutes	Power
Liquids	1	40	130
Solids	7.8	5	19
Liquids / Solids	≈ 1 / 8	≈ 8	≈ 7

(the system being nuclei per unit volume i.e. mass density). Necessary but not suffcient condition for piezonuclear reactions to take place is to overcome a threshold of energy and hence a threshold of energy density, which is more promptly overcome in denser materials. As we reported above, the HDS-100GN was also equipped with a gamma detector by which we could check the absence of any peak of gamma rays consequent to the detected neutron bursts. After the completion of these measurements by the neutron detector, we began the measurement of neutron spectrum, within the same experimental set-up. In Fig.2 we present two neutron spectra obtained during 1 hour of application of ultrasounds to one bar of ferrite (a) and one bar of steel (b) and in (c) the neutron spectrum of the background, i.e. with ultrasounds turned off. The difference between the two spectra (a) and (b) with the spectrum (c) can be easily spotted. Moreover the spectra (a) and (b) have a fairly clear log-normal shape which, from an intuitive and qualitative point of view, gives a fairly sound evidence of the existence of the phenomenon.

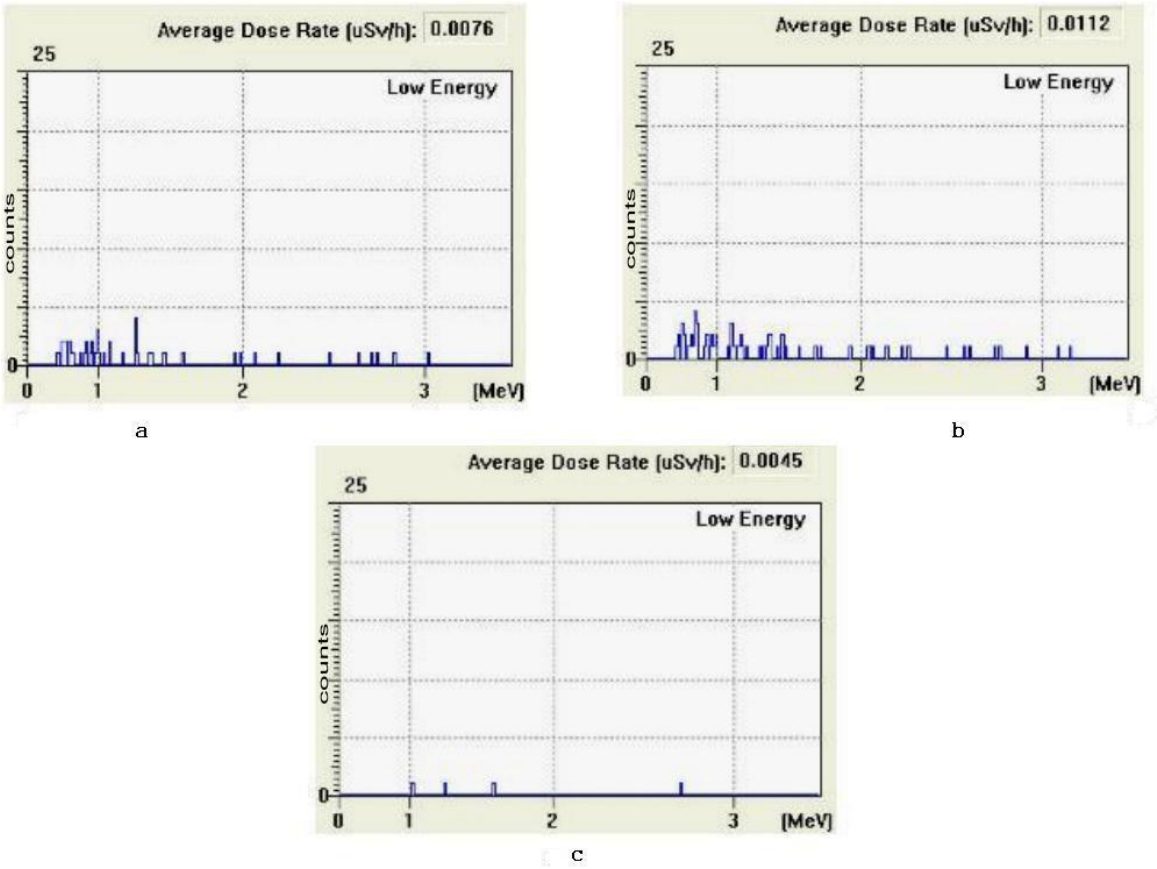

Fig 2: (a) Neutron spectrum from the bar of Ferrite - (b) Neutron spectrum from the bar of steel - (c) Neutron spectrum of the background. For all of them we have MeV on the abscissa and counts on the ordinate

Bar damages

We present here a further interesting evidence that appeared on the lateral surface of the bars and that was completely unexpected. As is visible in Fig.1, in the experimental set-up, the bar treated by ultrasounds, was held vertically with its axis aligned with that of the sonotrode by an empty cylinder made of dielectric material. Once the bar was pulled out of the empty cylinder, we noticed, with great surprise, that on its lateral surface peculiar circular spots had appeared as in Fig.3.

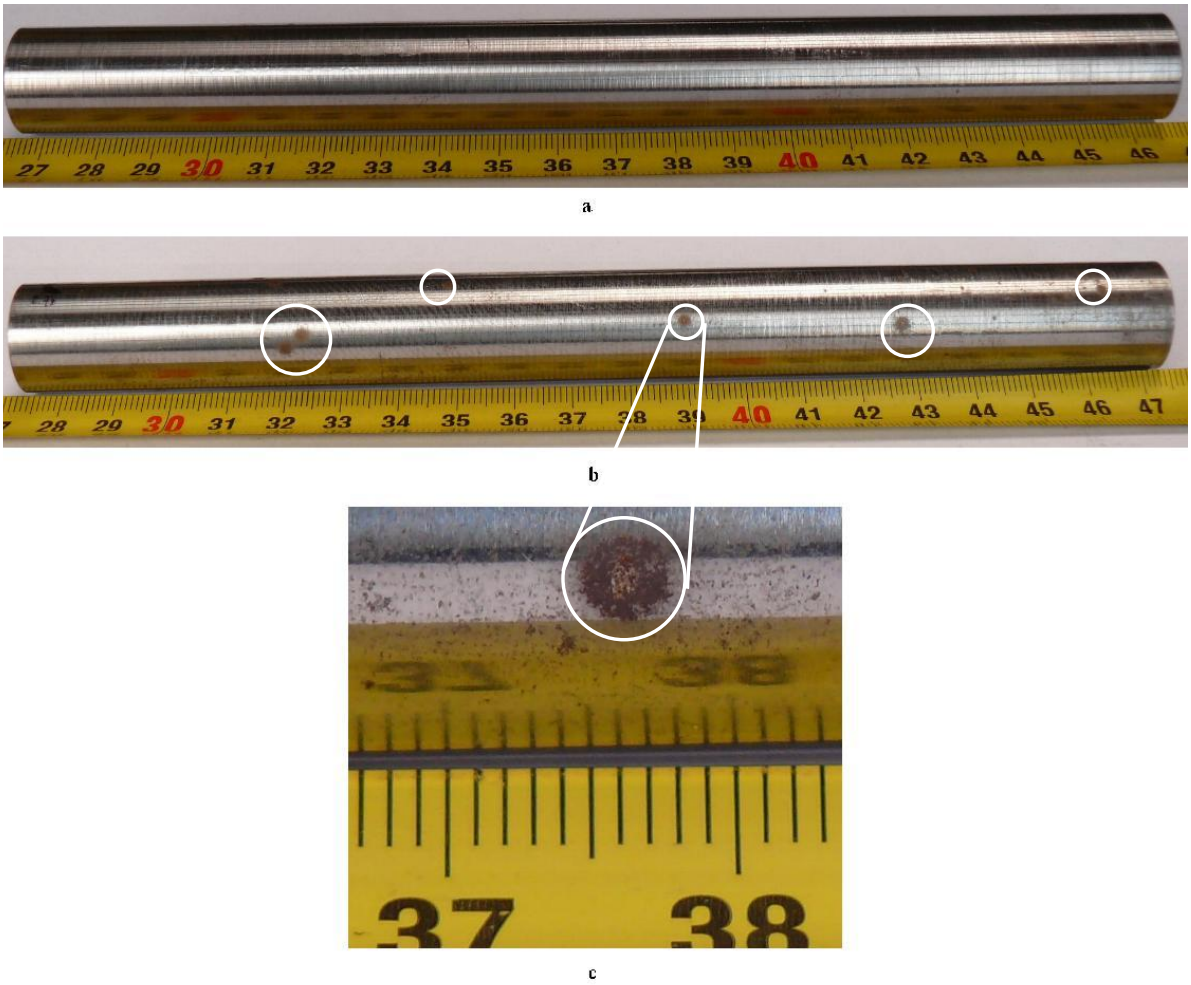

Fig 3: (a) - (b) - (c). Units in centimeters

As is possible to see from Fig.3, the ruler next to the bar clearly shows that these amazingly circular spots have a diameter that ranges from 2 to 3 millimeters. The surface of the bar on them is rougher and the roughness increases moving from the border of the circle to its centre. All of the spots have a fairly good circular symmetry at the unaided eye. While the colour of the bar is metallic grey as it normally is for steel, the predominant colour of these spots is brownish in a ring bound by two concentric circles and whitish in a circular central area. At a first sight, neither the distribution of these circles on the lateral surface of the bar had any particular symmetry, nor the distances between the centres of two spots apparently had any proportionality among them and/or with the dimensions of the bar. We would like to stress that these spots showed up on all of the bars, but they were more clearly visible on the bars of carbon steel. If one considers this last fact, i.e. a carbon steel bar, together with the ultrasonic energy conveyed into the bar, that was 19 *W*, one cannot be but puzzled. From a metallurgic point of view such a power, applied to the bar in the experimental conditions mentioned above, is just too low to produce these damages on a bar whose surface had been

hardened by carbon steel. However, the first thing that we checked was the presence of any possible ferric oxide or hydroxide on the damaged surface. We decided to treat some of the bars with these circular spots by a solution of hydrochloric acid at 33%. We immersed the bars into the solution and kept them submerged for one hour. Once we took them out of the solution of HCl and rinsed them, we noticed straight away that this treatment had had no effects on the damaged parts, whose morphology and colour had not changed. In order to obtain further information about the features of these damaged parts, we performed on them a semi-quatitative micro-analysis by a Zeiss Supra 40 FESEM with the electron beam at 20 KeV and equipped with an Oxford INCA energy dispersive X-ray detector Si(Li) whose resolution at MnKα is 133 eV. Of course, we analysed by the same technique some areas of the undamaged surface as well and found out a sound homogeneity of the concentrations of elements. In Table 2 the concentrations in weight of the elements are reported. Particular attention has to be paid to the variations of Carbon, Oxygen and Iron. In Table 2 we reported the values of concentration that were obtained at the centre of the circular damage. Beyond the amazingly macroscopic variation of concentration of the three elements mentioned above, some other elements appeared that were not part of the superficial composition of the bars. We highlight the remarkable fact that the decrease in weight of Iron seems to be counterbalanced by the sum of the increase in weight of Carbon and Oxygen.

Table 2: Concentration in weight of elements before and after ultrasound treatment.

Before Ultrasound		**After Ultrasound**	
Element	***Weight*%**	**Element**	***Weight*%**
C Carbon	2.37	C Carbon	19.80
- -	-	O Oxygen	29.27
- -	-	Na Sodium	1.20
- -	-	Mg Magnesium	0.19
- -	-	Al Aluminium	0.53
Si Silicon	0.21	Si Silicon	0.49
- -	-	S Sulfur	0.27
- -	-	Cl Chlorine	1.61
- -	-	K Potassium	0.54
- -	-	Ca Calcium	0.68
Mn Manganese	0.66	Mn Manganese	0.47
Fe Iron	91.92	Fe Iron	44.45
Cr Chromium	0.18	- -	-

With regards to the damages of the bars, we have to mention one more interesting evidence that corroborates the variations of concentration on the surface. From a private communication[2], we know that, by coring the bars where the surface is damaged, their interior below the damaged surface has been analysed by a FESEM that allows micro structural analyses by SE (Secondary Electrons) and BSE (Back Scatters Electrons) and X-ray micro analysis by EDS. What has turned out is that the interior part corresponding to a damaged surface is full of micro cavities with diameter of about 10 μm, either empty or full of irregular material with jagged surface, while the interior part corresponding to a not damaged surface present a small number of cavities with a much smaller diameter. The semi-quatitative analyses by EDS of these zones produced results that point towards the same direction of those presented in table 2. These cavities contain new elements other than to those present in undamaged parts. In particular, they found O, Na, Mg, Al, Si, S, Cl and Cr. Besides, it has been possible to notice that as iron decreases, carbon, oxygen, chlorine and potassium

[2] Dr Filippo Ridolfi, Dipartimento di Scienze della Terra, della Vita e dell'Ambiente Università degli Studi di Urbino Carlo Bo" Campus Scientifico

increase. Although these analyses are still in progress their preliminary results suggest that ultrasounds cause piezonuclear transmutations.

Discussion of the Results

Let us first remark the lack of gamma emission higher than the background, that conforms to the outcomes of our previous experiments [1,2]. Some discussion is duly needed both for the neutron spectra and for the peculiar marks that appeared on the surface of the bars. Let us refer to Fig. 2. Despite the fairly clear difference between the spectra 'a' and 'b' and the spectrum 'c', one might be dissatisfied with the poor height of the bars of the histograms 'a' and 'b'. Two main reasons can be presented as the possible explanations of this fact. First of all, from our experience of measurements of this kind of peculiar neutron emission which happens in bursts[1,2] that stick out over a neutron background, we can state that the detection efficiency of active detectors is very poor. This is due to their dead times that make them miss some consecutive bursts or miss the entire height of a burst and to the software that controls them which tends to average the bursts to the neutron background. The second reason has to do again with the emission in bursts. These bursts are not isotropically emitted over 4π steradians, but they are rather concentrated along a direction in space that apparently changes for every burst, as it is well evident in Fig. 3 where the damage spots on the bar are randomly scattered on its surface. With this in mind one understands that a neutron monitor will be able to detect only those bursts emitted aligned with it and will miss all the others. Let us now move to the second evidence of these experiments, that is the presence of macroscopical damages on the surface of the bars. The comparison of the X-ray microanalyses performed both on undamaged parts of the surface and on damaged ones showed macroscopical variations of the concentration of iron, oxygen and carbon, and the appearance of elements that were not initially present. Let us refer to Table 2: the percentages of disappeared iron is 47.47% while the percentages of appeared carbon and oxygen are 17.43% and 29.27%, respectively. Very interesting is the balance between the concentration of the disappeared iron and appeared carbon and oxygen, in particular:

disappeared iron 47.47% ≈ 46.70% appeared (carbon + oxygen).

The emission of neutrons, that was detected during the application of ultrasounds to the bars, certainly raises many questions of theoretical but also of phenomenological and experimental nature; for instance, as to where these bursts were emitted from. The macroscopical damages on the surface of the bars along with the variations and balances of the concentration of elements might be the possible answer to these questions. More explicitly one may think that this balance means that iron "turned into"[3] carbon and oxygen. From this perspective we can give some examples of the piezonuclear reactions that might take place. We want to stress that, by presenting the following reactions, we are in no way stating that these are the actual reactions that took place. The purpose is just to put forward a new type of nuclear reactions trying to follow the hints that nature gives us through experiments. If we consider the first balance between iron, carbon and oxygen, we can hypothesize the following reactions:

$$^{56}Fe^{30}_{26} \rightarrow 3\ ^{12}C^{6}_{6} + {}^{16}O^{8}_{8} + 4\ ^{1}n^{1}_{0}\ ;$$
$$^{56}Fe^{30}_{26} \rightarrow 2\ ^{12}C^{6}_{6} + {}^{16}O^{8}_{8} + 3\ ^{4}\alpha^{2}_{2} + 4\ ^{1}n^{1}_{0}.$$

[3] The use of the verb "turn into" was done in purpose, since we did not want to use either the word fission or the word lysis, or the fusion or the word synthesis. All of them remind too much of the well known nuclear processes which, according to our theory [9,11], have nothing to do with the nuclear processes in a piezonuclear reaction. Piezonuclear processes take place in the microscopically deformed spacetime that surrounds the nuclei, hence the various calculations to establish whether a nuclear reaction is endothermic or exothermic, based on the binding energy per nucleon, are not valid in this context, since the variation of the spacetime deformation, that occurs during the process, contributes to the energy balance.

These reactions, that do not have to be read as fission as stated before, produce neutrons as experimentally ascertained and alpha particles as well. From a private communication[4], we know that the latter may well have been produced in piezonuclear experiments similar to those done by Carpinteri's team [3]. If these kind of reactions, starting from medium weight or heavy nuclides and yielding lighter ones, take place also in CMNS/LENR experiments, one might argue that these alpha particles might account for the extra Helium [16], whose measured quantity is usually higher than that expected to be produced by d–d fusion. Besides, their high linear energy transfer (LET) might also account for some of the extra heat [16] in the condensed matter where these reactions take place.

Perspectives

The evidence of transmutations of macroscopical quantities of elements are certainly encouraging to carry on these kinds of experiments with solid bars that could be made of different compositions but always containing iron, in order to study the way of making these transmutations predictable. With all of this in mind, it is just one step forward to imagine similar experiments on bars of radioactive metals in order to check whether these 'piezo-transmutations' make them loose their radioactivity by the catalysis of ultrasonic piezonuclear reactions in close analogy with what was found out in radioactive liquids treated by ultrasonic cavitation [18].

Acknowledgements

We would like to thank Dr. Filippo Ridolfi for his subtle and accurate suggestions about the analyses by FESEM and his kindness in showing the results of his analyses in the micro-cavities.
We would also like to thank Professor Gianni Albertini for reporting to us beforehand the results of his measurements.

References

[1] F. Cardone, G. Cherubini, and A. Petrucci, A.: *Phys. Letts.* A 373, 862 (2009).
[2] F. Cardone, G. Cherubini, R. Mignani, W. Perconti, A. Petrucci, F. Rosetto, and G. Spera, *Ann. Fond. L. de Broglie* 34, 183 (2009).
[3] A. Carpinteri, F. Cardone, and G. Lacidogna, *Proc. Turin Academy Sci.* 23(V), 33 (2010), 27 (2009); *Exp. Mech.* 50, 1235 (2010).
[4] F. Cardone, A. Carpinteri and G. Lacidogna, *Phys. Lett.* A 373, 4158 (2009).
[5] A. Carpinteri, A. Chiodoni, A. Manuello, R. Sandrone, *Strain* (2010) (doi:10.1111/j.1475-1305.2010.00767.x).
[6] https://www.mirion.com/en/products/datasheets/hp/145298EN-C_HDS101G-GN.pdf
[7] http://www.bubbletech.ca/radiation_spectrometers_files/mobile.html
[8] http://www.bubbletech.ca/radiation_spectrometers_files/neutron_probe.html
[9] F. Cardone and R. Mignani, *Energy and Geometry* (World Scientific, Singapore, 2004).
[10] F. Cardone and R. Mignani, *Int. J. Modern Phys.*E 15, 911 (2006).
[11] F. Cardone and R. Mignani, *Deformed Spacetime* (Springer, Heidelberg, 2007).
[12] CNR (National Research Council of Italy) Patent Office number: WO/2008/041253.
[13] CNR (National Research Council of Italy) Patent Office number: WO/2008/041254.
[14] CNR (National Research Council of Italy) Patent Office number: WO/2008/041255
[15] "Dispositivo e metodo per rilasciare neutroni", http://worldwide.espacenet.com/searchResults?locale=en_EP&IN=Cardone+Fabio&ST=advanced&compact=false&DB=EPODOC

[4] Professor Gianni Albertini, Università Politecnica delle Marche - Dip. di Scienze e Ingegneria della Materia dell'Ambiente ed Urbanistica (SIMAU)

[16] E. Storms, *The Science of Low Energy Nuclear Reactions* (World Scientific, Singapore, 2007).
[17] A. Manuello Bertetto, Presentation at the ICCF16, Neutron emission measurements during loading tests on solid specimens and confirmations by EDS analysis, A. Carpinteri, G. Lacidogna, A. Manuello, O. Borla.
[18] F. Cardone, R. Mignani and A. Petrucci, *Phys. Lett.* A 373, 1956 (2009).