



1000 at 1000: “Indentation fracture: principles and applications”, past, present and future reasons of success

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The article «Indentation fracture: principles and applications» from Brian Lawn and Rodney Wilshaw published in Journal of Material Science in 1975 reaches more than 1000 citations [1]. This is remarkable, and this editorial will try to analyze the reasons for such a success.

A first and easy answer would be because it is a review! However, most review nowadays are a synthetic report of an extensive list of bibliographic references grouped by theme. Some authors indicate that, but others say otherwise the review of Lawn and Wilshaw is very different. However, this publication is definitely not a classic «review», since 65% of the publications cited come from the work of Brain Lawn

and Rodney Wilshaw. While this could be seen as only self-citation nowadays, this can be read in the presence as a demonstration of knowledge, experimental and theoretical, which highlights the excellence of two authors who have published a large number of papers since 1965 on the mechanical behavior of fragile materials. Brian Lawn himself published ten of them in the year 1975! (Lawn’s papers in the Journal of Materials Science with Fuller (1975) and Marshall (1979) have garnered nearly another 1000 citations between them [2, 3].)

A second reason of the success of this article is probably linked to the topic. The success of indentation fracture study is also probably due to the fact

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that a lot of researchers or engineers are interested in a nondestructive test that allows to predict the mechanical behavior of the materials in use. The indentation test is a quite straightforward test, which is mostly nondestructive and commonly used in laboratory or companies on production sites for quality control. Everybody dreams about such an easy test that give information about the future mechanical behavior of the part. Thus, a review about the indentation fracture, its principles and the potential applications is interesting a lot of people. We write interests and not interested because as previously said the article develop all the physical and mathematical bases that are eternal.

However, as perfectly introduced by Lawn and Wilshaw, the problematic of stress field is not only limited to indentation fracture. It also takes into account surface behavior, like nucleation crack, that is the fundamentals of numerous damaging mechanisms observed in the production, the shaping, the treatments or the use of materials. Here, the authors explain their method, based on the measurement of the indentation depth according to the load applied and the length of the cracks produced. This method is used to estimate a critical stress beyond which a fatal crack propagates through a brittle material, as well as fracture/surface energy and crack propagation rate. The authors present this theory in detail by considering a very large number of influential parameters and supplementing it with experimental considerations of great interest to all those concerned with rupture problems.

The overall article is structured much alike a lesson or book. It starts from the scientific origins of the study of stress fields with a touch of history through the works of Boussinesq and Hertz in the end of the nineteenth century. The authors show very precisely what it is possible to predict, thanks to the principles published long time ago by these great predecessors. They describe in detail the stress fields undergone by the material, when applying the load on an indenter. Moreover, they point out the simplifications included in these theoretical models as well as the parameters that have not been taken into account. We note here the benevolence and respect toward the illustrious predecessors. No criticisms are emitted, but remarks on the simplifying hypothesis used to produce fundamental equations of this new field of knowledge.

It progressively goes through all the basics of the mathematical writing, taking into account all the

complexity of the loading during indenting. Because it is the question of stress fields that is today still very difficult to concretely measure, due to the presence of devices which applied the load, this mathematical base is the heart of the subject. This stress field is commonly only studied through its consequences on the underlying material, namely cracks network or plasticity deformation. Later on, the general principles of fracture mechanics are discussed, with the thermodynamic aspects of crack creation, the effect of internal flaws, the evaluation of the energies released and the explanation of the shape of the cracks, depending on the indenters and the nature of the material. All this is remarkably described, written. All the figures accompanying the text are indispensable and very well commented.

This article is still quoted nearly 30 times a year because of the well-developed theoretical base of field explanation. Consequently, we propose herein to analyze the reasons that lead to such a success for this article. To do so, we find interesting to express the distinct view of three generations of researchers. Each generation will propose its own view on why this article is so remarkable.

Jean-Yves is a retired Associated Professor from Ecole Central University in Lille—France. He has trained tons of engineers and was already in action in 1975. David is currently Full Professor in Lille University—France, who began his career in 1995. Thibault is a young Ph.D. working in Post-doctoral position in Railenium institute in Valenciennes—France. All these researchers have initiated their career with an inevitable gap in terms of view on academic research. This is the gap we seek to emphasize when looking at this review.

Thibault, born in 1992

Indentation test is an extensively used technique in pretty much any modern characterization project in material science. It involves a wide range of physical phenomena, and it is far from being trivial to understand all the phenomena underlying beneath an apparently simple indentation test.

While most reviews aim to confront the state of the art of a given subject, Brian Lawn and Rodney Wilshaw decided to carry out an historical review on the key points of indentation fracture. The review is

displayed as a lesson-like document, providing all the information suited for further comprehension of indentation phenomenon. In my opinion, the most important reason for this review's success is because this text highlights all the prerequisites needed in order to understand indenting test.

First of all, it aims to provide an overview of indentation fracture, its mechanisms and consequences on tested material. It rises awareness on the possible consequences of this specific solicitation and how to further use this knowledge to link the indentation fracture mechanisms to material properties. However, while most authors would be satisfied with such a complete overview, this review also provides extensive details on the origins of these mechanisms and how to exploit this phenomenon.

Second, what makes this review so remarkable is the balanced combination of theoretical and experimental investigations. Indeed, physical and mathematical approach is first developed in order to explain the origins and consequences of stress fields in indentation testing. Then, numerous parameters impacting indentation test, such as time-dependent load, temperature and indenter shape, are studied experimentally and mathematically.

Coming from a young researcher specialized in microstructural investigations, I could not help but point out the absence of EBSD or TEM experiments in this review. This technique would now probably be one of the key techniques to investigate indenting. It would provide suitable information on the subsurface response after indentation test. However, Lawn and Wilshaw still succeeded to provide a clear and complete work detailing the material response using only affordable experimental techniques. Similarly, when most modern reviews on indentation would be supported by a numerical aspect, this could obviously not be done at this time. In this review, the absence of numerical aspect is counteracted by the extremely rigorous mathematical approach combined with a great amount of experimental data.

In the end, the old school's patient and rigorous investigations presented in this review lead to a more readable and trustworthy conclusion than an approach using solely numerical calculation or TEM/EBSD investigations. Everything in this review is thought to provide all the essential data for a newcomer, while providing gives substantial data to support a specialist's prior findings.

This means that this review is mandatory to both understand the physical quantities you are working with *and* determine all the data that can be exploited using this test. This is the exact definition of what a researcher seeks when doing his state of this art.

David, born in 1969

In 1975, I was only 6-year old. At this time, my first experiences for indentation fracture were probably the effect of my teeth on my favorite candy! More recently, with the Covid-19 pandemic, the University was closed, but we need to keep our students working. Distance learning grows significantly, and we have to change our habits. How to motivate students? How to be sure they work and they learn something? These are so many questions we ask ourselves. Based on article such as the Lawn and Wilshaw's one, we can imagine great works.

Young students are not often subjected to produce bibliographic reports on a specific area. It is why this article presents a good work is already done, in the form of example. He presents theory with physical laws but not too complicated to be understood in autonomy. It also illustrates the fact that to simplify mathematical writing, it is necessary to make the right hypothesis and keep the most important parameters. Today, we tend to use "universal" models, including terms that are sometimes negligible. This article gives a good lesson how to keep the good model in agreement with the experimental considerations. For example, today to verify if we have a logarithm law, we plot a curve y versus x , the logarithmic trend line and analyze the correlation coefficient. In the past, we simply plotted x versus $\log(y)$ and saw if it was a straight line...

However, if you give to young students a scientific text with more than 30 pages, you can be sure to lose them. The reading of the review of Lawn and Wilshaw needs a significant attention and the volatile spirit of today's young student, more useful with Internet surfing, need and adaptation. In general, it is better to give them a list of questions or problem that they will have to solve by looking for the solutions in the review. We can ask student to treat a real case with the help of this article in order to encourage the student to treat in deep the theory and the link with real life.

But because my generation has seen the transition to the Internet, we need to make the link between this comprehensive, accurate and thorough work and the superficiality of current trends. In the new context of distance learning, the article of Lawn and Wilshaw still has a bright future.

Jean-Yves, born in 1946

Reading this long and splendid article brought me back to the time when I was starting my career as a teacher–researcher. I have been teaching Material Science in an engineering school for 40 years. My research activity was focused on metal materials with good fracture behavior, compared to brittle materials studied by B. Lawn and R. Wilshaw. For this, I admire the audacity they have showed up to aim at explaining and predicting a type of rupture as unpredictable and brutal as thunder.

In 1975, the mechanics of rupture was one of the most popular branches of the science of matter. Many laboratories were devoted to this fairly recent science because the technologies of the moment needed new materials, with high efficiency and a guaranteed safety. Astronautics and aeronautics were in full glory: Concorde flew in Europe and, in the USA, the saga of the Apollo missions was only in the «season» 3 or 4. The rapid development of numerous nuclear plants, all around the world, needed great amount of researches, particularly in material science. Organ transplants had shown that many lives could be saved, provided that they mastered «biomaterials» still in its infancy. All these subjects were found in a large number of research projects and in the pages of scientific journals. It was the time of Maraging alloys, titanium, boron steels and many attempts to enhance tenacity and deformability of ceramics.

If we look closely at the research that was actually done by Lawn and Wilshaw, we can see that the technical resources were more modest than they are today. What did they use?

An excellent indentation machine, a very good optical microscope and access to a SEM, is complemented by a few solid grinders and a good quantity of abrasive paper. Neither rare nor original devices produce this result of the highest quality. But, besides the perfect mastery of the theoretical foundations of their subject, it also required a very rigorous

experimental method, and a great patience when we imagine the considerable number of indentations carried out (as shown in the legend of several curves “each point mean of at least ten tests”). There was a lot of research from that time that had that concrete, even practical, aspect.

That is still the strength and the interest produced by this paper.

Moreover, perhaps the most important point compared to today is the lack of the use of computers. They are hardly mentioned by the authors as “limited in their ability to deal with the more complex cases encountered in normal practice (p. 1068)”. Of course, computers had been around for a long time, but their use was not easy because they were machines that were accessible only in computer centers and were primarily used to perform complex or very long calculations. The 3D aspects, the volume modeling barely existed and the CAD concerned mainly the industrial world. In a word, the virtual world we know did not yet exist. It is likely that if Lawn and Wilshaw had published in 2015, their so meticulous and numerous measurements would have served primarily to calibrate the parameters of numerical models.

Finally, I would classify this paper among those few articles extensively handled with photocopies carefully locked in my desk drawer. One of the few I recommended and entrusted to my students or colleagues while saying: “Will you give it back to me? Okay?”.

References

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