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Review of Doctoral Dissertation entitled "Explosive acceleration of polymer bonded copper powder", by Aline Cardoso Anastácio, under supervision of Professor Doctor Jiri Pachman.

The presented Thesis is a contribution to solve a very interesting problem of dynamic behaviour of linear shaped charge, of polymer bonded copper powder, under the detonation of a plastic explosive, PISEM.

It is a well written text, in a clear english language, presenting figures and tables, and a complex list of nomenclature abbreviations, with the support of more than 150 bibliographic references. Sometimes the written sentences are written in an extensive way, but this procedure is normal from authors that have an original latin language. This way helps the reader to an easy understanding of the problems. It also shows the intensive reflection, from the author, of the discussed problems. The figures are well clear and help the reader to understand the developed experimental set-ups and the obtained results. **The thesis is structured in three parts.** The introduction text, preceding the first part, is very important to the reader, because explain the followed text and presented work, clarifying that "*linear shaped charges, with rigid liners, are difficult to be accommodate*" and "*flexible linear cutting charge, used in demolition works, is the Razor charge, produced by Explosia*". Continuing that "*it is fabricated with the plastic explosive PISEM",* having RDX and PETN explosive particles, *"and a polymer bonded copper powder as liner*".

The first part, entitled "**literature review**", includes two chapters regarding the shock response of inert materials, and the detonation parameters and detonation effects. The first part is a review of basic concepts. It introduces the main parameters problem, concerning transmission of shock and classic detonation properties. It is very difficult to explain scientific phenomena, in a short text, covering gas gun, Hopkinson bar and condensed explosives experiments. The author focus successfully the main problems, including technical differences and use. It is very difficult to resume, in an introductory text, so many technics and problems. The problem of shock behaviour and transmission in heterogeneous materials is very complex (it seems to me the main problem of obtained results) - the author well introduces the phenomenology of compaction before shock transmission, in such heterogeneous media. The literature review also cover, related to detonation effects, scientific works concerning TNT detonation properties and detonation products expansion. The presented introductory chapters are used to a further explanation of experimental results.

The second part of Thesis, "**experimental part**", includes two chapters (3rd and 4th). It shows the materials and techniques, and experimental arrangements and simulations. This part prove the excellent capabilities of the University of Pardubice in this scientific field of research. The PISEM explosive and the RAZOR charges, and metrology methods and equipments, are shortly and well cited. More interesting is the 4th chapter, regarding experimental arrangements and simulations, where the used techniques need critical selection and discussion. It is not simple to select conditions to obtain clear and useful results. Many experimental solutions, presented in clear pictures of experimental set-ups, prove the excellent level of experimental developments (in particular concerning the measurement of shock transmission and flyer acceleration). The size of explosive experimental set-ups were determined in order of being not influenced by the critical diameter. A very interesting presented and discussed technique is PDV, in the particular use of measurement of cylinder wall velocimetry, under cylinder wall expansion from explosive detonation. Dimensions and solutions are presented and well described. An extended application, using Razor shaped charges, complements this experimental chapter. A short temptation is always to try simulate experimental conditions, using a numerical computer code – I must agree that helps the guidance for future experiments and allow to discuss experimental results - but it is always a simple numerical approach in this very well, precise and complex experimental work.

The third part concerning "**results and discussion**" is the most important part of the thesis, presenting and discussing results of: polymer bonded copper powder under shock; PISEM detonation properties; and Razor shaped charges. **The 5th chapter is related to the *"shock response of polymer bonded copper powder"***. The shock transmission inside heterogeneous materials is a very interesting complex problem, because there are compaction phenomena coupled with shock transmission between different materials. The Hopkinson bar tests show variations that generate some reflective questions. Planar impact results are presented with discussions that help to clarify this problem. It was interesting to see the "P-u" Hugoniot curve, for polymer bonded copper powder, compared with other related materials (vd. figure 5.7). Also discussion and results, presented in pags. 56 to 58, are very interesting and rise promising subjects for future research work. The explosive accelerated inert experiments prove the validity of used techniques and discussed results. The symmetrical impact, Al-Al result, helps to clarify the phenomena. The measurements of flyer impact on Al+poly Cu target, including shock and particle velocities, are excellent results. It must be cited, with humor and confidence, the sentence of pag. 62 *"This behaviour is not surprising for a heterogeneous material and it is not an error, but a variation in the material response, captured thanks to the ability of PDV to measure multiple velocities"*. The average velocities used to perform impedance matching of shock, in P-u plane, were discussed and the results presented. The comparison of results, from explosive driven flyer and gas gun experiments, was discussed - obtained values of *"s"* are very interesting but can also be deeply discussed (vd. Table 5.7). In- contact explosive load results extend the experimental work, proving that *"the Hugoniot curve obtained at lower pressures can represent the shock response in the poly-Cu liner during the explosive loading ... supporting the previous conclusion that the polymer bonded copper powder shock Hugoniot is the same in both lower and higher pressure ranges"*.

Particle velocity results complement measurements. The numerical modelling of the explosive acceleration of poly-Cu liner, using Ls-Dyna, was a simple applied numerical work for the definition of parameters constant values. The 5th chapter is concluded by the visualization of explosive accelerated poly-Cu flyers. There are always problems when it is used fast integral movies - light and short time gap between frames. The author had selected ranges allowing quite quality images. The presented discussion allowed a better understanding of recorded images and results. **The 6th chapter shows detonation properties of used PISEM explosive.** It is necessary to mention the excellence of measurements of detonation pressure, shown in fig. 6.3, where the CJ point is very well defined. The cylinder tests, showing cylinder wall velocity vs. time, in a precise way, allow interesting results also extensive discussed. The correlation with "Explo 5" numerical code calculations, allow validation of obtained results, well presented in fig. 6.10. Extracted free surface velocities vs. time results, also confirm obtained values. The air blast measurements are important for those that apply these charges. They are always compared with TNT values. Presented results show the extension of presented experimental work. **The 7th chapter** concludes the thesis, **showing the entire charge evaluation in terms of cutting ability and collateral damage (applied study)**. The cutting performance was clearly presented by experimental results, using steel plates as target material. It was very interesting to see the high-speed video frames, from the detonation of the Razor 25 in the air. Results are clearly shown. The air blast evaluation concludes this specified applied work, also showing clear experimental fast videos and interesting quantitative results, very useful for those that need to apply these charges. **Conclusions close**, with short sentences, this dissertation of thesis that is a very extensive, precise and excellent experimental scientific work.

Concluding remarks: The presented doctoral dissertation, for the PhD examination, proves, not only the quality of supervision, but also that we are in presence of a really extensive, deep and excellent scientific work, with many obtained relevant results. I strongly recommend and support its presentation for defence, and suggest to grant to the candidate, Mrs. Aline Cardoso Anastácio, the Academic Degree of Doctor of Philosophy.

Coimbra, the 30th of September 2018

José Leandro Simão de Andrade Campos

(Professor Doutor José Leandro de Andrade Campos)