Appendix No. 2b

SUMMARY OF PROFESSIONAL ACCOMPLISHMENTS

Presenting the description of achievements and scientific accomplishments specified under Art.16 Paragraph of the Act

Lt. Col., Ph.D., Eng., Robert Panowicz
Faculty of Mechanical Engineering
Military University of Technology

Warsaw 2019

1. **Name and Surname:** Robert Kazimierz Panowicz

2. **Diplomas, scientific/art degrees – including name, place and year of their acquisition and the title of the Ph.D. dissertation.**

- **Doctor of Philosophy in Technical Science, discipline: Mechanics**, Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, 2003, the title of Ph.D. Thesis: "Modelling of combustion process with free points method";
- **Master of Science, Engineer,** Faculty of Chemistry and Technical Physics, Military University of Technology, 1994, subject: technical physics.

3. **Information on career in scientific entitles.**

- 2008 – present- Jarosław Dąbrowski Military University of Technology in Warsaw, assistant professor;
- 2007 – 2008 - Jarosław Dąbrowski Military University of Technology in Warsaw, senior specialist;
- 2003 – 2007 - Jarosław Dąbrowski Military University of Technology in Warsaw, assistant professor;
- 2002 – 2003 - Jarosław Dąbrowski Military University of Technology in Warsaw, head of laboratory;
- 1999 – 2002 - Jarosław Dąbrowski Military University of Technology in Warsaw, assistant;
- 1994 – 1999 - Jarosław Dąbrowski Military University of Technology in Warsaw, engineer.

4. **Indication of achievement under Art.16 Paragraph 2 of the Act of 14 March 2003 on Academic Degrees and The Academic Title as well as on Degrees and Title within the scope of Art (Journal of Laws 2016, item 882 as amended in Journal of Laws 2016, item 1311):**

a) Title of scientific/artistic achievement

After acquisition of Ph.D. degree, my scientific achievement, constituting a significant contribution to development of scientific discipline mechanics, specified under Art.16, Paragraph 2, item 1 of the Act, is a series of scientific publications thematically related titled:

"Numerical analyses of fast changing phenomena in dynamic tests on properties of materials".

b) list of publications included in the scientific achievement (author/authors, title/titles of publication, publication year, name of publisher, reviewers)

1. R. Panowicz, J. Janiszewski, Selection of a Constitutive Model used for Prediction of Behaviour of Ring Material Expanded by Pulse Electromagnetic Field, Solid State Phenomena, Vols. 147 - 149, 2000, SJR=0.236, 20 points acc. to Ministry of Science and Higher Education.
   I declare my contribution to be equal to 65%.

2. J. Janiszewski, R. Panowicz, Investigation of Copper Fragmentation Property, Solid State Phenomena, Vol. 165, 2010, doi 10.4028/www.scientific.net/SSP.165.66, SJR=0.192, 20 points acc. to Ministry of Science and Higher Education, WoS base.
   I declare my contribution to be equal to 50%.

3. J. Janiszewski, **R. Panowicz**, Numerical analysis of electromagnetic expansion process for thin-walled copper ring, Przeglad Elektrotechniczny (Electrical Review), Vol. 88, Issue 7A, 2012, IF=0.240 (2013), 0.244 (2011), 15 points acc. to Ministry of Science and Higher Education, WoS base.
   I declare my contribution to be equal to 50%.

4. J. Janiszewski, **R. Panowicz**, Development and Validation of Numerical Model for Predicting Electromagnetic Expansion of Composite Rings, Solid State Phenomena Vol. 198, 2013, doi: 10.4028/www.scientific.net/SSP.198.627, SJR=0.221, 10 points acc. to Ministry of Science and Higher Education, WoS base.
   I declare my contribution to be equal to 40%.

5. **R. Panowicz**, J. Janiszewski, Tensile split Hopkinson bar technique: numerical analysis of the problem of wave disturbance and specimen geometry selection, Metrol. Meas. Syst., Vol. 23, No. 3, 2016, pp. 425–436, doi: 10.1515/mms-2016-0027, IF=1.598, 20 points acc. to Ministry of Science and Higher Education.
   I declare my contribution to be equal to 60%.

6. **R. Panowicz**, J. Janiszewski, and M. Traczyk, Strain measuring accuracy with splitting-beam laser extensometer technique at split Hopkinson compression bar experiment, Bulletin of the Polish Academy of Sciences Technical Sciences, Vol. 65, No. 2, 2017, pp. 163–169, doi: 10.1515/bpasts-2017-0020, IF=1.361, 25 points acc. to Ministry of Science and Higher Education.
   I declare my contribution to be equal to 55%.

7. **R. Panowicz,** J. Janiszewski, K. Kochanowski, Numerical and Experimental Studies of a Conical Striker Application for the Achievement of a True and Nominal Constant Strain Rate in SHPB Tests, Experimental Mechanics, Vol. 58, No. 3, 2018, pp. 1325 – 1330, doi: 10.1007/s11340-018-0404-5, IF=2.319 (2017), 35 points acc. to Ministry of Science and Higher Education.
   I declare my contribution to be equal to 60%.

8. **R. Panowicz**, J. Janiszewski, and K. Kochanowski, The non-axisymmetric pulse shaper position influence on SHPB experiment data, Journal of Theoretical and Applied Mechanics, Vol. 56, No. 3, 2018, pp. 873-886, doi: 10.15632/jtam-pl.56.3.873, IF=0.783 (z 2017), 15 points acc. to Ministry of Science and Higher Education.
I declare my contribution to be equal to 55%.

9. **R. Panowicz**, J. Janiszewski, and K. Kochanowski, Influence of pulse shaper geometry on wave pulses in SHPB experiments, Journal of Theoretical and Applied Mechanics, Vol. 56, No. 4, 2018, pp. 1217-1221, doi: 10.15632/jtam-pl.56.4.1217, IF=0.783 (2017), 15 points acc. to Ministry of Science and Higher Education.
I declare my contribution to be equal to 60%.

10. **R. Panowicz**, J. Janiszewski, and K. Kochanowski, Effects of Sample Geometry Imperfections on Results of Split Hopkinson Pressure Bar Experiments, Experimental Technique, 2018, doi: 10.1007/s40799-018-0293-7, IF=0.806 (2017), 20 points acc. to Ministry of Science and Higher Education.
I declare my contribution to be equal to 60%.

A description of a Doctor of Science degree candidate's contribution to individual works is presented in *The list of published scientific works or creative professional works and information on didactical achievements, cooperation in science and science popularization,* Appendix No. 3.

The statements of co-authors of a series of scientific publications are presented in Appendix No. 4.

c) presentation of the scientific/artistic purpose of the above-mentioned work/works and the achieved results with a discussion of their possible use.

Introduction

Over last few decades, in all science fields, there has been a rapid development of simulation methods through a widespread application of a computer experiment in analyses of complex nature, social and economic phenomena.

In mechanics, computational methods in mechanics support both experimental tests and theoretical methods. These methods require determination of a mathematical and physical model reflecting the tested phenomenon at a relevant accuracy level. The fundamental elements in this system include *material models reflecting, along with parameters, real behaviour of materials with specified accuracy in an assumed range of parameters*. Conducting numerous numerical analyses, it was frequently found that the obtained results were considerably different than experimental tests results. In most of the cases, it resulted from application of material models with literature material data not relevant to the analysed case. Therefore, determination of materials properties or their selection became a key issue.

Computational methods in mechanics enable, among others, a detailed analysis of dynamic phenomena which are not possible to be observed in experimental tests due to various reasons (e.g. process of sample dynamic deformation or fragmentation). They also enable a research hypothesis to be proved faster and easier. They also contributed to improvement and development of experimental methods.

Due to my interests regarding application of computational methods in mechanics in dynamic phenomena analysis and considering the above mentioned factors, I assumed that the conducted tests aimed at improvement and development of knowledge within the scope of materials dynamic properties based on numerical analyses. Therefore, my scientific accomplishment comprises a series of publications under a common title:

"Numerical analyses of fast changing phenomena in the dynamic tests on properties of materials".

My scientific accomplishments presented in a series of publications contributed not only to improvement and development of knowledge on fast changing phenomena, but also provide details of methodical requirements for research techniques enabling determination of materials mechanical properties and material parameters of constitutive relations.

There are only few experimental research methods widely used in dynamic tests on materials:

- Taylor test;
- ring test;
- split Hopkinson pressure bar method (SHPB).

The results of materials dynamic tests are utilized in a relatively narrow area of technical applications (space technology, automotive industry, military technology). This area started its rapid development not earlier than after the World War II. Compared to tests on materials in quasi-static conditions, conducted with the use of universal strength machines, the dynamic tests methods are not popular, especially in Poland. Therefore, they will be briefly characterized in the further part of this summary.

Division into quasi-static and dynamic research methods is contractual. It is adopted that tests occurring with a strain rate higher than 10^2 1/s belong to a group of dynamic tests techniques.

Articles b1 – b4 included in a series of D.Sc. Candidate's publications and those mentioned in part 4b of the summary of professional accomplishments concerns the ring test, whereas the remaining works (b5 – b10) are related to split Hopkinson pressure bar method.

Taylor test

In 1984, Taylor developed a simple test enabling determination of dynamic yield strength of the material [1]. It consists in determination of dynamic yield strength based on measurement of geometric parameters for a cylindrical specimen before and after plastic deformation due to impact into a rigid barrier with a given velocity (1) (Fig. 1).

$$\sigma_{sr} = \frac{\rho V^2 (L - X)}{2(L - L_1)\ln(L/X)}, \qquad (1$$

where: σ_{sr} – dynamic yield strength, ρ – density of material, V – velocity of impact into the shield, L – initial length of the specimen, L_1 – length of the specimen after deformation, X – non-deformed part of the specimen.

The theory proposed by Taylor was developed in works [2 – 4]. Presently, Taylor test is frequently applied to verify constitutive models [5, 6] and determination of material parameters for constitutive relations based on a solution of the reverse problem [7]. This problem was also undertaken by the D.Sc. Candidate and presented in work [8]. However, due to a narrow scope of the conducted tests and a lack publications on the analyses results in prestigious journals, this accomplishment was not included in the presented series of publications.

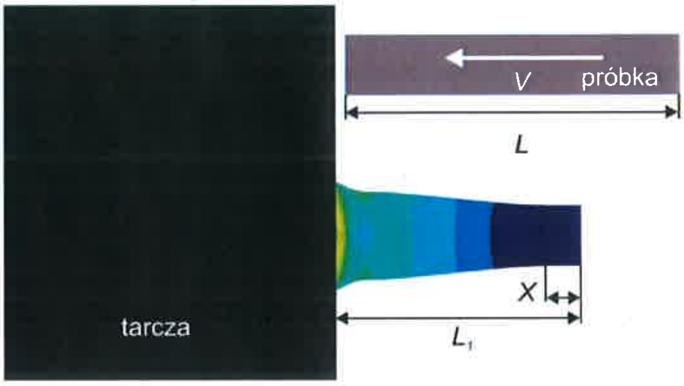

Fig. 1. Schematic diagram of Taylor test

Ring test

The nature of the ring test is to determine flow plastic stress and ductility of materials based on observation of pulse driven inertial movement of a thin walled ring, undergoing only axisymmetric radial expansion (Fig. 2). In this case, suppression of the ring movement is proportionately to plastic stress of the material (from which the ring is produced) flow [9].

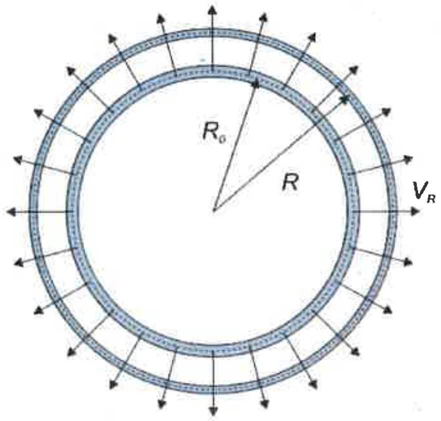

Fig. 2. Diagram of axisymmetric radial expansion of a thin walled ring; R_0 – ring initial radius, R – ring actual radius, V_R – ring velocity

Due to limited technical possibility, explosive materials were initially applied to the ring pulse driving [9, 10]. Rajendran and Fyfe used for this purpose an exploding wire method consisted in driving the specimen by a shock wave generated by electric current of a significantly high voltage [11]. However, Gourdin et al. applied electromagnetic field for this purpose [12].

The ring test was applied to investigate the following problems:

- behaviour of different types of metals and their alloys at strain rate equal to 5000 1/s [9];
- determination of materials susceptibility to strain rate [10];
- tests on effect of void occurrence in the material under tensile on the process of necks generation [11];
- behaviour of a thin walled copper ring driven by magnetic field [12];
- influence of grain size on copper behaviour in dynamic load conditions [13].

It should be noted that in works [12] and [14], attempts to apply computational methods in mechanics to describe behaviour of an expanding thin walled ring were undertaken. It should be also noted that the process of ring fragmentation was analyzed with a finite element method without electromagnetic coupling in [14], whereas part of work [12] was dedicated to a one-dimensional model of expansion of a thin walled ring driven by electromagnetic field.

Within the frameworks of the first work of a series of D.Sc. Candidate's publications [b1], based on the mathematical and physical model of electromagnetic drive of the thin walled ring (2) and on the experimental tests taken from literature [12], it was proved that Steinberg-Guinan and Preston-Tonks-Wallace constitutive relations along with literature material data describe best the behaviour of OFC copper in dynamic tensile conditions (Fig. 3). It results from compatibility of stress-strain dynamic curves, in the case of the experimental tests, and numerical analyses in the case of application of two above mentioned constitutive relations. It was also found that a widely used Johnson-Cook constitutive model does not accurately reflect real behaviour of the materials in the ring test.

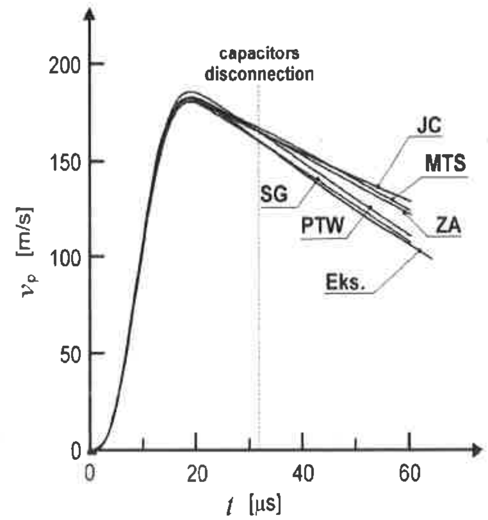

Fig. 3. Velocity of electromagnetic expanding ring; Eks. –experiment, results of numerical analyses using JC – Johnson-Cook, SG – Steinberg-Guinan, ZA – Zerilli-Armstrong, PTW – Preston-Tonks-Wallace and MTS constitutive models **[b1]**

The mathematical and physical model used by the D.Sc. Candidate considers mechanical and electromagnetical coupling and Joule heat effect both on the current flow in the setup and on mechanical properties of the specimen-coil system.

$$\frac{dV_R}{dt} = \mu\mu_0 \frac{b(R)}{4\pi\rho A} I_R I_c + \frac{1}{4\pi\rho A}\frac{dL_R}{dR}\frac{I_R^2}{R} - \frac{\sigma_\theta}{R\rho}, \quad (2$$

here: V_R – ring velocity, μ_0 – magnetic constant, μ –air permeability, $b(R)$ – geometric coefficient depends on the current ring radius resulting from application of Biot-Savart law, L_R – ring self-inductance, ρ – ring material density, A – area of the specimen cross section, I_R – ring current, I_c – solenoid current, R – ring radius, σ_θ – ring circumferential stress.

The above described approach was applied in work **[b2]** for analysis of the fragmentation process of the thin walled copper ring driven to the maximum velocity of 170 m/s, corresponding to a strain rate equal to $8.5 \cdot 10^3$ 1/s. In work **[b2]**, the results of both experimental tests and numerical analyses, using Mott statistic model to describe the fragmentation process, are presented. The conducted analyses allowed, first of all, for determination of strain ($\varepsilon_f = 0.35$), at which a dynamic fragmentation process begins, and also material parameters for the applied fragmentation model were specified. It was found that the value of strain, at which fragmentation occurs in dynamic loads conditions, is different than the value of strain in quasi-static conditions ($\varepsilon_f = 0.3$). The applied Mott model allowed for development of a fragments number distribution histogram dependently on their size (Fig. 4), as well as an average number and size of the fragments ($n_{avg} = 11$, $l_{avg} = 13$ – experiment, $n_{avg} = 10.47$, $l_{avg} = 13.9$ – numerical analyses).

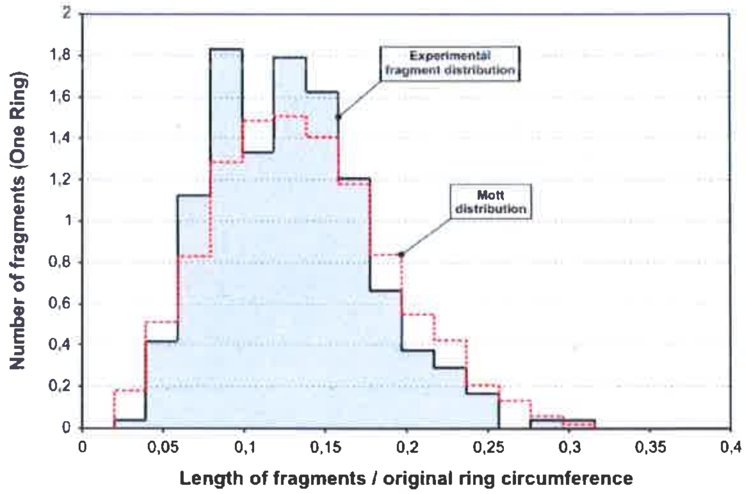

Fig. 4. Experimental fragment size data for copper rings driven to velocity of 170 m/s and comparisons with statistical Mott model **[b2]**

In work **[b3]**, the conducted numerical analyses aimed mainly at determining an influence of electromagnetic stand structural parameters for a ring test on the thin walled ring driving process. After validation tests, which showed good agreement of the model with the experimental test results (Fig. 5), a series of parametric analyses was carried out. There was determined, among others, a temperature growth of the driven ring dependently on the test stand structural parameters. In the analyses, both an influence of a number of coil turns of winding and energy of capacitor discharging were considered. The velocity of copper ring expansion, dependently on the same parameters (Fig. 6), and an influence of the coil structure on the ring driving process were defined.

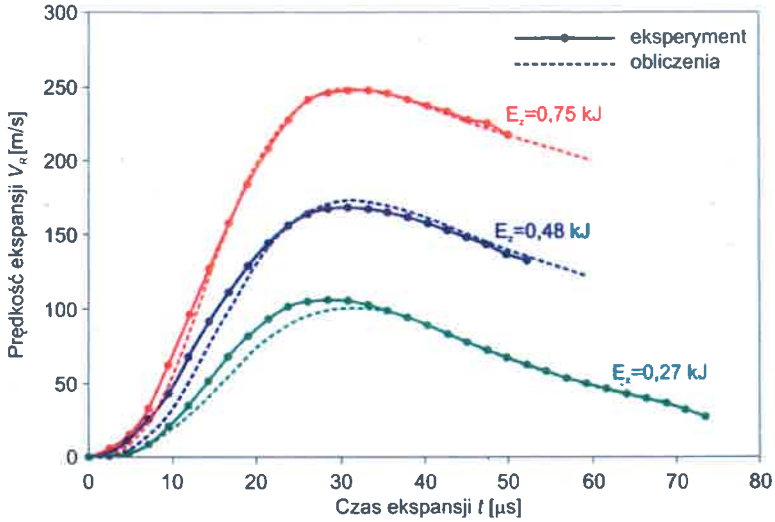

Fig. 5. Comparison of expansion velocity curves for both experimental and numerical tests dependently on capacitor discharging energy E_z **[b3]**

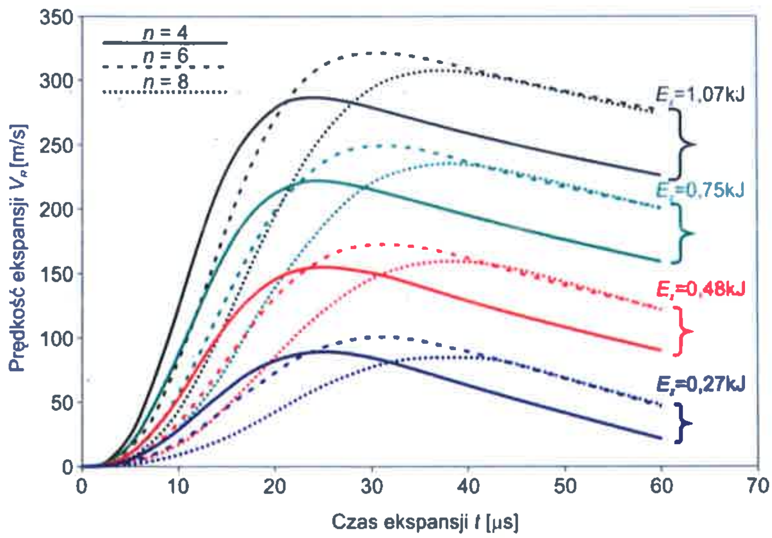

Fig. 6. Ring expansion velocity curves as a function of a turns of winding number n and capacitor discharging energy E_z **[b3]**

The results of numerical analyses and experimental tests of a composite ring, i.e., a ring made of high resistivity material put on a driving copper ring (3) are presented in work **[b4]** (Fig. 7). As a result of numerical analyses, a dynamic stress-strain curve of the tested material was also obtained.

$$\left(m_R + m_{pr}\right)\frac{dV_R}{dt} = \frac{1}{2}\mu\mu_0 b\left(R\right)RI_R I_c + \frac{1}{2}\frac{dL_R}{dR}I_R^2 - 2\pi\left(\sigma_\theta A_R + \sigma_{pr}A_{pr}\right), \qquad (3$$

where: R index refers to a copper ring, pr index is related to the specimen material, m is ring mass.

The conducted tests proved that, using a ring test, it is possible to investigate a wide range of material, including high resistance materials and the used mathematical and physical model satisfying reflects materials real behaviour.

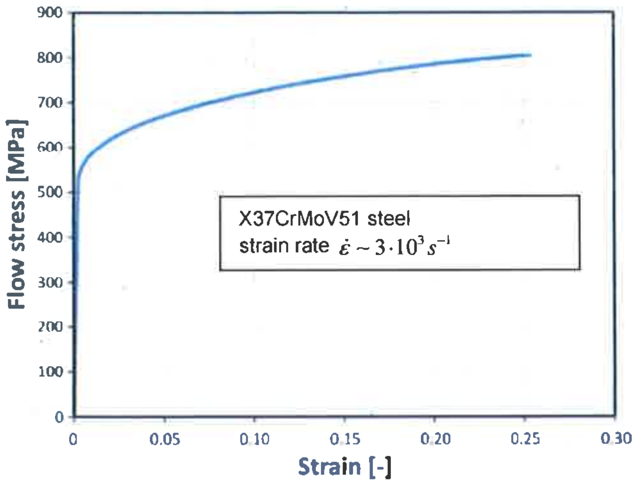

Fig. 7. X37CrMoV51 steel dynamic stress-strain curve **[b4]**

Split Hopkinson pressure bar method

The greatest number of publications, namely six **[b5 – b10],** included in scientific achievement refers to split Hopkinson pressure bar technique.

Split Hopkinson pressure bar method consists in measurement of a incident, reflected and transmitted pulse in order to determine a stress-strain dynamic curve in the system schematically presented in Figure 8 [15]. A incident pulse is generated through an impact of a short bar, called a striker, in a transmitted bar. An pulse, propagating into the specimen direction, is then subjected to partial reflection from the transmitting bar-specimen contact surface, which results from differences in wave impedances of both the bars and the specimen. The remaining part of the pulse, however, propagates further in the third (the last) output bar. Based on the registered pulses histories and equations (4) – (6), it is possible to determine: plastic flow stress (4), strain rate (5) and strain (6) for the specimen at the given moment [15]. Those relations allow thereby for determination of stress-strain dynamic curves at the given strain rate.

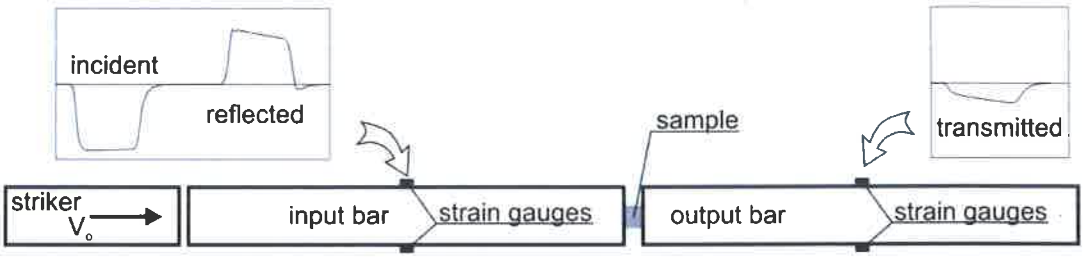

Fig. 8. A schematic diagram of the SHPB setup **[b10]**

$$\sigma(t)=\frac{A}{2A_S}E\left[\varepsilon_I(t)+\varepsilon_R(t)+\varepsilon_T(t)\right], \tag{4}$$

$$\dot{\varepsilon}(t)=\frac{c_0}{L_S}\left[\varepsilon_I(t)-\varepsilon_R(t)-\varepsilon_T(t)\right], \tag{5}$$

$$\varepsilon(t)=\frac{c_0}{L_S}\int_0^t\left[\varepsilon_I(\tau)-\varepsilon_R(\tau)-\varepsilon_T(\tau)\right]d\tau, \tag{6}$$

where: A_s, L_s – area of cross section and specimen length, C_0, E, A – sound velocity, Young modulus and area of bars cross section, $\varepsilon_x(t)$ – strain measured by gauges, index $x = I$, R or T denotes incident, reflected and transmitting pulse, respectively.

Presently, the split Hopkinson pressure bar method is the most frequently used method for material properties dynamic properties tests. It enables tests on a wide range of materials (metals, metal alloys, polymers, composites, ceramics, rocks, concretes) [15 – 18] under differ loading conditions [15, 19 – 21] as well in a wide range of temperatures [15, 22 – 24]. The tests results obtained with application of the split Hopkinson pressure bar method are used, among others, to determine material constants of constitutive relations [23, 24].

Methodical requirements of the method demand that the specimen deforms almost uniformly with a constant strain rate under the conditions of dynamic equilibrium stress state. Additionally, it is assumed that pulse propagation in the bars is described with a one dimensional wave propagation theory. To fulfil the above mentioned requirements for the split Hopkinson pressure bar method, numerous guidelines concerning both the structure of the experimental test stand and selection of experiment conditions need to be followed.

An influence of inaccuracy of both the arrangement and manufacturing of the bars in the split Hopkinson pressure bar method with the use of a finite element method was analyzed in work [25]. Further investigations in this scope, extended with experimental tests are described in publication [26]. Alves et al. analyzed an influence of friction between the specimen and the bars on the measurements results in the split Hopkinson pressure bar method. The analyses were conducted based on the analytical model and numerical tests results in the case of classic, cylindrical and ring specimen application [27]. An influence of the friction in the case of cuboid specimens and specimens composed of several layers of metal sheets was analyzed with the finite element method also in [28].

The first work **[b5]** of a series of D.Sc. Candidate's publications dedicated to the split Hopkinson pressure bar method concerns analysis of the specimen dynamic specimen tensile with the use of a shoulder. A diagram of the split Hopkinson pressure bar method test stand with a shoulder is presented in Figure 9.

The tests results included in work **[b5]** showed that in this experimental setup the utility pulses recorded by strain gauges located in the middle of the bars length, i.e., in a typical place of their assembly, are strongly disturbed (Fig. 10). These disturbances result from application of the transmitting sleeve and its geometric inaccuracy. They occur even in the case of numerical analyses, which is an effect of inaccuracy of contact between the interacting elements. Therefore, using the optimization process, there were found such locations of the measurement points that enable recording of the non-disturbed utility pulses. The above results of the numerical analyses were confirmed with experimental tests. Additionally, numerical analyses of copper specimen dynamic tensile were carried out. These analyses showed that the first pulse causes formation of small asymmetric plastic strains of the specimen. At the initial phase of the actual tensile process, specimen asymmetric strain occur and then these strains become symmetric. Based on the conducted numerical analyses, the maximum strain in the specimen, dependently on its geometry and experiment conditions, was determined. The determined values of the specimen maximum strain enable a simple selection of both the specimen geometry and experiment conditions under dynamic loading conditions.

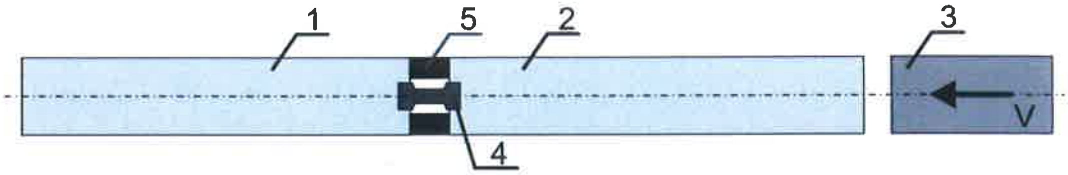

Fig. 9. A design of the tensile SHPB apparatus with a shoulder; 1 – input bar; 2 – output bar; 3 –striker impacting on the output bar with a velocity equal to V; 4 – specimen; 5 – shoulder **[b5]**.

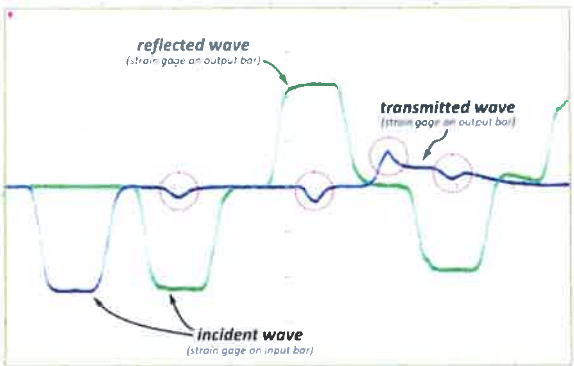

Fig. 10. The raw wave and disturbance (red circles) signals measured by the strain gages in the test configuration **[b5]**

Many authors prove that in a split Hopkinson pressure bar technique, a measurement of specimen strain is subjected to the greatest uncertainty. The D.Sc. Candidate also proved in his research that the greatest differences between the results of numerical analyses and experimental tests occur in the maximum values of specimen material strain. Therefore, a laser extensometer, described in work **[b6]** was built and tested. The developed measurement device is not only nationally but also worldwide unique. It enables a displacement measurement of both transmitting and receiving bars ends, which are in contact with the specimen. This measurement consists in determining a change in intensity of laser radiation illuminating the rods which is proportional to bars displacement.

Within the conducted research related to application of a laser extensometer, there was also defined a measurement uncertainty of specimen strain determination connected with application of this device. It was proved that differences in strain measurement with two methods, i.e., based on the reflected wave and with a laser extensometer in the range of little strain are negligible. They increase in the case of greater strain. The difference in strain values in the case of an aluminum specimen is almost constant, whereas for a copper specimen it increases along with a strain increase. However, in both the analyzed cases, strain measured with a laser extensometer is smaller than strain measured in a classic way (Fig. 11).

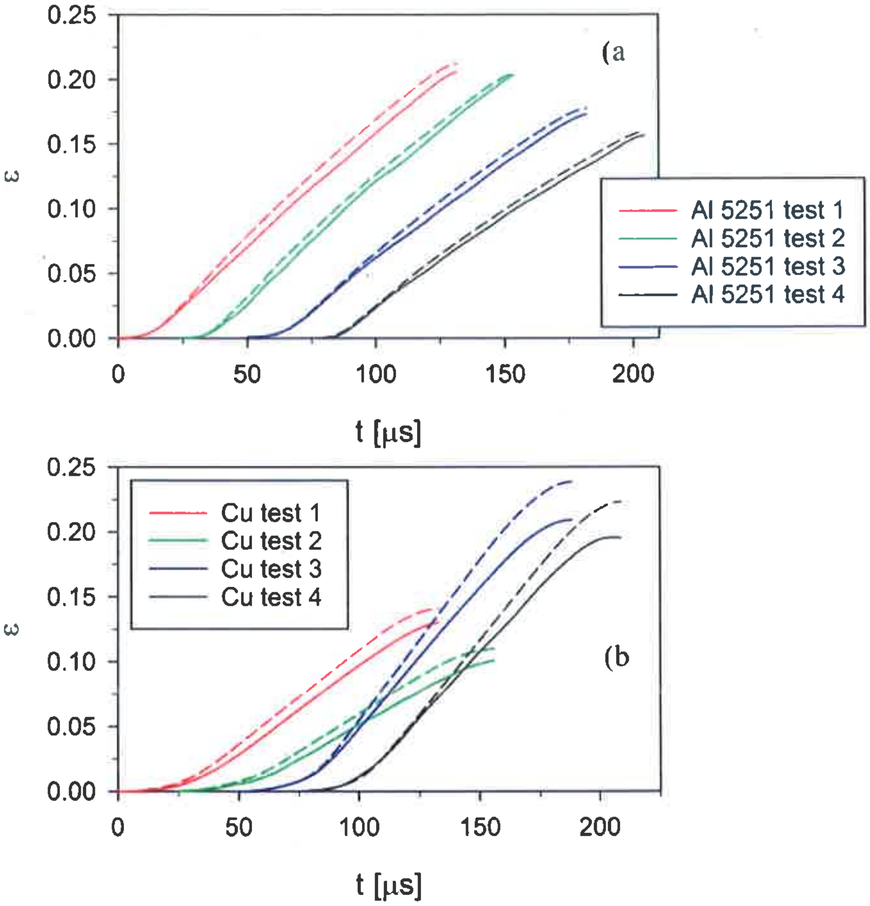

Fig. 11. Comparison of specimens strain history obtained from strain gage (dashed lines) and laser extensometer measurements (solid lines): a) Al 5251, b) Cu OFE. The lines were shifted in the increment of 25 ms for ease of comparison **[b6]**

The conducted numerical research showed that specimen strain values obtained with the use of a laser extensometer are convergent with the strain values obtained based on the numerical analyses.

The specified measurement uncertainty for determination of strain related to the application of the laser extensometer is not higher than 0.09 %.

For methodological requirements of a split Hopkinson pressure bar technique, a problem of ensuring a constant strain rate, both nominal and actual, is essential. This problem is discussed in work **[b7]** with the use of incident wave profile formation idea (Fig. 12) through modification of a input bar geometry (Fig. 13). It was adopted that to form a wave there will be applied a input bar with a geometry with a apex angle α was selected based on numerical analyses dependently on mechanical properties of the tested specimen material.

In work **[b7]**, there was also determined an influence of the specimen length, its diameter and velocity of a constraint bar impact on remaining the constancy of a strain rate. In addition, a dependency between geometry of a striking bar cane geometry and its velocity, which provides a constant strain rate, both nominal or actual, was defined. The accuracy of numerical analyses was verified with experimental tests.

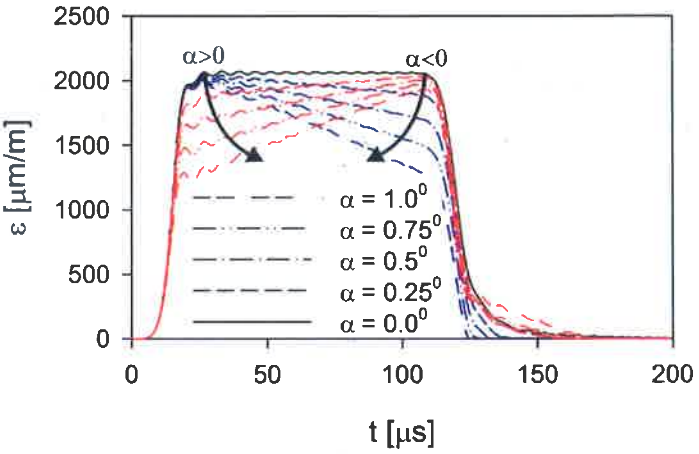

Fig. 12. Influence of apex angle α on the incident pulse shape, red lines – positive apex angles, blue lines – negative apex angles, black line – cylindrical striker, $V = 20$ m/s [**b7**]

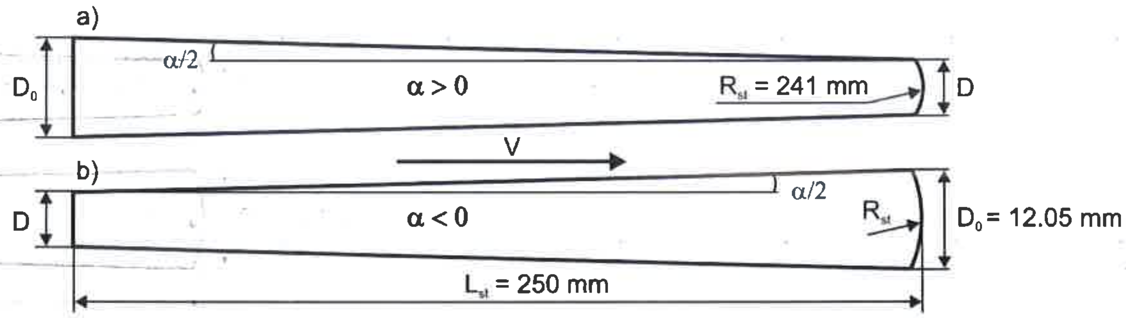

Fig. 13. Conical striker geometry; apex angle α is positive in the case of impact with the end of a smaller diameter (a), and negative in the other cases (b) [**b7**]

According to Pochhammer-Chree theory, high frequency oscillations causing measurement signal disturbances are generated in the bar with finite dimensions due to dispersion [15]. In such a case, waves propagation in the setup cannot be described with a one-dimensional wave theory, which is one of the basic methodological requirements for a split Hopkinson pressure bar method. The Pochhmmaner-Chree oscillations result in an increase in a measurement uncertainty of all the pulses registered in the setup and, thereby, an increase in measurement uncertainty for determination of stress-strain curve of the tested material.

For the purpose of levelling or limiting high frequency oscillations, the pulse wave shapers for the input bar are used or the front of the striking bar is rounded. The pulse wave shapers made of plastic material cause limitation of the incident signal frequency oscillations as well as elongation of the rise and fall pulse time acting as a mechanical low-pass filter (Fig. 14). In this case, disks with small dimensions mounted on the transmitting bar front are applied (Fig. 15).

Article **[b8]** proves that non central location of a pulse wave shaper causes, in the bar, generation of banding waves propagating as measurement signal distributions in the bars setup and registered by strain gauges.

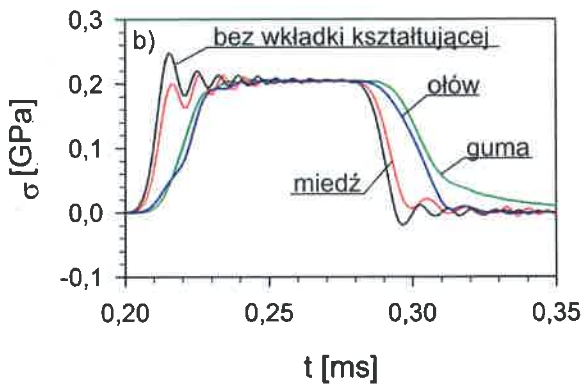

Fig. 14. Influence of a pulse wave shaper on an incident wave [29]

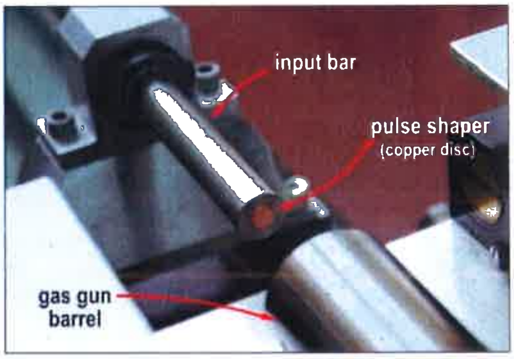

Fig. 15. View of a pulse shaper placed on the input bar impact face **[b8]**

In this work, the D.Sc. Candidate carried out analysis of an influence of pulse wave shapers location and thickness as well as striker initial velocity on the history of utility pulses registered in a split Hopkinson pressure bar method and on stress-strain curves. The analyses were conducted with the use of an implicit implementation of a finite element method. The performed tests showed that a little location imperfection occurring in the bars setup causes reduction in Pochhammer-Chree high frequency oscillations. However, this imperfection may be neglected if a relative distance between bars axis and a pulse wave shaper axis is less than 20% (approximately 15% of the bar radius value). It should be noted that an influence of such imperfections depends on a number and location of supports in the setup. Its influence is greater in the case of an experimental setup with a smaller number of supports. Also, the application of Wheaston quarter bridge in utility pulses measurement causes registration of disturbed pulses simultaneously influencing the stress-strain curve.

Work **[b9]** is dedicated to numerical analysis of pulse shapers different geometries on the history of a constrain and a reflected pulse histories. In this work, the D.Sc. Candidate analyzed also pulse wave shapers capability of damping the Pochhammer-Chree high frequency oscillations and their influence on the increment time of both the incident and the reflected pulse. It was proved that pulse wave shapers of other shapes than disk, particularly ring shapers, are characterized with better high frequency oscillations damping properties.

This effect is particularly visible in the case of higher velocities of striker impact. Application of pulse wave shapers of other shapes than disk results in reduction in the increment time of both the incident and the reflected pulse.

Numerical analysis of geometric specimens imperfections (Fig. 16) on the results of measurements and determination of stress-strain dynamic curves in a split Hopkinson pressure bar method is described in the last article of the series **[b10].** The article presents the tests results and conclusions drawn from analysis of different imperfections influence and their location in respect to the bars on the results of the tests in the analyzed method. It was found out that geometric imperfections, such as those presented in Figure 16, influence mainly the initial and final part of utility pulses and that this influence increases along with an increase in the imperfection level. Therefore, the initial and the final part of the stress-strain curve is also disturbed (Fig. 17). However, B type imperfection (Fig.16) does not influence signal history if the specimens fronts with such an imperfection are parallel to the bars fronts.

Numerical analyses showed that, in the case of all the considered cases of specimens geometric imperfections, their influence is neglected if an imperfection level is less than 0.3. However, from the engineering point of view, it can be adopted that the specimens with greater imperfections may be applied to the initial tests.

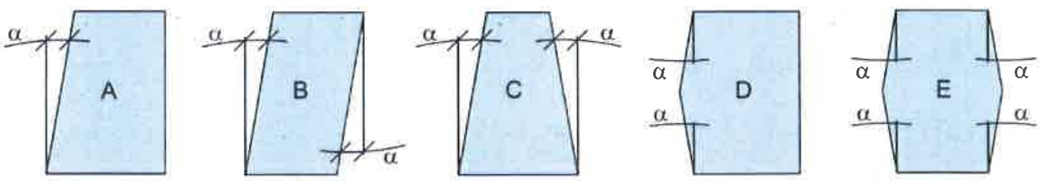

Fig. 16. Geometrical imperfections of the specimens; α – specifies the imperfection level **[b10]**

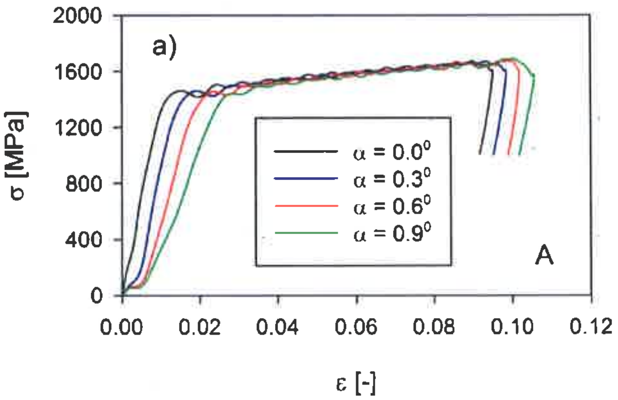

Fig. 17. Stress- strain curves for the specimen with A imperfection **[b10]**

Summary

The main achievement of the D.Sc. Candidate's scientific activity was improvement and development of the knowledge on *fast changing phenomena in research on materials dynamic properties* based on numerical methods. The results of the D.Sc. Candidate's included in a series of scientific publications may be used during dynamic tests, particularly tests based on the split Hopkinson pressure bar method, as methodological guidelines.

As the most important achievements described in the publications constituting the scientific achievement, as specified in Art.16 Paragraph 2 of the Act of 14 March 2003 on Academic Degrees and The Academic Title as well as on Degrees and Title within the scope of Art (Journal of Laws 2016, item 882 as amended in Journal of Laws 2016, item 1311) and constituting an essential author's contribution to the knowledge in the scientific field *mechanics,* I consider the following achievements:

- specification of constitutive relations, which successfully reflect actual properties of OFC copper under the conditions of dynamic tensile as well as constants for Mott fragmentation model **[b1, b2];**
- demonstration that application of Johson-Cook constitutive model in numerical analyses of the ring radial expansion process under the electromagnetic test conditions may result in obtainment of solutions burdened with a significant error **[b1];**
- determination of influence of structural and electrical parameters for an experimental stand for a ring electromagnetic test on the thin walled ring driving process **[b3];**
- demonstration that with the use of a ring test, it is possible to test a wide range of materials, including those of high resistance, and that the applied model reflects well the materials behaviour **[b4];**
- development of a method for determining a stress-strain dynamic curve with the use of the developed numerical code describing the behaviour of a pulse-driven thin walled ring **[b4];**
- demonstration that, in the split Hopkinson pressure bar method with a shoulder, in the initial chase of the specimen tensile, asymmetric deformation of the specimen occurs **[b5]**;
- development of dynamic research methodology and carrying out the theoretical and experimental assessment of deformation measurement uncertainty in the measurements realized with the use of a laser extensometer **[b6];**
- demonstration that it is possible to obtain a constant strain rate, both nominal and true, with the use of cone bars in the experimental tests **[b7];**
- demonstration that a non central location of a pulse wave shaper causes generation of bending waves in the bars **[b8];**
- determination of influence of a pulse wave shaper type and its non central location on limitation of Pochhammer-Chree high frequency oscillations as well as on the profile of both a constraint and a reflected wave **[b8, b9];**
- demonstration that a 20% non centricity of a pulse wave shaper location is of negligible influence on the measurements results in the Split Hopkinson pressure bar method **[b8];**
- determination of specimens geometric imperfection influence in the split Hopkinson pressure bar method on the stress-strain dynamic curves shape **[b10]**.

The above mentioned achievements were not previously known and described in the leading Polish and overseas publications to which I had access. Considering that, it can be assumed that the presented achievements are novel and constitute the D.Sc. Candidate's original contribution to development of scientific discipline *mechanics*.

Plans for the future

The subject matter presented in a series of scientific publications is still continued and it will be the subject of my future scientific activity.

I am finishing construction of two research stands enabling conducting the research on materials based on the split Hopkinson pressure bar method. The usage of these stands will allow me to conduct dynamic tests of materials in a wide range of strain rates (> $5 \cdot 10^4$ 1/s) and temperatures as well as analysis of damage generation and development. It will also allow me to determine constant values for constitutive and fracture models which will be applied to analyses of machines and devices structures utilized in impact load conditions.

Literature

1. G. I. Taylor, Proc. Royal Soc. London A, 194 (1038), 289–299, 1948.
2. M. L. Wilkins, M. W. Guinan, Impact of cylinders on a rigid boundary, Journal of Applied Physics, 44 (3), 1200–1206, 1973.
3. P. P. Gillis, S. E. Jones, M. H. Dehn, Some further results on the Taylor impact test, Mechanics of Materials, 6 (3), 293–301, 1987.
4. E. Włodarczyk, M. Sarzyński, Strain Energy Method for Determining Dynamic Yield Stress in Taylor's Test, Engng. Trans., 65, 3, 499–511, 2017.
5. J.-B. Kim, H. Shin, Prediction of a Modified PTW Model for Various Taylor Impact Tests of Tantalum, International Journal of Modern Physics B, Vol. 22, Nos. 31 & 32, 6247–6252, 2008.
6. F. Abed, T. Jankowiak, A. Rusinek, Verification of a Thermoviscoplastic Constitutive Relation for Brass Material Using Taylor's Test, ASME. J. Eng. Mater. Technol., 137(4): 041005-041005-10, doi: 10.1115/1.4030804, 2015.
7. C. Hernandez, A. Maranon, Determination of constitutive parameters from a Taylor test using inverse analysis, Strain, 53, doi: 10.1111/str.12249, 2017.
8. J. Janiszewski, **R. Panowicz**, Determining of the Johnson-Cook model constants extracted from Taylor test data, Seventh International Symposium on Impact Engineering, ISIE 2010, July 4-7, Warsaw, Poland, 2010.
9. P. C. Johnson, B. A. Stern, R. S. Davis, Measurement of Dynamic Plastic Flow Properties under Uniform Stress, Symposium on the Dynamic Behavior of Materials, ASTM, No. 336, 1963.
10. N. Perrone, On the Use of the Ring Test for Determining Rate-sensitive Material Constants, Experimental Mechanics, 8 (5), 1968.
11. A. M. Rajendran, I. M. Fyfe, Inertia Effects on the Ductile Failure of Thin Rings, J. Appl. Mechanics, Vol. 49 (1), 1982.

12. W. H. Gourdin, S. L. Weinland, R. M. Boling, Development of the electromagnetically launched expanding ring as a high-strain-rate test technique, Rev. Sci. Instrum., Vol. 60 (3), 1989.

13. W. H. Gourdin, D. H. Lassila, Flow stress of OFE copper at strain rates from 10^{-3} to 10^4 s^{-1}: Grain-size effects and comparison to the mechanical threshold stress model, Acta Metallurgica et Materialia, Vol. 39 (10), 2337-2348, ISSN 0956-7151, doi: 10.1016/0956-7151(91)90015-S, 1991.

14. S. Levy, J. F. Molinari, I. Vicari, A. C. Davison, Dynamic fragmentation of a ring: Predictable fragment mass distributions, Physical Review E, 82, 066105, 2010.

15. W. Chen, B. Song, Split Hopkinson (Kolsky) bar: design, testing and applications, Springer, Berlin, 2011.

16. A. T. Owens, H. V. Tippur, A Tensile Split Hopkinson Bar for Testing Particulate Polymer Composites Under Elevated Rates of Loading, Experimental Mechanics, 49(6), 799–811, 2008.

17. J. E. Field, S. M. Walley, W. G. Proud, H. T. Goldrein, C. R. Siviour, Review of experimental techniques for high rate deformation and shock studies, Int. J. of Impact Engineering, 30, 725–775, doi: 10.1016/j.ijimpeng.2004.03.005, 2004.

18. E. Cadoni, G. Solomos, C. Albertini, Mechanical characterization of concrete in tension and compression at high strain rate using a modified Hopkinson bar, Mag. Concrete Res., 61, 221–228, 2009.

19. R. Gerlach, Ch. Kettenbeil, N. Petrinic, A new split Hopkinson tensile bar design, Int. J. of Impact Engineering, 50, 63–67, 2012.

20. D. Mohr, G. Gary, M-Shaped specimen for the high-strain rate tensile testing using a split Hopkinson pressure bar apparatus, Experimental Mechanics, 47, 681–692, doi: 10.1007/s11340-007-9035-y, 2007.

21. T. Nicholas, Tensile testing of materials at high rates of strain, Experimental Mechanics, 21, 177–185, doi: 10.1007/BF02326644, 1981.

22. J. Kajberg, K.-G. Sundin, Material characterisation using high-temperature Split Hopkinson pressure bar, Journal of Materials Processing Technology, Vol. 213 (4), 522–531, doi: 10.1016/j.jmatprotec.2012.11.008, 2013.

23. A. Rusinek, R. Bernier, R. M. Boumbimba, M. Klosak, T. Jankowiak, G. Z. Voyiadjis, New devices to capture the temperature effect under dynamic compression and impact perforation of polymers, application to PMMA, Polymer Testing, Vol. 65, 1–9, doi: 10.1016/j.polymertesting.2017.10.015, 2018.

24. D. Forni, B. Chiaia, E. Cadoni, High strain rate response of S355 at high temperatures, Materials & Design, Vol. 94, 467-478, ISSN 0264-1275, doi: 10.1016/j.matdes.2015.12.160.

25. M. A. Kariem, J. H. Beynon, D. Ruan, Misalignment effect in the split Hopkinson pressure bar technique, Int. J. of Impact Engineering, 47, 60–70, 2012.

26. X. Wu, Q. Yin, Y. Wei, C. Huang, Effects of imperfect experimental conditions on stress waves in SHPB experiments, Acta Mechanica Sinica, doi: 10.1007/s10409-015-0439-0, 2015.

27. M. Alves, D. Karagiozova, G. B. Micheli, M. A. G. Calle, Limiting the influence of friction on the split Hopkinson pressure bar tests by using a ring specimen, Int. J. of Impact Engineering, Vol. 49, 130-141, doi: 10.1016/j.ijimpeng.2012.04.005, 2012.

28. W. Z. Zhong, A. Rusinek, T. Jankowiak, F. Abed, R. Bernier, G. Sutter, Influence of interfacial friction and specimen configuration in Split Hopkinson Pressure Bar system, Tribology International, Vol. 90, 1–14, doi: 10.1016/j.triboint.2015.04.002, 2015.

29. **R. Panowicz**, M. Trypolin, Kształtowanie impulsu wymuszającego w zmodyfikowanej metodzie dzielonego pręta Hopkinsona, XV Konferencja Naukowo-Techniczna „Techniki Komputerowe w Inżynierii" TKI 2018, Jora Wielka, 2018.

5. Presentation of the remaining scientific and research achievements

These are the shortly characterized the most import ant construction and technological achievements and research works which were completed with my participation.

One of the fundamental threats on the modern battle field, both symmetric and asymmetric, are guided and unguided missiles with shape charge. As an effect of missile impact into an obstacle, a fuse is activated and, consequently, an explosive material is detonated, which results in generating of a shape charge jet a main warfare agent in this type of charge. The jets moves with velocity of the order of several kilometres per hour and penetrates from 300 to 900 mm of RHA steel. Effectiveness of the jet depends significantly on the accuracy of warhead elements accomplishments and providing the symmetry to the entire charge.

Taking into consideration the method of cumulative charge operation, it is possible to protect against them through:

- disturbance of a shape charge symmetry (generation of a shape charge jet with low efficiency or lack of jet),
- short circuit in the fuse set up (no stimulation of explosive material),
- application of a thick armour (e.g. the front of the tower of American tank Abrams is 960 mm, whereas in the case of the Russian tank T90, it is 650 - 700 mm),
- weakening of a shape charge jet (reactive armour).

My special interest, in respect to the above mentioned solutions, concerns the application of the first described method for improving the protection of people and vehicles, namely, application of shape charge symmetry disturbance. In such a situation, the issue is not axisymmetric any more. A shape charge jet will not originate from a deformed charge or it will be much less effective.

5.1. Rod armour

Within the project supervised by me, titled "System of armoured vehicle passive protection against cumulative missiles", No. O R00 0121609 financed by the Ministry of

Science and Higher Education and then by National Centre for Research and Development, there were developed two types of rod armours characterized with small mass. I am a co-author of both these solutions. First of them – "Armour of small effective mass" – is protected by a utility model, whereas the other one – "Light rod armour" – is protected by both Polish and international patents (Appendix 3, item 2.3.1).

The solutions developed within the project were numerously awarded during Polish and overseas exhibitions:

- International Warsaw Invention Show IWIS'2011
- 7th Seoul International Invention Fair SIIF'2011,
- 15th Moscow International Salon of Inventions and Innovative Technologies, ARCHIMEDES'2012.

"Light rod armour" was also presented on T72 tank during International Defence Industry Exhibition in Kielce, in 2011 (Fig. 16).

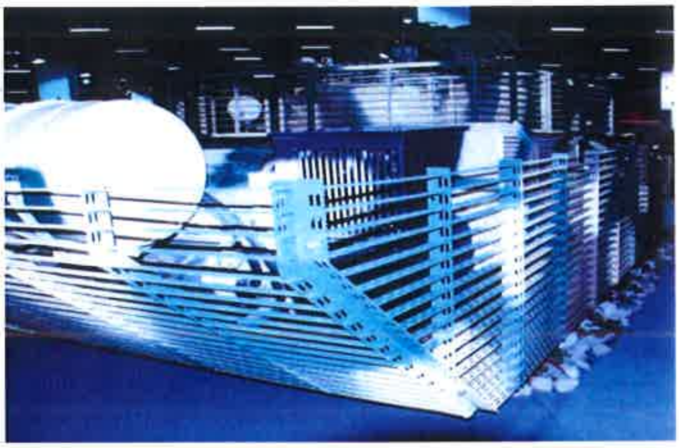

Fig.16. Light rod armour mounted on T72 and presented during International Defence Industry Exhibition in Kielce, in 2011

During the project implementation, I developed a research method, presented in Fig. 17, which enables simultaneous observation, from two directions, of a RPG type missile and rod armour interaction phenomenon. The method was used during field tests on the developed solutions. During these tests, both the solutions indicated high effectiveness.

The results of experimental tests and numerical analyses of interaction of RPG type missile and a rod armour are presented, among others, in the following publications:

- **R. Panowicz**, K. Sybilski, W. Barnat, T. Niezgoda, Numeryczne badanie wybranego typu pancerza prętowego wraz z weryfikacją eksperymentalną, Ochrona przed skutkami nadzwyczajnych zagrożeń, Vol. 2, a chapter of monograph edited by Z. Mierczyk and R. Ostrowski, Warsaw, 2011.
- **R. Panowicz**, T. Niezgoda, Experimental Research on Systems of Military Vehicles Protection Against RPG Type Missile, Solid State Phenomena, Vol. 240 (2016), doi: 10.4028/www.scientific.net/ SSP.240.244, 2015.
- **R. Panowicz**, K. Sybilski, T. Niezgoda, W. Barnat, Numeryczna ocena zniszczenia elementów pocisku PG-7G przy kontakcie z pancerzem prętowym, Górnictwo Odkrywkowe, 51, 3, 2010.

- **R. Panowicz**, T. Niezgoda, W. Barnat, K. Sybilski, Walidacja uproszczonego modelu pocisku z głowicą kumulacyjną typu PG7-G, Mechanik, 84, 7, 2011.
- **R. Panowicz**, K. Sybilski, R. Gieleta, P. Kupidura, R. Bazela, M. Magier, Badania eksperymentalne wybranego typu pancerza prętowego, Biuletyn Naukowy Wojskowego Instytutu Technicznego Uzbrojenia, issue 118, No. 2, 2011.
- **R. Panowicz**, K. Sybilski, T. Niezgoda, W. Barnat, Obliczenia analityczne prawdopodobieństwa zadziałania pancerza wykonanego z prętów o przekroju kołowym, Biuletyn Naukowy Wojskowego Instytutu Technicznego Uzbrojenia, issue 119, No. 3, 2011.
- T. Niezgoda, **R. Panowicz**, K. Sybilski, W. Barnat, Numerical analysis of missile impact being shot by rocket propelled grenades with rod armour, WIT Transactions on Modelling and Simulation, Vol. 51, WIT Press, doi: 10.2495/CMEM110551, 2011.
- T. Niezgoda, **R. Panowicz**, K. Sybilski, W. Barnat, Numerical analysis of a Shell with a main shaped charge warhead stroke into a bar armor with square section, Journal of KONES Powertrain and Transport, Vol. 17, No. 3, 2010.
- K. Sybilski, **R. Panowicz**, D. Kołodziejczyk, T. Niezgoda, Validation studies of the simplified model of the missile with cumulative head, Journal of KONES Powertrain and Transport, Vol. 19, No. 3, 201r.
- K. Sybilski, **R. Panowicz**, T. Niezgoda, W. Barnat, Analiza numeryczna uderzenia pocisku z głowicą kumulacyjną w pancerz wykonany z kątowników, Mechanik, 84, 1, 2011.
- P. Kupidura, Z. Leciejewski, **R. Panowicz**, Z. Surma, K. Sybilski, R. Trębiński, Experimental and model scale tests of an additional protection structure against RPG rockets, Zeszyty Naukowe Instytutu Pojazdów, 3 (89), 2012.

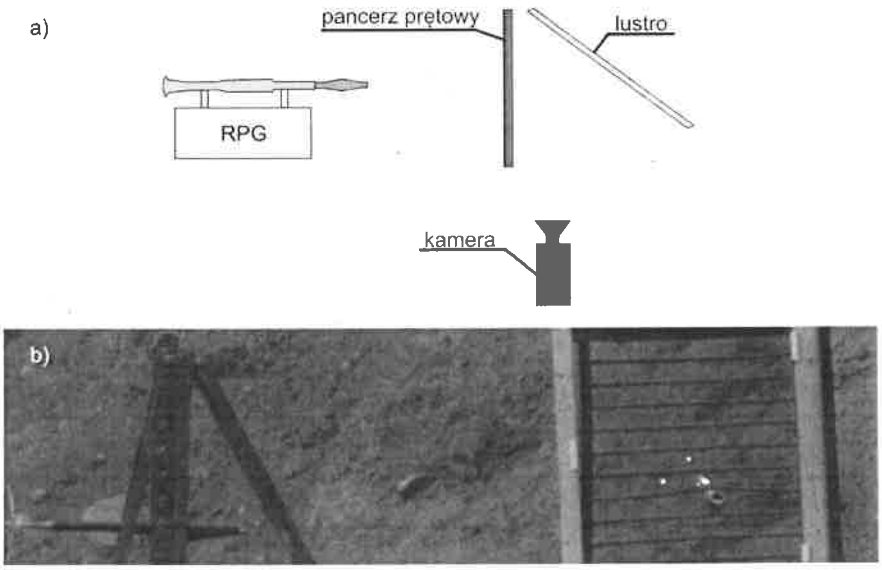

Fig.17. Experimental tests on rod armours; a) scheme of the stand, b) frame from the film shot during experimental tests

5.2. Active protection system

The active protection system aims at destruction or neutralization of the threat without contact with the protected object.

As this thematic field is concerned, I participated in implementation of two projects. Within the first project, titled "Active protection system for protection of mobile objects against missiles with cumulative warheads", an active protection system was developed based exclusively on the Polish construction thought (Appendix 3, item: 2.3.6). The project, due to its complexity, was implemented by an interdisciplinary team including representatives of four different scientific fields.

Within the second project, titled "Intelligent anti-missile for fighting anti-tank missiles", which was supervised by myself, an advanced antimissile fitted with its own intelligence was developed (Appendix 3, item: 2.3.5). The anti-missile aimed at detecting the passing threat and its effective neutralization or destruction. This project was, also due to its complexity, implemented by an interdisciplinary team including representatives of different scientific fields.

Within the conducted works, I developed combat warheads capable of protecting the objects at a direct and further distance (Appendix 3, items: 2.3.7. – 2.3.9). I was also in charge of an integration process of individual elements of the active protection system and anti-missile as well as preparation of field tests methodologies. I supervised the field tests and assessed them for implementation of projects utility aim.

Effectiveness of combat warheads operation was verified with experimental tests.

Selected results of the test are presented, among others, in the following publications:

- **R. Panowicz**, J. Nowak, M. Konarzewski, T. Niezgoda, Introduction to numerical analysis of directed fragmentation warheads, Journal of KONES Powertrain and Transport, Vol. 20, No. 4, 2013.
- **R. Panowicz**, M. Konarzewski, Influence of selected parameters of the fragmentation warhead on its effectiveness, Journal of KONES Powertrain and Transport, Vol. 22, No. 3, 193–200, 2015r., doi: 10.5604/12314005.1166020.
- **R. Panowicz**, M. Konarzewski, M. Trypolin, Analysis of the detonation initiation point position influence on the cylindrical fragmentation warhead effectiveness, Journal of KONES Powertrain and Transport, Vol. 23, No. 1, 2016.
- **R. Panowicz**, T. Niezgoda, M. Konarzewski, Numerical and experimental analysis of effectors used in active protection systems, Problems of mechatronics armament, aviation, safety engineering, 3 (25), 2016.
- J. Nowak, **R. Panowicz**, M. Konarzewski, Influence of destructor case type on behaviour of fragments in military vehicles active protection system, Journal of KONES Powertrain and Transport, Vol. 21, No. 1, 2014.
- D. Kołodziejczyk, P. Kupidura, Z. Leciejewski, **R. Panowicz**, Z. Surma and M. Zahor, Counterprojectile for active protection system, 27th International Symposium on Ballistics, Freiburg, Germany, April 22–26, 2013, WoS base.

Due to a unique character of the developed solutions for the country's defence, part of the results, both partial and overall, they could not be published in scientific journals or during science and research conferences (Appendix 5).

5.3. Other research works

The tests conducted by myself, both before and after acquisition of my Ph.D. degree, were mostly related to application of computational methods in mechanics to analysis of the problems in which dynamic phenomena are pivotal. Within the works conducted after acquisition of my Ph.D. degree, I dealt with such issues as:

- behaviour of single and complex energy absorbing structures loaded with a pressure wave from explosive material detonation as well as with design of such solutions. The effects of these works are, among others, the following papers:

  - **R. Panowicz**, D. Kołodziejczyk, K. Sybilski, W. Barnat, T. Niezgoda, Analiza numeryczna dynamicznego oddziaływania fali ciśnienia na złożoną strukturę panelu energochłonnego, Przegląd Mechaniczny, No. 11, 2012.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, R. Gieleta, Analysis of a protective composite panel with an energy absorbent in the form of foamed aluminium, Journal of KONES Powertrain and Transport, Vol. 17, No. 4, 2010.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, Numerical and experimental comparison of combined multilayer protective panels, Acta Mechanica et Automatica, Vol. 6, No. 1, 2012.
  - W. Barnat, T. Niezgoda, **R. Panowicz**, Warstwy energochłonne do ochrony pojazdów wojskowych przed wybuchem min i IED, Biuletyn Departamentu Nauki i Szkolnictwa Wojskowego Ministerstwa Obrony Narodowej i Centralnej Biblioteki Wojskowej im. Marszałka Józefa Piłsudskiego, Warszawa 2010r., ISBN 978-83-89875-31-0.
  - W. Barnat, T. Niezgoda, R. Gieleta, **R. Panowicz**, Investigation of a panel with an elastomer layer plus carbon fibres loaded with a blast wave, Journal of KONES Powertrain and Transport, Vol. 17, No. 4, 2010.
  - W. Barnat, T. Niezgoda, P. Szurgott, **R. Panowicz**, Numerical analysis of the composite - foam panels applied to protect pipelines against the blast wave, Techniczne wyroby włókiennicze, 17, 2 - 3, 2009.
  - Patent krajowy pt.: „Energochłonny panel denny", T. Niezgoda, **R. Panowicz** (percentage of 25%), R. Gieleta, W. Barnat, No. PAT.219799, 2014.
  - Patent krajowy pt.: „Przenośne stanowisko poligonowe do prób wybuchowych", M. Klasztorny, T. Niezgoda, P. Gotowicki, **R. Panowicz** (percentage of 10%), W. Barnat, R. Gieleta, A. Morka, No. PAT.217044, 2013.
  - Patent krajowy pt.: „Osłona kompozytowo-pianowa do ochrony załóg pojazdów lekko opancerzonych", M. Klasztorny, T. Niezgoda, P. Gotowicki, **R. Panowicz** (percentage of 10%), W. Barnat, No. PAT.217196, 2013.

- effects of interaction of a blast wave from explosive material detonation of a vehicle and its crew. The effects of these works are, among others, the following papers:

  - **R. Panowicz**, W. Barnat, K. Sybilski, T. Niezgoda, Numerical analysis of a light armoured vehicular personnel carrier loaded with a mine or IED explosion on a human transported in it, Journal of KONES Powertrain and Transport, Vol. 17, No. 3, 2010.
  - **R. Panowicz**, T. Niezgoda, W. Barnat, K. Sybilski, Computer modeling of complex action system of blast wave arising from mine or IED explosion on light armoured vehicle, Journal of KONES Powertrain and Transport, Vol. 17, No. 4, 2010.
  - **R. Panowicz**, K. Sybilski, D. Kołodziejczyk, T. Niezgoda, W. Barnat, Numerical analysis of effects of IED side explosion on crew of light armoured wheeled vehicle, Journal of KONES Powertrain and Transport, Vol. 18, No. 4, 2011.
  - **R. Panowicz**, W. Barnat, T. Niezgoda, K. Sybilski, Numeryczne badanie oddziaływania impulsu ciśnienia na wybrane typy pojazdów i ich załogę, Mechanik, 84, 5 - 6, 2011.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, Wybrane aspekty analizy konstrukcji pojazdów wojskowych obciążonych falą wybuchu, Ochrona przed skutkami nadzwyczajnych zagrożeń, rozdział w monografii pod red. Z. Mierczyk, R. Ostrowski, Warsaw, 2012, ISBN 978-83-62954-62-9.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, P. Dybcio, Influence of an armoured vehicle's hull structure on absorption of blast energy, Journal of Battlefield Technology, Vol. 14, No. 2, July 2011.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, P. Dybcio, A numerical analysis of initial and boundary conditions influence on the crew of tracked vehicle and the ground, Journal of KONES Powertrain and Transport, Vol. 18, No. 1, 2011.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, Influence of armoured vehicle's bottom shape on the pressure pulse, Journal of KONES Powertrain and Transport, Vol. 18, No. 1, 2011.
  - W. Barnat, **R. Panowicz**, G. Moneta, Numeryczne badanie oddziaływania fali wtórnej na załogę pojazdu, Systems Journal of Transdisciplinary Systems Science, Vol. 16, No. 3, 2012.
  - W. Barnat, **R. Panowicz**, G. Sławiński, K. Sybilski, G. Moneta, Numeryczna analiza wpływu elastomerowego elementu tłumiącego siedziska pojazdu wojskowego obciążonego IED na organizm ludzki, Systems Journal of Transdisciplinary Systems Science, Vol. 16, No. 3, 2012.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, Numeryczna analiza oddziaływania wybuchu na pojazd z uwzględnieniem fali odbitej od podłoża, Górnictwo Odkrywkowe, 51, 3, 2010.
  - W. Barnat, **R. Panowicz**, T. Niezgoda, Wpływ płaskiego dna pojazdu wojskowego na załogę z uwzględnieniem modelu gruntu opisanego modelem materiałowym Mie-Gruneisena, Modelowanie Inżynierskie, 11, 42, 2011.

- W. Barnat, T. Niezgoda, **R. Panowicz**, Analysis of a light caterpillar vehicle loaded with blast wave from detonated IED, Journal of KONES Powertrain and Transport, Vol. 17, No. 4, 2010.
- W. Barnat, G. Moneta, **R. Panowicz**, G. Sławiński, Wstęp do modelowania wybuchu bocznego ładunku IED na kabinę pojazdu specjalnego zgodnie z normami, Systems Journal of Transdisciplinary Systems Science, Vol. 16, No. 3, 2012.
- W. Barnat, G. Sławiński, G. Moneta, **R. Panowicz**, Introduction to modelling side IED explosion influence on special military vehicle, Journal of KONES Powertrain and Transport, Vol. 19, No. 4, 2012.

- possibility to apply the terahertz radiation to non-destructive tests on composite materials. The obtained results are presented in the following publications:

- D. Miedzińska, T. Niezgoda, N. Pałka, **R. Panowicz** et al., Non-destructive Terahertz Investigations of Polyethylene Composite Materials, 36th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), IEEE Microwave Theory & Tech Soc, doi: 10.1109/irmmw-THz.2011.6104979, 2011.
- N. Pałka, **R. Panowicz**, F. Ospald, R. Beigang, 3D Non-destructive Imaging of Punctures in Polyethylene Composite Armor by THz Time Domain Spectroscopy, J. Infrared Milli. Terahz. Waves, doi: 10.1007/s10762-015-0174-4, 2015.
- N. Palka, **R. Panowicz**, M. Chalimoniuk, R. Beigang, Non-destructive evaluation of puncture region in polyethylene composite by terahertz and X-ray radiation, Composites Part B, 92, 1, 2016.

6. Summary of publication achievement and other achievements

My Summary Impact Factor according to Journal Citation Reports (JCR) base in accordance to year of publication is 19.904, and a number of points granted by the Ministry of Science and Higher Education for scientific publications according to the publication year is 885. The remaining factors of scientific achievements are presented in Table 1.

A collective list of my achievements is presented in Table 2, whereas the specified details are presented in Appendix 3.

After acquisition of my Ph.D. degree, while working at Military University of Technology, I completed over 2000 didactic hours in the form of lectures, computational and laboratory classes, seminars and diploma theses at both at undergraduate and postgraduate studies and Ph.D. studies on such subjects as:

- strength of materials,
- technical mechanics,
- technical mechanics and strength of materials,
- computer simulation of thermo-mechanics problems,
- analytical mechanics.

In the case of some subjects, I was the author of the syllabus. I supervised 7 diploma theses at both undergraduate and postgraduate studies. I was a scientific tutor or auxiliary promoter of three Ph.D. theses, two of which were given a distinction (Appendix 3, item: 3.10).

Table 1. Factors of scientific achievements

	WoS	Scopus	Google Scholar
Hirsh Index	4	7	9
Number of citations	44	114	295

The carried out research enabled me to elaborate two original subjects conducted at studies.

- Modelling of blast wave interaction on structure elements,
- Selected problems of military vehicles active protection.

For my didactic, research and innovative activity, I was presented with the following awards and distinctions:

- diploma of recognition for a high number grade in periodical assessment of academic teacher for the academic years 2008/2009 – 2011/2012 within the didactic, scientific and research and organisational activity, Dean of the Faculty of Mechanical Engineering, Zdzisław Bogdanowicz, D.Sc., Eng., Professor of Military University of Technology, Warsaw 20.03.2013.
- in-kind prize from Commandant-Rector of Military University of Technology for effort, labour, devotion and special achievements in performing official duties – Order of Rector-Commandant of Military University of Technology WAT 15/RKR 2013 of 18.12.2013.
- medal of the Commission of National Education, Warsaw, 25.08.2014.
- distinction for T. Niezgoda, W. Barnat, **R. Panowicz** from the Ministry of Economy, Department of Offset Programmes for implementation and development of "Foam-composite panel improving life and health protection of crew of caterpillar vehicle with flat bottom" Warsaw, 16.03.2011.
- gold medal at international Warsaw invention show IWIS'2011 for T. Niezgoda, W. Barnat, **R. Panowicz**, K. Sybilski for solution "Light rod armour against RPG", Warsaw, 5.11.2011.
- distinction in competition for the best paper presented within poster session for **R. Panowicz**, K. Sybilski, W. Barnat, T. Niezgoda for presentation of the paper titled "Analysis of missile impact into rod armour in the aspect of fuse operation", TKI'2011, 12th Science and Technology Conference, Słok near Bełchatów, 18-21st October 2011
- cash prize and diploma of Rector of Military University of Technology for development of "Technology demonstrator of intelligent anti-missile for fighting

anti-tank missiles”, decision of Rector of Military University of Technology No. 249/RKR/2018 of 17th September 2018

A detailed list of the received awards and distinctions is presented in Appendix No. 3, items 2.11 and 3.3.

Table 2. Scientific accomplishments

No	Items	Number
1.	Scientific publications in journals included in Journal Citation Reports (JCR) base	20
2.	Authorship of accomplished original design, construction or technological achievement	7
3.	International and Polish patents	9
4.	Authorship/co-authorship of monographs	6
5.	Authorship or co-authorship of scientific publications in international journals	44
6.	Authorship or co-authorship of scientific publications in Polish journals	35
7.	Authorship or co-authorship of collective elaborations, documentation of research works, expert opinions	6
8.	Summary Impact Factor according to Journal Citation Reports (JCR) list in accordance to year of publication	19.904
9.	Number of citations of publications according to Web of Science (WoS) base	44
10.	Hirsh Index according to Web of Science (WoS) base	4
11.	Papers delivered at international thematic conferences	15
12.	Papers delivered at Polish thematic conferences	23
13.	Supervision over international and Polish research projects and participation in such projects	20
14.	International and Polish awards for scientific activity	15
15.	Active participation in organizing committees of these conferences	2
16.	Participation in consortiums and research networks	4

17.	Supervision over projects implemented in collaboration with researchers from other Polish and overseas centres and in collaboration with entrepreneurs	3
18.	Membership in international or Polish scientific organizations and associations	4
19.	Scientific guidance over Ph.D. students as a scientific tutor or auxiliary promoter	3
20.	Internships in Polish and overseas scientific or academic centres	2
21.	Participation in contests and expert groups	5
22.	Reviewing international and Polish projects and publications in Polish and international journals	22

20. 02. 2019 ....   Robert [illegible] ....

date   signature