

A Collaborative Project Between Industry and Academia to Enhance Engineering Education at Graduate and PhD Level in Ceramic Technology*

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Results of an intensive and effective industry-academia partnership are presented, demonstrating that barriers to inter-sectoral mobility have been overcome, achieving an enhancement in the quality of both graduate and doctoral programmes in engineering.

The industrial and social needs of improving the ceramic production process and of developing novel advanced ceramic multifunctional materials and structures were essential for the creation of a synergetic cooperation between a world leader industry for Ceramics (SACMI), a medium enterprise specialized in Virtual Prototyping (ENGINSOFT) and an academic research group in Solids and Structural Mechanics of the University of Trento. The research collaboration has lasted several years producing a continuous inter-sectoral and inter-disciplinary transfer of knowledge among the partners and maximising in this way their performance, in particular in terms of added value generated through human capital improvements. An additional impact of the above mentioned cooperation has been the award of a Marie Curie—Industry Academia-Partnership & Pathway four years grant focused on boosting skills exchange between the commercial and non-commercial sectors through secondments of academic staff and PhD students to industry and vice-versa. Moreover, the partnership has led to a significant enhancement in the teaching results, together with an increasing motivation of the students, crucial in the Engineering Education.

Keywords: ceramic industry, transfer of knowledge, FP7-PEOPLE-2011-IAPP Marie Curie Action.

1. Introduction

Recent studies have shown how entering the Italian labour market for young graduates has become harder over the past decade. In particular, between 2002 and 2010 Italy has faced a significant drop in the employment rates of the higher educated population (25–64 year-olds) from 82.2% to 78.3% [1].

This paper is based on the conviction that in order to cope with the new challenges of the domestic and international economy, particularly in terms of competitiveness, the main target of an Engineering School should be to train students (at graduate and PhD levels) with a deep knowledge of the industrial and social needs so that they will be able to face properly a professional career in public and private sectors. In fact, despite the increasing unemployment rates of tertiary graduates, linked to the current economic crises, the data of the Excelsior Informative System reveal a gradual change in the qualitative profile of the Italian labour demand and show a relative growth of the request for highly-skilled workers: between 2007 and 2011 high-skills jobs have risen from 18% to 22% of the non-seasonal

recruitments planned by companies. Moreover, inside the category of high-skilled workers, the intellectual and scientific professions, a sort of ‘task force’ of innovation processes, are growing by nearly 20%, helping to strengthen business strategies oriented to technology improvement and knowledge transfer [2].

In order to efficiently respond to this demand, the Italian tertiary education system should deal with a significant problem of skill mismatching. As underlined by the 2011 Employment Forecasts of the Italian Union of the Chambers of Commerce (Unioncamere), a large number of companies consider inadequate the education of new graduates, with three out of four reporting the need to provide initial training to compensate the original lack of competencies [3].

This problem concerns also Engineering Schools in Italy. In fact, a flaw of the teaching programs currently implemented is to rely mainly on an academic approach that leaves a lack of experience essential for completing the education of an engineer and for launching him into the labour market. To reduce this discrepancy, the Solid and Structural

Mechanics Group (SSMG) of the University of Trento is putting much effort in keeping close collaborations with several industrial partners, to create interactions with the students of the Engineering School of the University of Trento through different activities, such as workshops, seminars, short courses, conferences, symposiums, summer schools, training, internships, staff visits, students visits and joint research projects.

These collaborations are bringing effective improvements to the Engineering Education in terms of:

- understanding how to address social needs by facing actual industrial problems;
- increased motivation of the students given by the applicative approach typical of the industrial sector;
- achieving higher standards of analysis by using state-of-the-art industrial technologies;
- obtaining financial support through contracts with outside stakeholders;
- active business involvement of the university staff;
- academic publications or novel insights and ideas for follow-on projects;
- opportunities to enhance career paths and improve employability.

Our experience evidences that an industry-academia cooperation leads to positive results when promoted by high scientific and economical interest of both parties on the research topic, which guarantees a deep involvement of all partners in the development and improvement of the research project.

In our case, the cooperation arose from a lack of scientific approach in the description of an important engineering problem, namely, the manufacturing processes in the production of ceramic materials. The problem was posed to SSMG by SACMI, a world leader industry operating in the field of ceramics and covering the entire process of ceramic production, from the powder to the final

piece and design of the machineries for production. Indeed, nowadays the strong industrial production of ceramic components is still based on empirically engineered processes, often poorly understood and difficult to control [4]. Consequently, a relatively large amount of wasted material is produced and energy is consumed with the related negative impact on the production costs and the environment, so that the achievement of an optimization would lead to a reduction in the reject of the ceramic products with a deep effect in the reduction of the above pollution effects.

To this purpose, the expertise in the field of non-linear theories of material behaviour of SSMG is fundamental for the advancement of the research, since the development of sophisticated constitutive models is required in the description of the forming process of ceramics by cold compaction and the completion of the process of ceramic production occurring through sintering (Fig. 1) [5–7].

The collaboration between SSMG and SACMI has been strengthened thanks to the award of a European research grant financed through a Marie Curie Action—Industry Academia-Partnership & Pathway (IAPP), which has helped extending the cooperation to another industrial partner, ENGINSOFT (Italy's largest service provider for Computer Aided Engineering and Virtual Prototyping technologies), and two academic research groups established in the UK, the University of Liverpool (UoL) and the Aberystwyth University (AU). Figure 2 describes the peculiarity of the network and the expertise of partners.

In the IAPP Marie Curie Action participants from academia and industry propose a joint research project designed to exploit complementary expertise of the participants and to create synergies between them. In addition to advancing research knowledge in a particular area, IAPP projects are also expected to create additional benefits for the participants in terms of transfer of knowledge. In fact, in each consortium, staff secondment is compulsory and the recruitment of new personnel is also

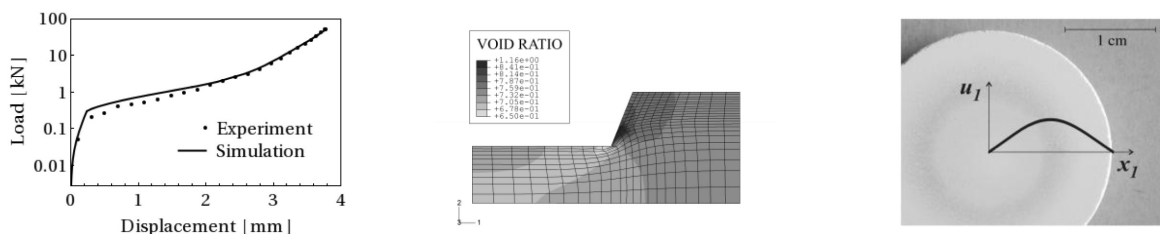


Fig. 1. A mechanical model of ceramic forming developed by SSMG correctly predicts: (left) the load/displacement curve during cold pressing, (centre) the density (void ratio) map within a formed piece and (right) the dark annular region evidenced on the bottom of a formed piece. Finally, the contribution of ENGINSOFT, representing one of the major players in the field of Computer Aided Engineering (CAE) and Virtual Prototyping (VP) technologies in Europe, is crucial in the development of novel computational technologies and the implementation of innovative constitutive theories within commercial codes with the aim to support and optimize design and production processes of innovative ceramics products.

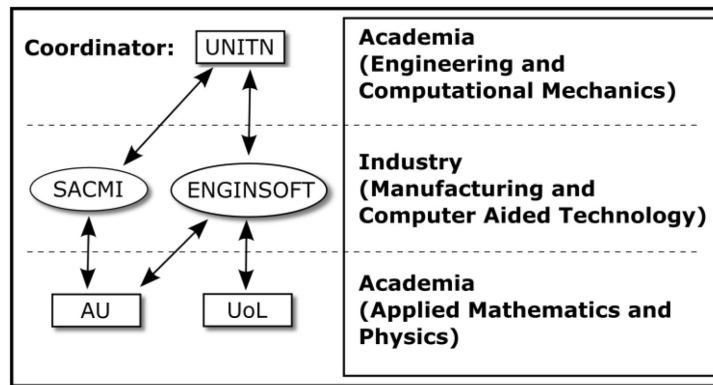


Fig. 2. The INTERCER2 Network.

an option to bring new knowledge into the host organisation. However, with the aim to promote inter-sectoral mobility, all staff exchanges must be between the non-commercial and commercial sector [8]. The project will be further described in section 3.

2. Teaching-learning methodology

Although contacts between the parties started a long time ago, only in the last five years they evolved into a strong collaboration, once a common research challenge was defined. Indeed, the driving force of this collaboration is represented by the interest of all partners in the development of a constitutive model capable of describing the manufacturing processes involved in the production of ceramic components, in order to improve the quality of the final pieces and reduce the waste of materials and energy. This synergetic cooperation is positively influencing the daily-life of the engineering students of the University of Trento through the following activities described below together with the related impact.

- *Workshops*: organised each 4 months and significant for fostering interest, introducing new ideas and methods, motivating students to action. In particular, SACMI has provided participants with opportunities to improve complementary skills such as:
 - commercial exploitation of results: experts of the technical and marketing department analyse how new scientific ideas could influence innovative industrial technologies and devices to be used in the ceramic industrial market;
 - intellectual property rights: experts of the internal patent office analyse the opportunities to transform new ideas into patents to be shared between the partners.

Students have underlined that workshops are

very useful when participants can follow up with an expert able to help them with their specific projects and interests in order to build on workshop topics.

- *Seminars*: during the ordinary lectures of ‘Mechanics of Solids’ and ‘Strength of Materials’ foreseen in the undergraduate degree and within the Doctoral School in Engineering of Civil and Mechanical Structural Systems, professionals of ENGINSOFT and SACMI offer seminars with topics ranging from mechanical problems in applicative industrial processes to numerical difficulties deriving from simulation of non-linear materials. Students highly appreciate these activities, which give them a practical engineering approach that is usually missed in ordinary classes. A large number of high-quality questions raised by the students at the end of the seminars proves their interest in the problems encountered in the industrial processes.
- *Short courses*: offered by ENGINSOFT through the TCN Consortium (Centre for Higher Training for Computational Technologies) on the following subjects:
 - CAE (Computer Aided Engineering);
 - virtual prototyping and testing;
 - numerical simulations;
 - IDP (Intelligent Digital Prototyping);
 - disciplines linked to statistics, data structure, Information Technology and software engineering in general.
 These courses have been followed by a growing number of participants eager to improve their knowledge of the corresponding software technology and resulting very interested in acquiring a certification organized according to the International Registered Analyst scheme, as suggested by NAFEMS [9].
- *Conferences, symposiums and summer schools*: several experts from the industrial partners participate in these events, sharing their experience

with bachelor's, master's, PhD and post-doc students, and confronting themselves with the last achievements of the university staff. Moreover, companies sponsor the organisation of conferences and summer schools in order to disseminate the results of their activities and get in touch with excellent and motivated students with whom to develop future research collaborations. A questionnaire distributed during the most recent events organised in 2012 and reported in the next section—the *Summer School on Computational Multiscale Fracture Mechanics* and the *IUTAM 2012 Symposium on Fracture Phenomena in Nature and Technology* held in Brescia on June 25-29 and July 01-05, and the *1st International School on Smart Structure* held in Trento on September 03–07—shows that the feedback from the attendees was very positive.

- **Training:** SACMI arranges experimental activities on the characterization of ceramic powder in its internal Research Centre, while ENGINSOFT organises online high education courses in the areas of structural engineering, metallic materials and metallurgical processes, computer aided engineering [10]. In addition, ENGINSOFT offers the following initiatives:
 - tailor-made activities for industry;
 - fellowships to support life-long learning [11].
 These activities are usually preferred by the motivated and high-level students that recognise in this training courses a way of enhancing their CV and more specifically of acquiring new tools useful for the tasks they could face in their future job.
- **Internships:** in some cases Master's theses, PhD theses and internships are assigned with the joint supervision of an academic and an industrial tutor, so that periods ranging from 1 to 6 months can be spent in industry to develop the thesis or some research. Similarly to training, only motivated and high-level students are prone to face this extra effort since it involves additional mobility, time, and, in the case of the thesis, costs. On the other hand, this activity has a deep impact on the intern since prior work experience is useful for jobs in engineering, it helps in skills development and also heightens commercial/industrial awareness. Moreover, trainees have the unique opportunity to interact with a multidisciplinary team composed by academic and industrial members and collaborate with experienced engineers before entering the labour market. The company providing the internship releases an evaluation at the end of the experience (see next section), which students consider particularly useful in order to understand their strengths and weaknesses, and effi-

ciently respond to the expectations of the industrial sector.

- **Staff Visits:** One day, weekly or long period visits of academic staff to industry and of industrial staff to university are experienced in our collaboration. For the students the impact is mainly related to the latter type of visits since in this case they have the time and feel the possibility to discuss technical aspects of the industrial sector.
- **Students Visits:** One day industrial visits have been introduced recently for interested students attending undergraduate courses. This activity is showing a very positive feedback since participants, in addition to the good feeling given by getting out of the routine, achieve a greater awareness of the dimensions, products and dynamics of a particular business environment.

The interaction between engineering students and industrial staff, based on all the above mentioned activities, has led to several job offers for graduates, in particular for those who were working as interns.

Finally, the continuous industry-academia partnership has permitted to conceive and elaborate joint research projects strongly motivated by the manufacturing experience and with a great impact on the production and the environment. One of them, the INTERCER2 project, is exposed in the next section.

3. Main results

The common interest of the parties in the mechanical modelling of ceramic production processes has led to the award of a grant financed through the FP7-PEOPLE-2011-IAPP Marie Curie Action call of the European Commission addressed to industry-academia collaborations. Quoting the guide for applicants [12], 'the IAPP (Industry-Academia Partnerships and Pathways) action seeks to enhance industry-academia cooperation in terms of research training, career development and knowledge sharing, in particular with SMEs, and including traditional manufacturing industries. It is based on longer term cooperation programmes with a high potential for increasing mutual understanding of the different cultural settings and skill requirements of both the industrial and academic sectors'.

The 4 years INTERCER2 project (<http://intercer2.unitn.it/>) was successfully evaluated by the European Commission and has been running since October 2011. The grant mainly supports secondments at different levels (PhD, post-doc and researchers) from academia to industry and vice-versa for a total period of 192 person-months. In addition, funds are planned for the recruitment of researchers external to the Consortium for a total of

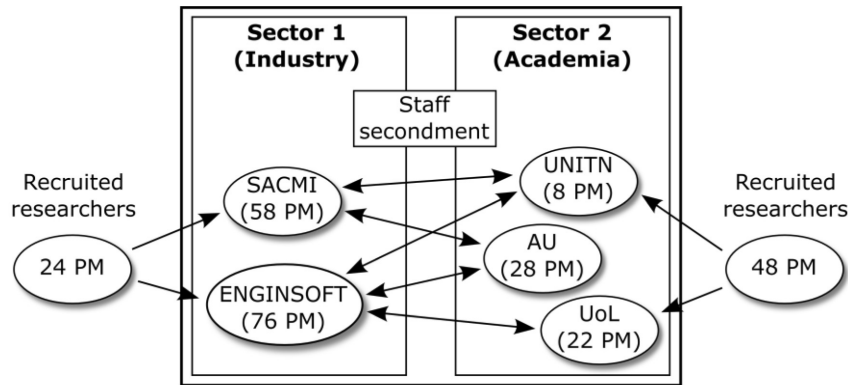


Fig. 3. Staff exchanges inside the INTERCER2 Network.

72 person-months (see Fig. 3), for training activities, dissemination events and the organisation of an International Congress and a Mini-symposium on Ceramics throughout the course of the project.

Thanks to this grant, the collaboration between SSMG and the industrial sector has been intensifying, bringing significant advantages to students that have seen increasing the amount of activities dedicated to their personal carrier advancement and the educational offer of their engineering faculty. The following table reports the evaluation given by participants in the *Summer School on Computational Multiscale Fracture Mechanics*, the *IUTAM 2012 Symposium on Fracture Phenomena in Nature and Technology* and the *1st International Summer School on Smart Structures*. They were all joint events to the training program of the INTERCER2 research project. The attendees were asked to mark from 1 (= not acceptable) to 4 (= most positive) several aspects of the events, and here below are the averages.

Table 1 shows a very positive feedback from the

participants and in particular a very high appreciation of the involvement of the industrial sector in each event. Question n. 6 is indeed the one to which attendees have answered with most enthusiasm.

During the above mentioned events and all the other activities described in section 2 of this paper, the industrial partners ENGINSOFT and SACMI have had the possibility to observe students and most importantly to think about the general skills they would require in order to offer them a job or give them advices on the expectations of the employers. The skills most commonly sought include:

- sound technical knowledge and the ability to apply it;
- keen analytical and problem-solving skills;
- team-working ability;
- good communication skills;
- commercial awareness;
- organisational skills, such as time and resource planning;
- ability to build relationships with customers;

Table 1. Evaluation Questionnaire filled in by participants of the *Summer School on Computational Multiscale Fracture Mechanics*, the *IUTAM 2012 Symposium on Fracture Phenomena in Nature and Technology* and the *1st International Summer School on Smart Structures*.

Events	Summer School on Computational Multiscale Fracture Mechanics	IUTAM 2012 Symposium on Fracture Phenomena in Nature and Technology	1st International Summer School on Smart Structures
Number of attendees	23	56	33
Questions	Feedback		
1. The course was worth your time	3.4	3.5	3.5
2. The material was taught at a good technical level	3.2	3.4	3.3
3. The course structure was appropriate	3.1	3.4	3.3
4. Lecturers were well coordinated and no overlaps were found	3.1	3.3	3.4
5. Considering the course length, the course covered the main topics	3.2	3.4	3.5
6. The contribution of industrial experts was important	3.6	3.6	3.8
7. You would recommend the course to others	3.5	3.6	3.6

Please take a few minutes to answer these questions. Did the student show during this seminar/ internship, the following skills?			
	YES	NO	UNNOTICED
a. Ability to exploit knowledge of mathematics, engineering and science.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Ability to run experiments, analyse data, reach solutions.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Ability to define and solve engineering problems.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Ability to work in a multidisciplinary team.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Ability to meet customers' needs.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Ability to synthesise information and communicate it effectively.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. Extended background to perceive the impact of engineering solutions in a global/social context.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. Satisfactory computer competences.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i. Good knowledge of the English language and/or other foreign language.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
j. Ability to adopt the techniques and modern engineering tools fundamental for engineering practice.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Fig. 4. Questionnaire adopted by the industrial partners SACMI and ENGINSOFT to evaluate general skills of students/interns since 2009.

- creativity and ability to generate new ideas
- computer skills;
- knowledge of foreign languages, specially English

Moreover, in the last three years both ENGINSOFT and SACMI have completed a seminar/ internship evaluation form (Fig. 4) in order to assess the performance of students on those skills.

They have evaluated around 60 students per year and the results indicate a significant improvement in almost each item considered (Fig. 5). In particular, scholars show an outstanding and growing ability to use modern engineering tools/techniques and score

high in computer competences, while improvements need to be made in foreign languages and in the background necessary to perceive the impact of engineering solutions in a global/social contest.

Another satisfactory result related to the impact of the industry-academia collaboration is that among graduates experiencing an internship at SACMI and ENGINSOFT, several of them have been offered a full-time position, with an increasing trend (Fig. 6). In fact, while in 2009 just two of the six interns selected were hired, in 2011 not only the number of overall interns grew up to ten but also the vacancies offered raised up to six. This data is very

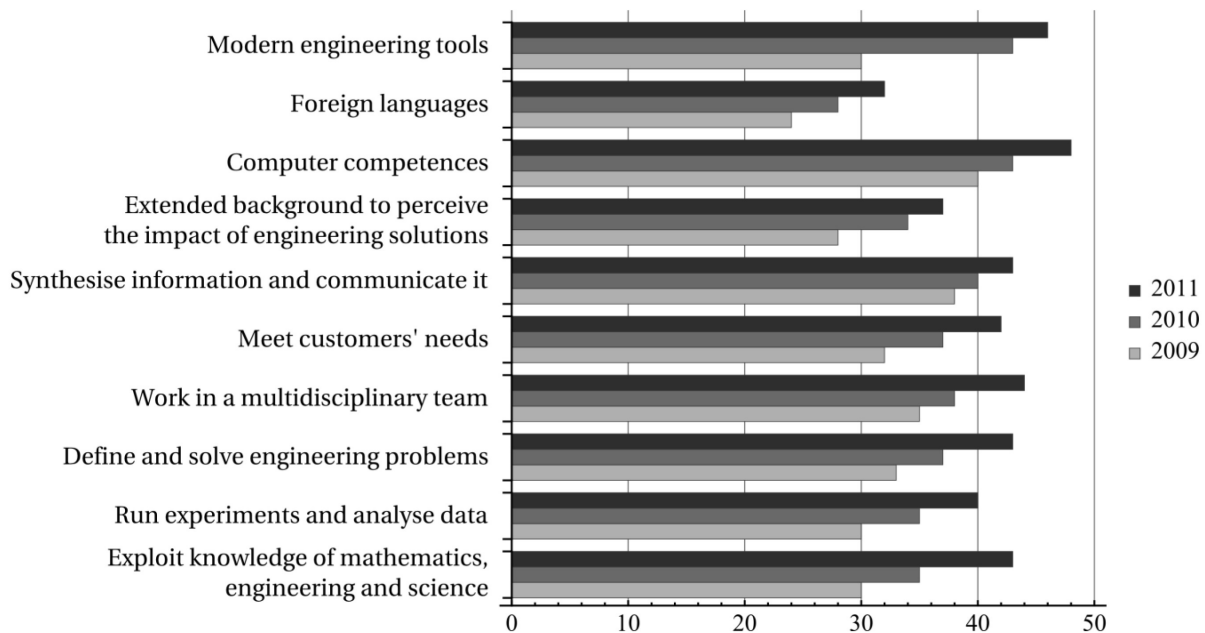


Fig. 5. Results of the questionnaire adopted by ENGINSOFT and SACMI in 2009, 2010 and 2011.

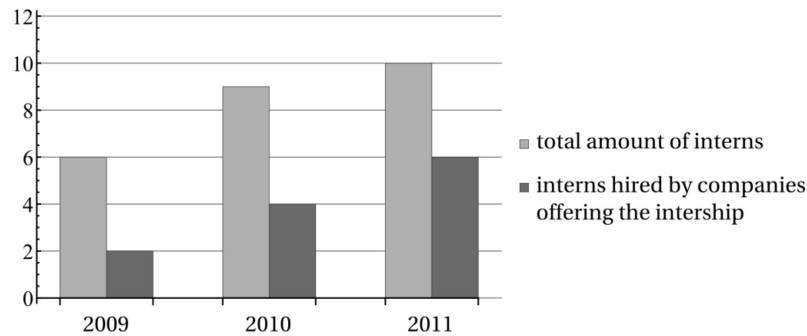


Fig. 6. Internships trend at SACMI and ENGINSOFT since 2009.

important both for businesses, which have at their disposal a pool of talented trainees eager to gain a “real world” perspective on a job, and for the university that strengthens in this way relations with the industrial sector.

4. Future issues

After careful consideration of the results of the questionnaire adopted by ENGINSOFT and SACMI in 2009–2011, in order to improve the weaknesses of students in skills such as: (i) extended background to perceive the impact of engineering solutions in a global/social context, (ii) knowledge of the English language and/or other foreign language, and (iii) ability to run experiments, analyse data, reach solutions, SSMG has decided to implement the following activities:

- yearly *Crash Course on Research Funding, Intellectual Property and Enterprise Creation*, with a particular focus on business planning for the development of new companies, entrepreneurship facilities, European law on state and non-state aid, labour market, spin-off and start-up, customers satisfaction and competitiveness, SWOT analysis;
- tutoring on programming and FEM analysis in the Computational Solid and Structural Mechanics Lab;
- experimental activities in the Lab for physical modelling of structures and photoelasticity;
- advanced courses on nonlinear elasticity, nonlinear solid mechanics, mathematical methods for engineering, coupled effects influencing the mechanics of solids, analysis of geometrically non-linear and tensile structures, finite elements in structural engineering;
- blended and intensive English-German-French-Spanish courses organised at the beginning of each semester;
- a growing number of seminars given by international invited scientists, together with the request

to write and expose papers/presentations/thesis in English.

Moreover, in order to give students the opportunity to further develop contacts with businesses and high-level scientists coming from all over the world, the INTERCER2 consortium, with the support of the Institute of Science and Technology for Ceramics (ISTEC-CNR), is going to organise the following international research events over the next three years:

- an International Congress on “Modelling and Simulation meet Innovation in Ceramics Technology” to be held in Trento on July 10–12, 2013. More than 100 external participants are expected and 15 of them will be funded by the INTERCER2 consortium: 5 invited speakers and 10 young researchers (on an equal opportunity basis);
- a three-days Mini-symposium on “*Optimizing the ceramic processing for industrial applications*” to be held in Imola (SACMI’s location) in 2015. Around 60 external participants from the industrial and academic sector are expected and 10 of them will be funded by the INTERCER2 consortium: 3 invited speakers and 7 young researchers. The event will be complemented by visits to research laboratories and production units of the INTERCER2 partners, and industrial exhibitions in the conference venue. During the mini-symposium, INTERCER2 researchers will present the main results on processing, performance, new high-tech developments of ceramic materials with emphasis on industrial applications.

The organising committee of both events will be composed by members of the INTERCER2 network and staff of the ISTEC-CNR, which is the only structure of the National Research Council of Italy (CNR) with long term activity programs on the whole range of ceramic materials [13]. The Scientific Committee will consist of international recognised scientists as well as representatives of the industrial sector. This multi-disciplinary composition has been decided after considering the high-apprecia-

tion expressed through the Evaluation Questionnaire reported in Table 1 on the contribution of industrial experts to the *Summer School on Computational Multiscale Fracture Mechanics*, the *IUTAM 2012 Symposium on Fracture Phenomena in Nature and Technology* and the *1st International Summer School on Smart Structures*.

5. Concluding remarks

The partnership described in details in this paper brings to the Solids and Structural Mechanics Group of the University of Trento the following benefits: (a) intensification of the research activities; (b) improvement of the international profile and strengthening of the research group through development of joint publications and organisation of congresses/workshops; (c) elaboration of a multidisciplinary research; (d) implementation of new training courses and enhancement of the existing ones to fully satisfy the demand of ceramic and related industries; (e) enhancement of the scientific knowledge and competitiveness of young researchers, especially in multidisciplinary research areas involving the engineering of production processes; (f) promotion of the Seventh Framework Programme of the European Commission; (g) increased attractiveness of the Engineering Faculty for both Italian and international students, eager to be in contact with a challenging industrial reality.

On the other hand, the expertise of SSMG in constitutive modelling of elastoplastic and porous materials brings to SACMI new technological and numerical methods to design presses and molds for ceramics production, and to ENGINSOFT new ideas for the development of software for structural applications and additional training of their researchers in advanced fields of mechanics and applied mathematics.

Moreover, this efficient industry-academia collaboration is greatly beneficial for the teaching-learning process in Tertiary Education. It helps to provide the high level of skills and research output required to keep up the pace of a changing industry and to avoid lagging behind international standards in terms of scientific performance by better preparing students for their future tasks. The promotion of

inter-sectoral mobility and the development of activities which enhance those skills necessary to fit business demand and efficiently supply firms' current needs are crucial for making Engineering Education a driver of productivity growth.

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