U.Porto Journal of Engineering, 7:1 (2021) 37-47
ISSN 2183-6493
DOI: 10.24840/2183-6493_007.001_0006

Received: 5 November, 2020
Accepted: 9 February, 2021
Published: 19 February, 2021

European Adhesive Bonder - A Targeted Training for Portuguese Professionals Harmonized with European Directives

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Abstract

Adhesive bonding is increasingly being used in industrial applications mainly due to its adaptability and ability to reliably join a wide range of materials. Numerous industrial sectors have now adopted adhesive bonding as a key manufacturing technology, with the automotive industry being the leader in adhesive usage. This is a key sector for the European Union (climate and energy policy, which has established a target of improving energy efficiency in the European Union by 20% by 2020. Consequently, this industry is constantly demanding lighter, stronger, more durable and more environmentally friendly materials. The increasing popularity of this technology is linked to the noteworthy benefits related with its application, compared to traditional joining process, such as welding or mechanical fastening process. With the increasing popularity of such joining techniques comes the necessity to train qualified professionals. The European Welding Federation developed a harmonized qualification system, which divides the training process into 3 levels: European Adhesive Bonder (EAB), Specialist (EAS) and Engineer (EAE). Currently, in Portugal, the first level of training, corresponding to European Adhesive Bonder is already in operation. The EAB level is accredited by the European Welding Federation (EWF) and therefore meets the requirements of EWF-515r1-10 and EWF-515r2-19 to which the Faculty of Engineering of the University of Porto is bound as a result of the accreditation as an ATB (Authorized Training Body). This training is targeted for professionals using adhesive bonding technology and professionals who do not currently use this technology but want to use it, and as such has a strong practical component. In Portugal, since 2016, three EWF certified editions have been held, with a high approval rate and met the expectations and objectives of the participants.

Author Keywords. Adhesive Bonding, Training, Harmonized Qualification System, European Adhesive Bonder.

Type: Research Article
Open Access Peer Reviewed CC BY

1. Introduction

The application of adhesive bonding and sealants was pushed by the aeronautical industry during World War 2, but its widespread application was only apparent after the recurrent use

of composite materials and the need to reduce the weight of structures, imposed mainly by the many regulations that apply to this industry worldwide (da Silva et al. 2012; da Silva, Öchsner, and Adams 2018; Banea and da Silva 2009; Banea et al. 2014). Nowadays, adhesive bonding technologies have a substantial implementation in many industrial entities, encompassing the aerospace, automotive, shipping and railway sectors (da Silva et al. 2011; da Silva et al. 2012). According to FEICA (Association of the European Adhesive Sealant Industry), the global market for adhesives and sealants reached a value of near 55 billion euros in 2018, in which Europe holds a 31% share (FEICA 2018). The increasing acceptance of this technology is correlated to the benefits associated with its usage, especially when compared to welding or mechanical fastening processes: lower heat input, prevention of contact corrosion and, perhaps the more relevant amongst these, the fact that adhesive joints leads to a more uniform stress distribution, high joint strength and can be used to join practically all types of materials or combination (Cognard 2006; Marques et al. 2021). Thus, in recent decades it can be observed that traditional bonding technologies are being replaced to adhesives (Messler 2013). Its usage is growing rapidly in Europe, as it embodies a strong competitive advantage for the companies and industries able to acquire the knowledge, competencies and techniques that are required to better leverage it. This is especially true as industries currently face a juncture where there is a growing need for EU businesses to become more competitive through talent and innovation. Unlike other bonding technologies, such as welding, where all welders must be trained as required by law, the same is not valid for the application of adhesives. To date, there is only a legal requirement for workers performing adhesive bonding in the railway industry. DIN 6701 is a comprehensive set of rules for quality assurance in the field of adhesive bonding in rail vehicle industry and its maintenance (Deutsches Institut für Normung 2015b). This standard dates back to 2000, when awareness to an increasing number of damage events led to additional control not only of adhesive bonding, but also of welding processes. DIN 6701 paved way to DIN 2304 considering quality requirements for bonding processes in all other sectors (Deutsches Institut für Normung 2015a, 2015b, 2016; Meiß 2016).

In a study carried out by the Adtech project (Co-funded by the Erasmus+ programme of the European Union), it was found that 90% of the failures that occur in adhesive joints are due to errors by professionals, so it is imperative that all personnel involved in the adhesive bonding process (bonder, specialist and engineer) have specific training for each step of the work being carried out, guaranteeing that any failures that may occur are not due to the lack of knowledge of the personnel involved in the project (Adtech 2015, 2016, 2017; European Federation for Welding 2015). In countries that already have significant industrial implementation of adhesive bonding processes there are several institutions where it is possible to obtain a qualification in adhesive technology. Portugal is following this trend and since 2016, there is a training course certified by the EWF that allows to obtain the bonder degree. EWF developed a harmonized qualification system, which divides the training process into 3 levels: European Adhesive Bonder (EAB), Specialist (EAS) and Engineer (EAE), that represent the foundation of the harmonized qualification system developed by EWF since its beginning in 1992 (European Federation for Welding 2010a, 2010b, 2010c, 2019). This training arises from the need to suppress the lack of training in this joining technology, essential due to its highly specific characteristics (Quintino, Fernandes, and Assunção 2013; Wacker et al. 2004). For the elaboration of the guidelines imposed by the EWF and later for the elaboration of the pedagogical methods of the course taught in Portugal, the Bonder profile was studied. The EAB should be a professional with industrial experience, capable of conducting a joining

process without supervision, i.e. consciously and autonomously (Adtech 2017). This professional must be able to interpret the working instructions and technical datasheets of the different adhesives and master all equipment necessary for the elaboration of a joint, being well informed about the production process concerning the adhesion technology. With the acquired knowledge, an EAB will be responsible for surface preparation of substrates, apply the adhesive and/or sealant and must have the necessary knowledge and critical spirit to identify possible non-conformities due to errors in the production process, according to Figure 1.

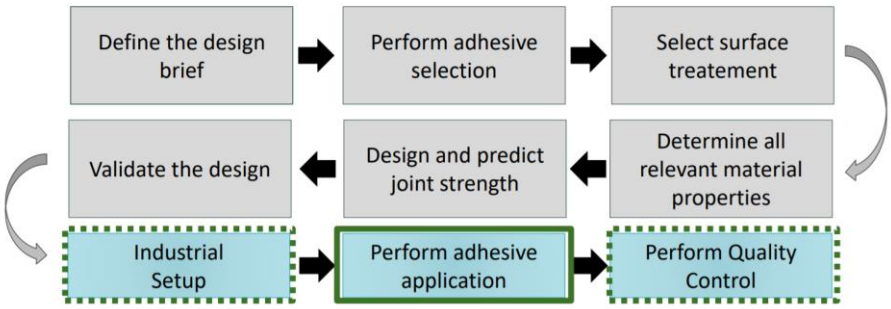

Figure 1: European Adhesive Bonder's (EAB) Role in Industry

2. Course Content and Schedule

A course, entitled "European Adhesive Bonder" was designed for professionals with reduced experience in the area of adhesive technologies or candidates simply interested in this topic. The European Welding Federation (EWF) accredited this course, therefore, in accordance with the requirements of the EWF-515r1-10[9] later replaced by EWF-515r2-19[12] guidelines to which the FEUP is bound as a result of the accreditation process as an ATB (Authorized Training Body). According to this guideline to have access to this training candidates must have a minimum age of 16 years and basic material processing skills.

The selection of candidates is be based on the evaluation of their Curriculum Vitae (CV). In the CV evaluation the candidates are evaluated and scored according to a set of parameters, on a scale with a maximum score of 20 points. Professional experience in the area of adhesives is the most valued parameter in the evaluation, being ranked between 0 and 9 points. The applicant's knowledge in the field of materials and particularly polymer/adhesives is scored between 0 and 5 points. If the candidate holds a technical workshop course in the areas of mechanics and related, he is awarded a score of 4 points. Finally, if the candidate has completed a course in engineering and is looking for specific training to deepen his knowledge in the area of adhesive bonding he will be awarded two points.

The course aimed to give professionals broad information on adhesive technology topics, and the course contents were tailored to fit a one-week schedule. The training begins with a period of theoretical classes, which is complemented with practical classes, where several important joint manufacture procedures are practiced by the participants. Until 2019, the EWF-515r1-10 guideline was in effect. However, in 2019, the EWF introduced a new guideline for EAB course where there are some changes that are shown in Table 1. So far, there have been no editions according to the new guidelines imposed by EWF. However, these changes should be reflected in future editions. A complete course content is shown in Table 1.

Component	*Program content*	*Duration (hours) EWF-515r1-10*	*Duration (hours) EWF-515r2-19*
Theoretical	Fundamentals of adhesives and adhesion	1	1
	Surface preparation before adhesive bonding	4	4
	The main families of adhesives and sealants	3	10
	Design and construction of adhesive joints	1	0.5
	Quality control of bonded structures	3	1
	Durability of adhesively bonded joints	1	0.5
	Benefits and limitations of adhesive bonding technology	2	1
	Health and safety	1	1
Practical	Practical Skills Training	18	15
Final exam	Theoretical Part	1	
	Practical Part	Minimum 15 minutes	
	Oral evaluation	4h45	
	Total	40	

Table 1: European Adhesive Bonder course schedule

From the analysis of Table 1, it is possible to verify that the theoretical part is divided into 8 modules. The first module of this course is "Fundamentals of adhesives and adhesion", where basic concepts should be introduced to help understanding the following modules. Trainees are expected to be able to understand the separate stages of the bonding process. The terms definition should comply with EN 923:2015, defining the vocabulary and terminology that should be used to adhesives, adhesive-bonded joints, adhesion tests and bonding (BSI 2016). In this module the different steps of the adhesive process and its description are presented. At the end of this module, trainees should be able to describe the stages of the bonding process.

The second module is dedicated to the study of Surface Preparation. This module aims to understand the purpose of surface treatments and establish the link with adhesion theories. Trainees will be able to classify materials as adherent according to their surface energy. This module employs didactic contents which detail the different stages of surface preparation according to the class of material being prepared (metals, polymers, composites, ceramics, etc...). Ways to evaluate the superficial state of the substrates are also discussed thoroughly. This module is accompanied by several practical examples, where the trainees carry out a select set of superficial preparations.

The study of the main families of adhesives and sealants is the focus of the third module. This module teaches adhesive classification methods, lists the existing adhesive families, adhesive storage procedures, adhesive selection procedures and some adhesive characterization techniques. As in the previous module, practical examples from different adhesive families will be provided. Trainees will be able to experiment with various forms of adhesives (film, liquid or paste) and how to apply them.

In the fourth module the Adhesive Joint Project is presented. The different loading modes, the types of existing joints, and how their design can be made from analytical methods and finite element methods are all be presented to the trainee. Although this module is intrinsically more theoretical than the previous ones, substantial effort is made so that the trainees can internalize these concepts more quickly. To this end, a tool developed by the Trainers of this course at the Faculty of Engineering of the University of Porto is used. The *JointDesigner* tries to automate and simplify the design process so that the engineer does not have to take the time to implement all the method's equations and retrieve the necessary charts and values

(Costa, da Silva, and Campilho 2013). Although this is not a free to use application, the trainees are able to use it freely in the context of the course.

Quality control is the theme of the fifth module of this course. Different ways of controlling the various stages of the manufacturing process of a joint up to the final product are presented. Initial discussion is devoted to tests suitable to attest the quality of the surface preparation (wettability, roughness, chemical composition). However, the quality of the joint also depends strongly on the properties of the adhesives, so tests of viscosity and chemical composition are also presented. Finally, this module discusses methodologies to assess the behaviour of a joint, using both destructive and non-destructive approaches.

The sixth module concerns the environmental degradation of adhesive joints. The behaviour and durability of an adhesive joint will vary with the exposures it is subjected to during its life cycle. The factors that can influence adhesive and adhesive joint performance are presented: temperature, humidity, fatigue, impact and vibrations.

The seventh module, on the benefits and limitations of adhesive bonding technology, summarizes concepts previously taught and illustrates how they affect practical implementation processes. The objective of this module is to make sure that the trainee understands the benefits and limitations of using adhesive joints. These benefits and limitations are presented using industrial applications where bonding technology is compared with other bonding techniques.

The eighth and final module of the practical component, health and safety in the use of adhesives, precedes the practical component of this course. Trainees will be informed of the health and safety hazards related to the use of adhesives and associated manufacturing processes, including techniques to minimize them. Hygiene and safety related to surface preparation, application and curing and environmental protection aspects, including waste disposal rules and regulations, are also be addressed.

In the practical component of the course, several procedures used to manufacture adhesively bonded joints are approached. With knowledge of these procedures, the trainees will be able to use their theoretical knowledge and produce an effective adhesive joint. This includes steps such as the correct selection of the adhesive, surface preparation, and the evaluation of the joint using destructive and non-destructive tests. According to EWF-515r2-19[12], practical skills training should be divided into four components, as it can be observed in Table 2. A complementary review of knowledge is made in the practical component, in preparation for the final examination.

At the end of this course, it is expected that candidates who obtain a positive assessment will be able to:

- Understand the different stages of the adhesion process.
- Understand and propose the different surface treatments and their connection with adhesion theories.
- Understand and describe the different types of adhesives, their processing requirements and storage restrictions.
- Understand and describe the use of quality control techniques applied to bonded structures.
- Understand the influence of environmental factors on adhesive joints.
- Understand the benefits and limitations of using adhesive joints.
- Understand the health and safety hazards related to adhesives and associated manufacturing processes, including techniques to minimize them.

- Manufacture adhesive joints without supervision.
- Read and understand work instructions and be informed about production methods related to bonded products and components.

Surface treatment of substrates	The trainees are expected to experience the main methods of surface treatment, on different types of substrates (polymers, metals). The trainees should understand the influence of the treatment and non-compliance of the procedures on the final quality of the joint.
Health and safety	Health and safety considerations should be made in the handling of adhesives and equipment necessary for the production of adhesive joints, storage conditions and understanding the importance of environmental conditions (temperature control, humidity and cleaning).
Use of different adhesives	In the practical component, instructions should be given on how to handle adhesives (storage conditions, opening pot, mixing of the components), they should have knowledge and experience how to apply different adhesives (manually or semi-automatically) The trainees should perform several tests in order to understand the influence of the joint production parameters (curing and calibration process).
Quality control of joints/testing	The trainees must have practical experience of different methods of joint quality control, in their different stages of the process. Destructive and non-destructive tests will be presented.

Table 2: Practical Skill Training

3. Exams

At the end of the course, an examination takes place, consisting of written, oral and practical components. This exam has a total duration of 6 hours. The final theoretical examination papers are of multi-choice or essay nature and are elaborated under the authority of the Board of Examiners of the ANB, sealed, and opened in the presence of the candidates and Authorised Examiner immediately before the examination begins, according to EWF-515r1-10 and EWF-515r2-19 (European Federation for Welding 2010a, 2019). The final exam for all the EAB editions were performed in Faculdade de Engenharia da Universidade do Porto facilities, since is a test centre approved by the ANB in accordance with the requirements of the EWF guidelines. The team of examiners, presented for this course, is composed of three elements:

- Team leader, who should be a representative of the ANB, being independent of the course.
- The head trainer of the EAB course.
- An expert in industrial applications of adhesive technology.

Admission to the final exam is restricted to trainees who attend at least 90% of the course. To pass the final exam, trainees must obtain a minimum score of 60% in each component of the exam.

The final mark obtained will be determined as follows in Equation (1):

$$0.3 * \text{Written Component} + 0.3 * \text{Oral Component} + 0.4 * \text{Practice Component} \quad (1)$$

Trainees may request a review of the exam or component of the exam no later than four weeks after the date of release of ratings. The result of this review must be reported no later than two weeks after the request.

If the student still does not obtain the minimum classification required for approval, he or she may request a new examination (or component of the examination). This new exam can be requested up to two times and must be taken no later than 15 months after the exam in which it failed. If the candidate does not take part in the re-examination within 15 months, in any of the exams, they must retake the whole course.

According to EWF Guidelines, a Diploma is awarded to the trainee by the ANB (ISQ in Portugal) after a successful examination. Those qualified as "European Adhesive Bonder" may be called European Adhesive Bonder in the national language (Técnico Europeu de Adesivos) and use the professional designation "EAB" (unchangeable in all member countries).

4. Student Outcome and Discussion

The EAB course, began in Portugal in 2016, has already had three editions, with a total of 26 trainees. Using the data provided by the trainees, an analysis was performed, correlating age, gender, education and work position with the results obtained in the exam. An index of student satisfaction was also made using an anonymous questionnaire.

The education of the trainees was divided into three academic degrees: basic, secondary and higher education. In Portugal, compulsory education was only extended to secondary education in 2009. According to the data provided by the trainees, 19% of trainees only completed basic schooling. Taking into account the target community of this training it would be expected that more candidates will present this level of schooling. However this was not found to be entirely the case, as the course is relatively recent in Portugal and standards that require the certification of bonders were not yet in force (with the exception of the railway industry, which does not have much expression in Portugal compared to other member countries). Before 2016, bonders that were subject to compulsory EWF certification resorted to training in other European Union countries. It was observed that the majority of the trainees have a higher level of education. This leads to the conclusion that in fact, middle management posts are obtaining this training, driven not by legal obligation, but instead to acquire knowledge in a new and critical area for certain industrial sectors in Portugal. Currently there are still few engineering courses that include Adhesion Technology in their study plans, which justifies the search for new information by this particular group. The average age of trainees was 34 years. The youngest and oldest trainees were 23 and 52 years old respectively. This leads to the conclusion that even trainees with a higher education degree did not have access to this content during their academic background.

It was observed that the trainees were mostly male (69.2%), In fact, the first session of the course the class was exclusively composed of men, but this trend has been gradually reversed, as 12.5% of the participants in the second session were female, a figure which increased to 33.3% in the third session. These results are in line with what is observed in academic institutions and industry. Employment in areas associated with metalworking is still mostly associated with men, but in the last decade there has been a change in this situation. It is observed, mainly in academic institutions that there has been an increasing interest of the female population for higher education courses related to metalworking, which is an excellent barometer to assess the number of women present in this type of industry. Currently, there are approximately 30% of women in engineering courses associated to this area, a trend which is patent in the EAB courses (Universidade do Porto 2019).

Most trainees are of Portuguese nationality. It was observed that 15.4% of the trainees were of Brazilian nationality. This does not mean that Brazilian trainees came to Portugal in order to attend this course, but rather they are a reflection of Brazilian immigration in Portugal. In 2019, according to SEF (Portuguese Foreign Service and borders) there were around 151,000 Brazilians residents in Portugal.

The analysis of the data showed that 11.5% of the trainees needed to repeat the theoretical examination, since they did not reach a classification of more than 60% in this component. After repeating the exams, all these trainees eventually obtained a positive classification and are thus certified by the EWF as Bonders, which leads to an approval rate of 100%. It should be noted that the trainees who needed to repeat the theoretical component had still had quite satisfactory results in the remaining components (oral and practical). This shows that these trainees have a high level of practical skills and often are technicians who perform these activities in their daily work environment. This result was directly related to the level of education of the trainees, it was observed that all trainees who repeated the exam have just the basic level of education. The workload of this course is quite condensed. During six consecutive days (8h daily) trainees have access to the didactic content, and on the seventh day they take the final exam, which limits the time available for the trainees to the study of content. For this reason, trainees are prepared during the course, which includes knowledge revisions before the exam. For most trainees this practice is sufficient. However, it is noted that for trainees with a basic level of education this effort should be reinforced, since they have unlearned habits of study and the assimilation of knowledge is done by different mechanisms compared to trainees who have a higher education level. Thus, since the EAB course intends to form bonders, an additional effort should be made to follow the educational standards of trainees with a lower level of education.

At the end of each edition, the trainees were given a satisfaction survey regarding various aspects of the course, such as the content, the pedagogical aspects and the support documentation provided. In order to summarise the results of this survey, a discussion is made only on the overall assessment of the trainees' expectations regarding the course and whether the training objectives have been achieved. Trainees were invited to complete this questionnaire anonymously, rating different aspects on a scale of 1 to 4, where 1 is very unsatisfied and 4 is very satisfied. Looking at the data from the three editions, it is seen that on average the trainees had a high degree of satisfaction regarding the expectations (3.7) and objectives (3.7). In Figure 2 it is possible to observe the evolution of the degree of satisfaction of the trainees throughout the three editions. Since the first session, the surveys have been a valuable tool in improving the teaching content, pedagogies used and the documentation provided. As previously indicated, the typical trainee corresponds to a middle management position and this course is dedicated to the training of bonders, which may raise some questions about the expectations of the trainees. It was also observed that some trainees expected to find in the training the solution to very specific problems of their area of intervention in industry, which in most cases is not in line with the more general EWF guidelines for EAB courses. It was observed that most of the trainees who enrolled in these editions, due to their academic degree and position in the workplace, were qualified for a training course with a higher knowledge character, such as Specialist (EAS) and Engineer (EAE). However, in Portugal these courses are not yet available.

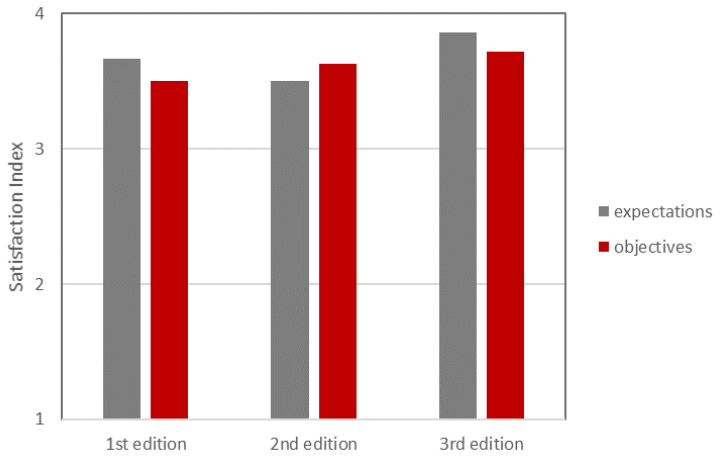

Figure 2: Degree of satisfaction of the Bonder course participants

5. Adhesive Bonding Technology in Europe

In Portugal, the EAB course was first held in 2016, followed by two additional editions. Table 3 shows the number of diplomas given by the EWF between 2015 and 2017. During this period, the project to harmonise training in adhesive technologies (AdTech) was underway. Analysing this table, it is evident that the situation in Portugal does not reflect the rest of the EU. For example, in Germany this course has been taught since 1994 and has trained more than 7,000 Bonders. These discrepancies are mainly based on market needs (European Federation for Welding 2015).

Country	EWF Diplomas
Austria	155
Czech Republic	187
France	89
Germany	4505
Italy	201
Netherlands	93
Poland	146
Portugal	14
Spain	255
Total	5645

Table 3: Number of diplomas awarded by the EWF members, between 2015-2017, per country

In countries with a highly developed automotive, aeronautical and railroad industries the need for qualified professionals is higher and constant. It should be noted that the rail industry legally requires qualified professionals, and that a greater number of bonders are trained in countries where this industry is most prevalent. In Portugal, where the first bonders are being trained, companies are betting on the training of middle managers who will transfer knowledge to the jobs hierarchically below. This technology is not yet fully disseminated in Portugal, so this technical training follows its development. It is projected that in the next few years its demand will increase, which will lead to more trainees, especially those with a more technical profile, which better suits Bonder's profile.

6. Conclusion

The indicators of the three editions of the Bonder course held in Portugal were analysed. The following conclusions can be drawn:

- The three sessions taught in Portugal were certified by the EWF, are in accordance with the prevailing guidelines.
- The course had high approval rates and met most of the expectations and objectives set for this training.
- The population sample of this training follows labour market trends. Most of them are male, with higher education level, aged 30-35 and hold middle management positions in an industrial environment.
- The EAB have a critical spirit regarding the manufacture process of adhesive joints and at the end of the training were found to be more capable and with the adequate knowledge to perform their tasks.

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