EDUCATION OF INDUSTRIAL USERS OF LASER MATERIALS PROCESSING TECHNOLOGY

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Abstract

The extensive use of high power laser for materials processing in industry has brought a new era in manufacturing technology. High speed processing with low heat input and high precision offers up-to-date manufacturing. New processes like laser hybrid welding are developed and introduced in industry. But the potential of laser technology is not by far fully utilised due to lack of knowledge of laser processes in the industrial environment.

The national Swedish programme, “proDesign – Expert competence in industrial product development and materials processing”, offers new opportunities of providing education for industrial managers, designers and manufacturing people. Within the scope of proDesign, Luleå University of Technology has developed several new courses in laser material processing for people in industry. These courses have now successfully been introduced to the Swedish market and this paper presents experiences from this work.

Keywords: laser, education, materials processing, welding, cutting

1 Introduction

Laser material processing has been used in Swedish industry since 1977 when the first industrial cutting machine was installed in a job shop. We now estimate the number of high power CO₂-lasers used in industry and R&D to be more than 500. The number of Nd:YAG-lasers are significant, but not as high as for CO₂-lasers. Cutting and marking are the main laser applications used in Swedish industry, but laser welding has gained considerable interest in recent years. Laser hybrid welding is, for many industries, the most interesting joining method today.

Education in laser material processing technologies in Sweden is mainly done by Luleå University of Technology, (LTU) which has offered qualified courses for Master of Science and PhD students for the last 25 years. Special courses on specific topics have also been given to industry from time to time. But until recently, there have been no organised activities at LTU to educate industrial laser users in laser material processing.

The Swedish Association of Laser Applications in Manufacturing Industry, (the Swedish Laser Group), laser systems supplier and suppliers of components and consumables
such as optics, gas etc. communicate knowledge about laser technology to their customers which also is a part of the education given to industrial users.

Of course the need for relevant education for industrial users is profound. The investment in laser systems can be significant and engineers, technicians and operators must have an in-depth knowledge of the whole area of the laser technology to be able to run the systems in the most efficient way to insure a good return on the large amounts of invested capital. Laser technology itself is very complicated both from the system point of view but also from the process perspective. Laser material processing is also a unique, new technology with special characteristics which may not be familiar to industrial users.

2 proDesign – an education programme for manufacturing industry in Sweden

In 2002, the Knowledge Foundation in Sweden launched a 5-year programme named “proDesign” directed specifically towards the Swedish manufacturing industry. The objective of proDesign was to give Swedish companies new knowledge to help them develop their products and processes. proDesign funds development of market lead short courses in specific technologies and techniques related to design, manufacturing technology and manufacturing management. LTU is one of a consortium of seven universities and institutes who runs the programme. At LTU, the Division of Manufacturing Systems Engineering is responsible for the programme. As laser material processing is the main activity at the division, it was natural to developing laser courses. At the same time discussions had started within the Swedish Welding Commission’s working group “Laser Material Processing” to develop an EWF- (The European Federation for Welding, Joining and Cutting) special course on laser welding. So by a (lucky) coincidence there was an interest from the market and funding available for course development at the same time.

3 Industrial courses in laser welding and cutting

Laser welding involves very complex phenomena during the interaction of the laser beam with matter. Absorption, plasma formation, heat transfer, melting, vaporisation and stirring of the melt pool take place simultaneously in the interaction zone and all influences the welding results. Parameters linked to the laser system such as wavelength, divergence, beam diameter and focusing optics will influence the result. In addition, the physical and chemical properties of the material and the mechanical factors such as edge preparation, clamping and positioning accuracy make a significant contribution to the quality of the result. Table 1 summarises the most important parameters involved in laser welding [1, 2, 3].

It is obvious that this complex process requires substantial theoretical knowledge from welding engineers and operators in order to understand and control the welding process. In addition it is also obvious that successful laser welding requires a lot of practical experience from welding in different situations. This knowledge is not obtained by any “quick course”.
### Table 1. Important parameters in laser welding

<table>
<thead>
<tr>
<th>Laser</th>
<th>Beam path</th>
<th>Focussing</th>
<th>Material properties</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>Distance laser - working area</td>
<td>Type of optics, f-value</td>
<td>Composition</td>
<td>Shielding gas, type, flow rate, direction</td>
</tr>
<tr>
<td>Divergence</td>
<td>Mirrors, type, coatings</td>
<td>Focal length, Depth of focus</td>
<td>Absorption</td>
<td>Joint configuration</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>Fibre optics type, diameter</td>
<td></td>
<td>Heat conductivity</td>
<td>Clamping</td>
</tr>
<tr>
<td>Intensity distribution</td>
<td></td>
<td>Beam diameter, spot size</td>
<td>Melt temperature</td>
<td>Edge preparation</td>
</tr>
<tr>
<td>Pulsing or cw</td>
<td></td>
<td>Focal point position</td>
<td>Melt viscosity</td>
<td>Welding speed</td>
</tr>
<tr>
<td>Pulse parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### 3.1 EWF special course in laser welding

The European Federation for Welding, Joining and Cutting (EWF) has developed guidelines, for special courses in laser welding. The guidelines [4] define the minimum requirements for the education, training, and examination for engineer, technologist and specialists to provide the basic core education in laser welding technology for laser welding personnel in many different job functions.

### Table 2. Guidelines for EWF Special Course in Laser Welding

<table>
<thead>
<tr>
<th>Module</th>
<th>Numbers of hours of education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineer</td>
<td>Technologist</td>
</tr>
<tr>
<td><strong>Theoretical education</strong></td>
<td></td>
</tr>
<tr>
<td>1. Laser welding process and equipment</td>
<td>13</td>
</tr>
<tr>
<td>2. Materials and their behaviour during welding</td>
<td>14</td>
</tr>
<tr>
<td>3. Construction and design</td>
<td>4</td>
</tr>
<tr>
<td>4. Fabrication, application engineering</td>
<td>14</td>
</tr>
<tr>
<td><strong>Practical education</strong></td>
<td></td>
</tr>
<tr>
<td>5. Fundamental practical skills</td>
<td>15</td>
</tr>
<tr>
<td>6. Preparation of reports</td>
<td>12</td>
</tr>
<tr>
<td><strong>Examination</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>75</td>
</tr>
</tbody>
</table>
Each of these modules is described in detail in the guidelines, but it is not obligatory to follow exactly the order of the topics and choice of the arrangement of the syllabus is permitted. All students, engineers, technologists or specialists have access to this course. It is recommended to have a corresponding specialisation of European Welding Engineer, European Welding Technologist or European Welding Specialist or similar experience.

Using this guideline, a Swedish version of the engineer level was developed. An important consideration for the successes of the planned course was to make it possible for employees from industry to attend the course, without unduly disturbing their ordinary work. It was unlikely that delegates would be able to leave their work for two weeks to attend the course. For this reason, the course was divided into three separate parts, maintaining the modular structure presented in Table 2. The three parts were separated by approximately four to six weeks, giving a total scheduled time for the course of approximately three months. This arrangement also provided time for the attendees to prepare for the next session and to write up laboratory reports and home work in order to fulfil the EWF requirements. Each of the three parts contained a mixture of theory and practical work designed to enhance the learning effect.

The examiner is the Swedish Welding Commission, which has formally appointed an examiner to represent the Commission in the examination committee.

The practical work was carried out in the laser laboratory at Luleå University of Technology using 6 kW CO₂- and 3 kW Nd:YAG-lasers.

![Attendees at the EWF special course in laser welding at Luleå University of Technology.](image)

Figure 1. Attendees at the EWF special course in laser welding at Luleå University of Technology.

Until now (April 2005) two courses have successfully been completed. In the first, one attendee did not pass the examination the first time but made it in the second try. In the second course, 33% of the attendees failed in the first examination but they will make a second test and hopefully pass the course. A new course is planned for 2006.

### 3.2 Laser Welding Course for Operators

The EWF Special Course in Laser Welding is a fairly advanced course giving in-depth theoretical and practical knowledge of the complex processes involved in laser welding. This level was felt to be too advanced for operators, who have recently become involved or are planned to be involved in laser welding. For this category of people LTU developed a “Laser Welding Course for Operators” within the framework of proDesign.
This two-day course (16 hours) combines theory and practical training to give the attendees basic knowledge about laser welding. The theory covers laser physics, the properties of laser light, optics, safety considerations and the laser welding process. In the practical, work the attendees learn how to operate the laser welding equipment, measure of power and focal point position using a laser beam analyser and experience the correlation between power and welding speed, weld depth and welding speed and the influence of the shielding gas. Different weld configurations are produced and tested for strength.

3.3 Laser Hybrid Welding Course

Research and development on laser hybrid welding has been carried out at LTU for a number of years in cooperation with Swedish industry. In response to the substantial interest from the industry in this new welding technology, LTU has developed a three-day course to give basic knowledge of this technology. The theory of laser hybrid welding is introduced day one, followed by practical work day two and three, using a 6 kW CO₂-laser and a 3 kW Nd:YAG-laser.

![Laser Hybrid Welding](image)

The laser hybrid welding course is suitable for welding engineers, welding technicians, manufacturing engineers and designers looking for a basic knowledge in this welding process. The course will give them the skills to work on laser hybrid welding projects and evaluate new welding applications.

3.4 Workshop on Laser Cutting

Laser cutting is by far the most commonly used laser process in Sweden. It is estimated that approximately 90% of the 500 high power CO₂-lasers used in industry and R&D are used for cutting. The hundreds of operators using the laser cutting equipment obtain their main knowledge through practical work using the machines and to some extent through training offered by the system suppliers, which usually focuses on machine handling, programming and maintenance and not on the laser cutting process. Contact with laser operators in industry has indicated that this is a problem, as they do not have the necessary technical knowledge to optimise cutting parameters to achieve optimum productivity. Instead they have to rely on the tables of cutting parameters provided by the machine suppliers complemented by their own experience. This is not a desirable situation as operators in many companies in Sweden are expected to continuously improve the efficiency in the processes they are responsible for.

A two-day course in laser cutting for laser operators was developed, using funding from proDesign. The aim of the course was to give both theoretical and practical knowledge to
operators. The theory covered lasers physics, beam propagation and focussing, laser optics, the cutting process, cutting parameters, materials properties important for the cutting result and laser safety. The practical training covered handling of the optical focusing system (alignment, focal point position etc) and the influence of cutting parameters on the cutting result.

![Figure 3.](image)

Figure 3. *Practical training of laser cutting in small groups in the laser laboratory of Luleå University of Technology*

Both CO₂- and Nd:YAG-lasers are used in the practical training which is done in the laser laboratory at Luleå University of Technology.

### 4. e-learning in laboratory training

Laboratory training is of great importance in manufacturing education. As laboratory equipment is very expensive, university and other training facilities can only offer limited equipment, and thus the scope of the training may be limited and dependent on the regionally available facilities. The equipment available at each training site can be complementary. Today access to other laboratories with complementary equipment requires travelling, which is expensive and time-consuming, and consequently usually not possible.

The EU-funded CyberLab-project aims to provide easy virtual access to any laboratory equipment by developing a method for distance laboratory training. The challenge for the project is to realise distance laboratory training using videoconferencing that matches the learning effect achieved by traditional laboratory training. This is difficult since laboratory training is highly complex and interactive in nature, involving teamwork, discussions, visual observation of laboratory equipment and experiments, changing of the experimental set-up and parameters, handling of test equipment, microscopes and measuring devices etc. In CyberLab it is essential to identify the important ergonomic and pedagogic aspects of laboratory training and to try optimally realizing them on an interactive videoconferencing level.

Different complementary methods will be developed and evaluated in parallel, e.g. remote manipulation of a microscope, controlling remote cameras, verbal communication between trainees and trainer or operator, etc., figure 4. A pilot course shall demonstrate the applicability of the developed methods.
The vision is that the partners and other training organisations can share complementary laboratory equipment by offering common distance courses for trainees from all over Europe. Thus extending the traditional local training and improving the quality of practical skills.

The project involves partners from five countries; six universities and research institutes, five other manufacturing laboratory facilities and one medical laboratory, all with different videoconferencing expertise. In addition, four relevant industrial partners, both SME’s and large industry, will use and evaluate the applicability of the methods developed throughout the project.

A laser course, “Laser Welding using Seam Tracking” will be developed within CyberLab and it is expected to be ready for testing in 2006. The success of CyberLab will significantly improve the possibilities in practical laser training for people working in industry. Substantial savings in travelling time and cost will be achieved, thus facilitating laser education in all industrial level and areas.

5 Conclusions

Laser materials processing is an advanced and highly productive manufacturing technology. To fully utilise the large investments costs and potential, it is important to educate people working with the technology at different levels in industry. Several laser courses for industry have been developed and given by Luleå University of Technology. In the near future, modern communication techniques will make it possible for training organisations to share complementary laboratory equipment by offering common distance courses to trainees from all over Europe. Substantial savings in travelling time and cost will be achieved, thus facilitating laser education in all industrial level and areas.
6 Acknowledgements

We gratefully acknowledge the financial support from the Knowledge Foundation in Sweden for developing the laser courses for industry within the programme proDesign.

7 References


4. EWF Document 494-01, 1999