INTERNATIONAL INSTITUTE OF WELDING
A world of joining experience

65th Annual Assembly of IIW
Denver, Colorado, USA
8-13 July 2012

Minutes of Commission IV Meeting – Power Beam Processes

Vice Chair: Herbert Staufer (Austria)* Chair Jens Kristensen was unable to attend.
Vice Chair Staufer served as Acting Chair for this Assembly

Secretary: Patrick Hochanadel (USA)

Location: Colorado Convention Center, Denver, Colorado, USA
Dates: 9-11 July 2012

Attendance: Twenty-four (24) countries participated in Commission IV activities.
59 Attendees on 9th July
122 Attendees on 10th July
73 Attendees on 11th July

Australia	Austria	Brazil	Canada
China	Denmark	Finland	France
Germany	India	Italy	Japan
Korea	Netherlands	Portugal	Slovakia
Slovenia	South Africa	Spain	Sweden
Turkey	Ukraine	United Kingdom	United States

Monday 9 July 2012: Commission IV Meeting:

Room: CCC Room 203

14:00-18:00

1. **Opening of the Meeting**
   Vice Chair Herbert Staufer opened the meeting and welcomed delegates and experts to the 65th IIW Annual Assembly.

2. **Appointment of Secretary**
   Patrick Hochanadel, United States Delegate for Commission IV, was appointed secretary.

3. **Apologies for Absence**
   Vice Chair Staufer reported on apologies that were received from the following Delegates:
   - B. Yudodibroto – The Netherlands
   - A. B. Kaplan –Sweden
   - F. Vollertsen - Germany

4. **Adoption of Agenda (Doc. IV-1073-12)**
   The C-IV 2011 agenda (Doc. IV-1073-12) was approved by delegates.

5. **Approval of the minutes of the Commission IV Meeting at the 64th Annual Assembly in Chennai, India (Doc. IV-1067-11)**
   The minutes from 64th Annual Assembly in Chennai, India (Doc. IV-1067-11) were approved as written.

6. **News from the Chairmanship**

   Chair Jens Kristensen sends his regrets and is not able to make this meeting. He has recently retired. Vice Chair Staufer took the role of Chairman for this meeting. Rights of the delegates, experts and observers were presented.

7. **Commission Organization and Chairmanship in the Future**

   Vice Chair Staufer presented possible organization of Commission IV. The subject of two Vice Chairs *versus* three subcommisions was briefly discussed. The three subcommissions were Laser Beam Welding, Electron Beam Welding and Laser Hybrid Welding.

8. **Brief Report from the Intermediate Meeting in Berlin, Germany, April 2012**

Vice Chair Staufer discussed the Intermediate Meeting. Thirteen papers were presented and nine countries were represented in this meeting. A visit to BAM was part of the meeting. Commission IV Chair Kristensen closed the meeting.

9. **Brief report from the 2nd International Electron Beam Welding Conference in Aachen, March 2012**

A report was given by Former Chair E. Levert. The conference was held over three days. Eighty-two attendees from thirteen countries were in attendance. Thirty-five papers were given. The next electron beam welding conference is tentatively planned in 2015 in conjunction with the AWS Welding Show in Chicago, Il, USA.

Mr. Levert showed a NASA video of a flyover of the International Space station and discussed electron beam welding guns used in space.

10. **Discussion of IIW Business Plan Updates**

The general discussion of the business plan was deferred until the end of the meeting.

11.0 **Presentations**

Chaired by Mr. Ernest Levert, Former Chair of Commission IV

(Presenters are Underlined)

11.1 IV-1074-12

Quality Control by an Innovative Measurement System for Electron Beam Welding

by Uwe Reisgen[1)], S. Olschok[1)], J. deVries[1)], A. Backhaus[1)], S. Ufer[1)] , S. Tiedke[2)], T. Schmitz-Kempen[2)], B. Reichenberg[2)], E. Drichel[2)], 1):Welding and Joining Institute, RWTH Aachen University and 2) aixACCT GmbH (Germany)

The presentation discussed electron beam welding diagnostics and the measurements tools. The trade names for the diagnostic tools are *diaBeam and diaBeam II* . An overview of beam diagnostics in electron beam welding was first given, including the need for beam diagnostics. Various measurement principles were presented. Some examples of earlier diagnostic tools include the Arata test, the dual edge test, the slit aperture test, the moving wire test and an indirect measurement with back scattered electrons. Diagnostic outputs include power densities , beam diameters, beam caustic/beam aperture measurements, beam emitttance, beam astigmatism, and beam alignment. The *diaBeam* device in use at Aachen was discussed. It was stated that the beam power could be up to 15kW for repeatable/reproducible measurements with this tool. The tool is a combined slit/hole aperture system. The new diagnostic tool – the *diaBeam II* , is a slit/hole aperture tool, in which two slits in the earlier design were replaced by two circulars.

This tool is able to diagnose beams with or without fast beam deflection. The software is a user-friendly application to help the operator. The circular slit enables automatic adjustment by measurement of the signal shift. Power density measurements and power distribution possible with this tool. The beam caustic may be surveyed to arrive at the focus. The tool may be either permanent or temporary within the electron beam welding system. No questions were asked to the secretary's knowledge. The paper was not recommended for consideration to be published in *Welding in the World.*

11.2 IV-1083-12

Deposition Welding with Electron Beam Technology as Repair Technology (Basic Investigation and Industrial Application)

by Thomas Krüssel and Andreas Richter – Braunschweig, Germany (Germany)

Electron beam deposition (wire-fed) was introduced first. This is a free-form fabrication technique which uses weld repair methodology. The goal is to regenerate the components after use/wear. New components take long times to manufacture and are quite expensive. Defects are locally repaired and filler metals may be selected to tailor properties. The machines were all pro-Beam machines. The weld wire used included both solid and metal flux core wires. Minimal dilution was desired to obtain the properties needed. The electron beam deposition process optimization was discussed as well. Steel and aluminum cross-sections were shown with minimal dilution and few weld anomalies. Manufacturing was done on a test part , which was a roller shaft (shaft-to-shaft). Questions: A questions was asked about beam oscillation. The reply stated that it was used in this process. A question was asked about spot size of the electron beam. The presenter was unsure. A question was asked about the deposition rate. The presenter stated that it was unoptimized at 4-5 kg/hour, although higher rates should be possible. A question was asked about why they used flux-core wire. The presenter stated that the customer requested it and it allowed for composition changes. The final question was regarding the advantage of the electron beam process compared to laser beam deposition. The presenter stated that the efficiency of the process was higher than laser deposition processes. The paper was not recommended for consideration to be published in *Welding in the World.*

11.3 IV-1082-12.

Oxygen Content in Weld Metal Resulting from Arc Welding Processes as Repair Technology on Cast Iron Components and Its Influence on Electron Beam Welding of Gas Turbine Casings

by Thomas Krüssel and Wilfried Storch – Braunschweig, Germany (Germany)

This talk was to help in understanding the issues with large-volume casting components which need to be joined. High penetration (>50mm) welds were needed; as such high power EBW was used. A gas turbine casing was shown as an example. The casings need to be modified and re-welded. A large chamber electron beam welder from pro-Beam was used. The chamber size of the machine is 6.9mx6.9mx12m. Casting defects such as pores or shrinkage voids were found to interact with the beam during welding. The interaction of the defects with the electron beam was found to cause large weld defects. Mild steel blocks coated with Fluxofil 25 welded by MAG resulted in gross porosity in the weld. Sievers reported on a similar problem in which the issue was tied to oxygen content and surface tension flow. A reference standard was welded to ensure that the machine was not the cause of issues – it was found that the welder was not the problem. The resulting porosity was found to be wormhole porosity. The measured oxygen content was found to be much higher than the reference material (285 ppm *vs.* 16 ppm). Questions: No questions were asked. The paper was recommended for consideration to be published in *Welding in the World.*

Coffee Break – 16:00

Session Chair – United States Delegate P. Hochanadel

11.4 IV-1085-12

Non-Vacuum Electron Beam Cutting and Welding – Two Partnering Processes for Fast and Highly Efficient Metal Working

by T. Hassel, N. Murray, R. Konya, A. Beniyash and Fr.-W. Bach – Hannover, Germany (Germany)

An introduction to non-vacuum electron beam cutting and welding was given. The equipment was a PTR-built 175kV/140mA system. A schematic drawing of the welder was shown. The "spread beam" photo was shown to illustrate the effect of working distance on weld penetration. Larger gap tolerances are acceptable for non-vacuum electron beam welding (NVEBW). Cutting principles for non-vacuum electron beam cutting (NVEBC) were shown. Like other thermal cutting processes, a gas jet is used in NVEBC to remove the molten material. Argon was the gas used. Nitrogen, air and oxygen (oxy-cutting) were also used. The gas nozzle was placed at an angle. Cutting speeds were on the order of 10 m/min, and the beam power was 21 kW. These parameters were used to cut 2.5 mm steel. Top and bottom views were shown after cutting. Cutting by suction from underneath the work piece was another cutting technique shown. The work piece is placed on a vacuum set-up to pull material from the cut. Aluminum (3mm thick) was cut at 14 kW with a cutting rate of 20 m/min. In addition, 6 mm thick aluminum was cut at 9m/min and 24.5kW. Marine steel that was 15 mm thick was cut at 1.5 m/min and 21kW. Light optical microscopy was used to characterize the cuts. The results included a minimal heat affected zone (20-45 HAZ µm). Molybdenum was also cut, and a comparison of water jet and NVEBC was presented. Delamination was seen on molybdenum cut by the water jet. It was noted that small cracks were seen in cutting of molybdenum. Resulting surface roughness values were shown. The power density measured by the *diaBeam* method (see earlier talk in today's meeting) was found to be 8.5×10^6 W/cm^2 with a beam diameter of 2 mm. The melt film was calculated to be 100-280 µm. The plug efficiency was shown to be 53%, with an overall process efficiency of 46.7%. The process was compared with plasma cutting – 30 mm thick cut for NVEBC *vs*. 15mm thick cut for the plasma process. Questions: A question about the vacuum levels needed under the plate was asked. The author stated that they need 100mbar to cut. The author went on to state that sliding seal will be needed to accommodate long cuts. A second question about the application interests was asked. The author answered that the cutting of thick copper plates for electrical applications. The paper was recommended for consideration to be published in *Welding in the World.*

11.5 IV-1087-12

OpenCL as Novel Platform for Laser or Electron Beam Machinery Control System Design

by Peter Fodrek[1),]Jr., Jan Murgas[1)], Kolenic Frantisek[2)] and Peter Fodrek[2)], Sr. (Slovakia)

1) Institute of Control and Industrial Informatics, Slovak University of Technology Bratislava, (Slovakia)
2) First Welding Company, Bratislava, (Slovakia)

This paper was illustrated initially as a control system presentation for various applications such as plasma, laser and electron beam cutting. The presenter stated that the technical details were recently published in a book chapter. A brief overview of terms was given. The talk rapidly moved to a political talk on open source software in Europe. The secretary had difficulty in finding the tie between the presentation and power beam processes. Questions: A question was asked about what the product has to do with power beam processing. The presenter stated that it will help for more precise control and movements in laser and electron beam welding. The paper was not recommended for consideration to be published in *Welding in the World.*

11.6 IV-1093-12

Economical Joining of Tubular Steel Towers for Wind Turbines Employing Non-Vacuum Electron Beam Welding for High-Strength Steels

by T. Hassel, R. Konya, M. Collmann, P. Schaumann, S. Priebe, T.A. Deißer, A. Beniyash, N. Murray and Fr.-W. Bach, (Germany)

A brief introduction into wind turbine towers was given. The component to be welded contains very large circumferential and straight seam welds that are 20-30 mm thick. A submerged arc weld (SAW) cross-sections was shown and the weld variables (including the set-up) was shown. It was stated that standard welding techniques consumes long times. The desire is to weld18-20 mm thick materials with one pass. The process included a NVEBW with the top and bottom seal weld with SAW. This process allows for a process which takes several weld passes to a process with 3 total passes. The mechanical test data were found to be satisfactory. Solidification cracking was seen in mid-bead of the weld. The root penetration was found to fluctuate, and the gap was found to influence the properties. In addition, notch sensitivity was an important consideration with regards to the top of the weld. Cracking was found to be present. Scanning electron microcopy (SEM) results showed a dendritic surface indicative of solidification cracking. Material preheating and alloying were used to decrease solidification cracking susceptibility. The preheating of the material was at 200°C. A gap tolerance of 0.1 mm is sufficient. A gap greater than 1 mm causes issues; however, a second pass with NVEBW or with SAW may be used to alleviate issues. Successful welds were made with gaps of up to 3 mm using this technique of a second pass. The effect of composition on solidification cracking is currently being investigated. Humping/ropy welds were also observed. This appearance was correlated to the root inconsistencies. Some of the positive aspects of this welding process include the reduction of the heat input by 61% and the reduction in number of passes by 50%. Questions: A question was asked about mechanical properties expected in high strength steel welds. The presenter agreed that this area needs investigation. A second question was asked about the type of cleaning used before welding. The presenter stated that grinding is done first, followed by an acetone rinse. This is all followed by preheating and welding. The paper was recommended for consideration to be published in *Welding in the World.*

12.0 **Adjournment – 18:00**

Tuesday 10 July 2012, 08:30 -18:00

Commission IV in Joint Meeting with Commission XII and SG 212

The opening was given by Professor Hirata (Japan). A discussion of Intermediate Meeting (April, 2012), which was a Joint meeting of Commission XII and Commission IV was held. Professor Hirata was the Session Chair of the first morning session.

13.0 **Commission IV, Commission XII and SG212 Presentations**

13.1 XII-2078-12/212-1249-12/IV-1100-12

Energy Balance Study of Gas Shielded Arc Welding Processes

by A. Hälsig, P. Mayr (Germany)

The heat flow in the welding system was discussed, and welding energy losses were discussed. The first part of the presentation was for gas tungsten arc welding (GTAW). A description of heat losses was given – these included cooling of the welding system and radiative heat loss. The energy of the welding system during welding was investigated with a difference temperature calorimeter. Radiative losses were measured by way of a different calorimeter. The energy losses due to cooling of the welding system were also measured by measuring the inlet and outlet water temperatures from the torch. The efficiency of the welding was found to decrease with increasing welding current. Approximately 81% of the welding input energy was found to go into the work at 50A, while, with all other parameters equal, this energy level was found to be at 71% when the current was 300A. The effective weld efficiency was found to decrease with increasing wire feed speed for gas metal arc welding (GMAW). The three different transfer modes of GMAW (short circuit, globular and spray) had three efficiency levels as wire feed speed (WFS) increased. Each mode of welding was found to decrease with increasing WFS. Explanations for decreasing weld process efficiencies were given in each scenario. Questions: One question was that if 5% of the welding energy was not accounted for, was the energy of gas considered? The author stated that it was in terms of radiative losses. Other areas of efficiencies need investigation. Another question was about the evaporation of water with water bath calorimeter. The author stated that none was observed, and the amount of evaporation during welding will rapidly go to 0%. A third question was about how the energy was separated between wire temperature and work during GMAW. The author stated that the temperature of current carrying cable was measured separate from torch – the author did not understand the question. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.2 XII-2061-12/212-1218-12/IV -1101-12

Intrinsic Errors on Cryogenic Calorimetry Applied to Arc Welding

by O.Liskevich, L.Quintino, (Portugal) L.Vilarino, A.Scotti (Brazil)

This talk began with discussion of heat input in welding. In the author's view, three pitfalls related to heat input in welds exist: (1) the power is not actually average,(2) the measurement of the heat input (with different types of calorimeters) is inconsistent– different approaches give different outcomes, and (3) the total heat is difficult to measure in welding. A question was raised - What is more important, total heat or heat that interferes with cooling? Various losses in welding were described as well. A very detailed description of the heat losses was presented, showing that the concept of heat losses is not simple. The goal of the work was to show that some intrinsic errors are found when working with calorimeters. An overview of automated cryogenic calorimeter was given: after welding (a couple of seconds), the welded part is dropped into a cryogenic container with liquid nitrogen. Using this technique, some intrinsic errors cannot be avoided. The concept of net (effective) heat input was given. It states that the effective heat input should be used rather than classical definition of heat input, since it more accurately describes heat into the system. Questions: On question was regarding the prior presentation, where the question was regarding the presenter's thoughts on exact values of the losses. The author stated that the heat input does not depend only on the process, but on other things. The part thickness and material condition will vary. The author feels that the net heat input is more important than heat efficiency. A second question was asked about the amount of heat should that should be used for calculations. The presenter stated that the heat input value should be extrapolated to a weld length of zero. A third question was regarding the concept of effective heat input – strange effects in other welds, such as tandem arc welding may be seen where very deep penetration is possible. The author stated other possibilities not described in this work. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.3 IV-1084-12/XII-2091-12/212-1251-12

Keyhole Surface Waves during 1 µm-Laser Welding and Resulting Local Absorptivity Modulation

by A.F.H. Kaplan, I. Eriksson, H. Engström (Sweden)

This work dealt with the interaction of the weld pool with the laser in the keyhole, specifically at the keyhole front. The laser interactions are very complex in this area, which makes it difficult to calculate and understand. A5-15kW fiber laser was used to weld stainless steel with 3-15 m/min, focal length 300 mm and spot size of 900 microns. High speed (180000 fps) video used to image keyhole front, in which a wave-like pattern was observed. The flow velocity was measured to be several meters/second (up to approximatey17 m/s). This flow velocity was not linear for laser welding energy – it was found to be 0 m/s until a power of approximately 3-4 kW of laser power was reached, where it moved rapidly to 5 m/s. After this level was reached, the flow was observed to be linear with welding power. As the laser interacts with the materials wavy surface, the absorptivity increases with the wave areas as expected. With a smooth surface, absorptivity remains constant. Questions: One question was asked about keyhole collapse and keyhole weld melt thickness. This was followed by a question about the pressure in the keyhole. The presenter stated that it would be interesting to investigate these topics further. Another question was raised about fluid flow in the keyhole *versus* wave flow. The presenter stated he thought the fluid flow was in the keyhole. Questioner thought that was odd. The paper was recommended for consideration to be published in *Welding in the World.*

13.4 212-1233-12/XII-2099-12/IV-1102-12

Study on Structure and Characteristics of Laser Induced Plasma in High Power Laser Welding Process

by Cai Yan, Xie Wenjing, Wu Yue and Wu Yixiong (China)

This work was related to the study of laser-induced plasma. The belief is that the plasma plume (shielding gas diluted plasma of metal vapor) contains different colors. A 5 kW CO_2 laser was used as the heat source. Spectral lines were shown as a result of welding an Al-Mg alloy. The lines were observed to be at various wavelengths. The intensity of the plasma plume was measured for red, green and blue components and color images were shown. The blue spectrum was viewed as a function of increasing shielding gas – as the flow of gas increased, the blue spectrum was found to decrease. This was similar for green spectrum. The composition of the plasma plume was determined as a function of location. Questions: One question was regarding the composition of the plasma plume and how would it be used. The presenter stated that it could be used for determining the composition losses/changes that result from the welding. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.5 XII-2087-12/212-1242-12/IV-1103-12

Identification of a Heat Source Model for Multipass Deep Narrow Groove GMA Welding Process

by O.Asserin,D.Ayrault, G. De Dinechin,P.Gilles, E.Guyot, J.Schroeder (France)

The presentation began with an introduction about AREVA and CEA. Further, welding was primarily narrow groove techniques used to decrease the amount of filler metal in the weld. Currently, SAW used for welding in flat position on low alloyed C-steel. Orbital GTAW was used to weld stainless steel. The narrow groove welding was performed in horizontal position on low alloy C-steel for the reactor vessel. Numerical simulation was performed for the narrow groove welding, but the heat sources still need to be calibrated. For GMAW, an inverse method of 3-dimensional (3-D) heat flow was used. Experimental data is needed, and the data must be very accurate to ensure the thermal model identification is accurate. Thermocouple data were shown. The numerical method was performed using the Goldak double ellipsoid heat source. This was applied to the narrow gap multipass GTAW. Questions: One question was regarding the efficiency and how it could be related to the distribution function. The presenter stated that the model did not relate the efficiency to the distribution model. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

Coffee Break

Professor Norrish (Vice Chair of Commission XII) served as Session Chair

13.6 212-1239-12/XII-2102-12/IV-1110-12

GMA Welding of 9% Ni Steel in the Pure Argon Shielding Gas Using Coaxial Multi-Layer Solid Wire

by T.Nakamura, K.Hiraoka (Japan)

This talk dealt with the instabilities in GMAW of 9% Ni steel using argon as a shielding gas, in which a column of liquid melting (CLM) of the weld wire was caused by non-uniform melting of the wire. The CLM was generated at the wire tip. Another term, CMS, which is the control of the wire melting by coaxial multilayer solid wire, was discussed. CMS allows large droplets to form and stable detachment of the droplets. The inner wire used has a low melting temperature and the outer wire used has a higher melting temperature. A new concept introduced was the placement of a potassium compound layer between the low melting inner wire and the high melting outer wire. Videos of droplet transfer with CMS and potassium-aided CMS were shown. It was found that the potassium compound was not effective in decreasing the CLM at 300 A. At 400 A, the potassium compound was shown to be effective in decreasing the CLM. A characterization of the weld metal was presented, including mechanical properties. Questions:

One question asked was about the surface tension driven fluid flow of the weld wire, based upon previous work with oxygen additions to gas. The speaker decided to address this later with the person asking the question. A second question was asked about the voltage drop in welding. The presenter stated that the voltage was found to drop from 38 V to lower voltage with potassium additions. This question was followed up with a question regarding the stability of the droplet transfer. The author could not answer because of the complexity of the question. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.7 XII-2051-12/212-1247-12/IV-1104-12

Keyhole Welding with CF-TIG

by M. Lohse, U. Fuessel, M. Schnick (Germany)

The concept of cathode-focused GTAW (CF-TIG) was introduced. This technique was presented as causing the plasma flow to be concentrated by cooling the electrode which forces the arc attachment to the tip, thus allowing for a keyhole with GTAW. The presenter stated that the technique is inexpensive and very available without stringent safety measures, in which it offers an advantage over plasma and laser welding. No filler metal is needed with CF-TIG. The trade name for the welding torch is the "InFocus" GTAW weld torch. Cross-sections were shown of resulting welds. The welding currents were varied from 400A to 800A and speeds were varied from 25 to 115 cm/min, depending upon weld test. The stainless steel thickness was varied from 6 mm to 10 mm and the steel thickness was varied 6mm to 12mm. The gap in the butt-joints was varied from 0 mm to 2.5 mm to determine the ability to bridge gaps. Questions: One question was regarding the reproducibility of the welds and electrode erosion. The presenter stated that the electrode does not erode due to the cooling, and the welds were found to be quite reproducible. It was noted that the erosion will occur with poor electrode care. A comment came from the person who asked the first question that longer term data on the electrode life is needed. A second person asked about the distinct advantage of this process. The presenter stated that advantages include smaller torch and this process is adaptable to higher gap welding needs. A final question was asked about the heat inputs resulting from this technique. The presenter stated that they are similar to GTAW. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.8 XII-2080-12/212-1250-12/IV-1105-12

Visualization of Dynamic Keyhole Behaviours In Waveform-Controlled Plasma Arc Welding

by Z.M. Liu and C.S. Wu (China)

During the introduction, it was stated that conventional plasma arc welding has a shortcoming in terms of keyhole issues. The strategy for this work was to control the current waveform and to use a vision-based sensing of the keyhole. The keyhole was observed with two viewing directions– towards the front and towards the rear. Welding process parameters were compared and related to the measured keyhole size. The controlled waveforms were then coupled to the keyhole size and area. Questions: One question asked about whether one sensor would be sufficient to control the welding. The presenter stated that either sensor could control. A second question was asked about a difference between the paper and the presentation on keyhole mechanism. The discussion that followed was about arc pressure on both plasma welding and GTAW processes. A final question was asked about whether undercuts were observed. The presenter stated that they were not seen, which was probably related to welding speed. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.9 XII-2055-12/212-1213-12/IV-1106-12

Plasma Welding with a Superimposed Fiber Laser Beam

by S. Rose, M. Schnick, A. Mahrle, T. Pinder, E. Beyer, U. Füssel (Germany)

An overview on plasma welding was given. The water-cooled gas nozzle and cold shielding gas allows for a plasma torch to produce keyhole welds. A review of prior work done by the authors using an inclined plasma torch with laser assistance was given. It was then stated that this work was done to modify and optimize the laser assisted plasma welding by allowing the laser to be coaxial with the plasma torch, in which the laser helps to stabilize the arc. Observed voltage changes were compared to parameters such as arc length, current and welding speed. This work was similar to Phil Fuerschbach's work on having the laser come coaxial with the plasma torch. The first set of conclusions is not new. The interactions between laser and plasma were outlined and the effects allowed the authors to reach some important conclusions in high-speed and deep penetration welding. Questions: One person asked if electromagnetic stirring was considered. The presenter stated that it was and these results are forthcoming. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.10 IV-1090-12/XII-2092-12/212-1252-12

Feasibility Study of Laser-Welding with Feeding Wire for Narrow-Gap Butt Jointed Thick Plates of High-Strength Steel

by F. Kong, J. Ma, E. Levert, R. Kovacevic (USA)

This presentation documented the laser welding of high-strength steel with a wire feed system, which was compared to hybrid laser welding. A fiber laser was used at a power of 4kW. No cracks or porosity was observed in welds made with either wire-fed laser welding or GMAW/Laser welding. The tensile strengths of the welds were found to be acceptable when welding with near-matching filler metal. Finite element analysis was used to estimate the thermal profile of wire-fed laser welding and GMA/laser hybrid welding. Questions: No questions were asked. The paper was recommended for consideration to be published in *Welding in the World.*

Lunch Break

Commission IV Vice Chair Staufer mentioned the Intermediate Meeting for C-XII, C-IV and SG 212 in March of 2013 in Europe.

Professor John Lippold, one of the editors for *Welding in the World*, spoke about the state of the IIW journal. Professor Lippold discussed the large number of papers rejected because they were too commercial – and mentioned that the commercial aspects of papers submitted should be avoided.

Presentations were then continued.

13.11 IV-1095-12/XII-2093-12/212-1253-12

<u>Development of High Efficient Hot Wire-Laser Hybrid Process for Narrow Gap Welding - Welding Phenomena and its Adequate Condition</u>

by R. Phaoniam, <u>K. Shinozaki</u>, M. Yamamoto, K. Kadoi, S. Tsuchiya, A. Nishijima (Japan)

A background on narrow gap welding on steam boiler materials was given. Higher service temperatures and pressures are needed. The narrow gap process is required to meet the needs, since lower distortion, lower dilution and a smaller heat affected zone (HAZ) are required. The hot wire laser weld process was utilized to meet these needs. Inconel 600, 304 stainless steel and another material were investigated. A fiber laser was used at 3 kW with a travel speed of 0.5 m/min. The spot size of the laser was 3 mm and the WFS was 8.0 m/min. The wire feed angle was at 70°. High speed videos of the welds were shown. The wire current for hot wire feed was approximately 140 A. The effect of wire position on the weld flow was shown with the high speed video. In one case, where very little dilution is needed, reflection of the laser beam was used. Tensile test results were given. Questions: One question was regarding the maximum thickness of the material. The presenter answered that it depends on WFS, laser power and wire temperature. A second question was regarding if the spot size was varied. The presenter answered no. Was a different laser spot size used? Not really. The paper was recommended for consideration to be published in *Welding in the World.*

13.12 IV-1091-12/XII-2094-12/212-1254-12

Characteristics and Strength Behaviour of Laser Hybrid Welds on T- and Butt Joints Considering European and International Standards

by J. Neubert, B. Kranz (Germany)

This work dealt with the characteristics and fatigue properties of both butt and T-Joints in welding. The need for laser hybrid welding was related to a need in the reduction in weld passes, a decrease in the amount of weld filler metal and a decrease in the weld joint preparation. In hybrid laser welding, the three zones were identified: (1) an arc dominated zone, (2) a transition zone and (3) a laser dominated zone. The arc dominated zone contains mainly the filler metal. The laser dominated zone was found to be similar in composition when compared to the base metal. Root imperfections are believed to impact fatigue properties. Fatigue results for butt joints were compared to specification limits. The results were acceptable when compared to IIW standards. Similarly, the fatigue results for hybrid laser T-joints were investigated. It was found that the hybrid laser results were acceptable as well. Questions: none were asked. The paper was recommended for consideration to be published in *Welding in the World.*

13.13 XII-2058-12/212-1248-12/IV-1107-12

Residual Stresses and Distortion in Electron Beam Weld Joints with Thin Steel Plates

by T.Suga, R. Kasai, T. Nagai, K. Ueno, M. Shindo and M. Mochizuki (Japan)

The electron beam welding was used to weld thick-section Cr-Mo steels. The thickness investigated ranged from 3 to15 mm. The resulting residual stress and distortion was investigated. The electron beam welding machine was a 6 kW system. The beam power was varied from 600 to 1200 W and the beam diameter was varied from about 0.5 mm to 1.5 mm with a travel speed of 500 mm/min. An x-ray residual stress analyzer was used according to the Standard Method of the Society of Materials Science, Japan. Distortion was measured by a standard process on what was initially a flat plate. The weld penetration was shown as a function of welding parameters by way of weld cross-sections. The weld thermal analysis was found to agree with the measured temperatures within reason. Both analytical and experimental results showed that the beam power increasing caused a compression at the weld toe. As the beam diameter was increased, the residual stress at the weld toe went into tension. In general, the residual stress distribution for EBW was found to be in compression at the toe and root, while at the weld middle, the residual stress was found to be in tension. As the weld penetration increases, the compressive stress was found to increase. The predicted and measured weld distortion was compared and was found to be in agreement. Questions: One question was asked – if laser welding was used, were the results expected to be similar? The author did not know. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.14 IV-1094-12 /XII-2095-12/212-1255-12

Laser Butt Welding of NiTi to Ti6Al4V and Stainless Steel

by E. Assunção, L. Quintino, R. M. Miranda (Portugal)

Laser butt welding of three materials was performed. At longer pulse durations, the mixing was found to be more complete. With a pulse length of 50 ms, the composition variation was found to be no more than 5%. In welding stainless steel to NiTi, avoiding the intermetallic phase rich in Fe and Ti (Fe_2Ti) is important to decrease the weld solidification cracking susceptibility. One method used to avoid this cracking was with a Ni interlayer between the stainless steel plate and the NiTi plate. The Ti6Al4V was also welded to NiTi. When these materials were welded together, a band structure between the two materials was found. The thickness of this band was determined to be approximately 60-70 µm. This brittle "intermetallic" on the Ti6Al4V side is believed to be caused by nickel migration to the beta titanium. Questions: One question was asked regarding how to avoid intermetallic formation. The response was the formation cannot be avoided, but the amount formed can be manipulated. Another question was regarding if the band structure was really an intermetallic, since the intermetallic formation is seen as a distinct phase with a single composition, rather than a band with a composition range. – The presenter answered that this was an intermetallic region. No paper was submitted. However, the work was recommended for consideration to be published in *Welding in the World*.

13.15 IV-1097-12/XII-2096-12/212-1256-12

Deep Penetration Phenomena during Welding with Combined High Power Lasers

by S. Katayama, M. Hirayama, M. Mizutani, Y. Kawahito (Japan)

A background on high power lasers was given. A single disk laser and twin disc lasers were used to investigate deep penetration. For the twin disc laser system, the laser spots were configured either tandem or side-by-side. At very low welding speeds (<1 m/min), a weld penetration of 14 mm or slightly greater was achieved. Deeper welds with a better surface appearance resulted when the laser was in an underfocus condition. If the focal position was moved closer to sharp focus from the underfocus position, a shallower penetration and spatter were observed. When the focal position was moved to greater underfocus, then porosity was observed. The disc lasers were 10 kW and 16 kW systems. In tandem, the distance between the laser spots was 0.5 mm. When the distance is decreased, the heat distribution appears to act as one large heat source. The parallel (side-by-side) configuration did not appear to perform as well as tandem in terms of both penetration and weld surface appearance (spatter). By putting the beam at an angle of 20° (pushing), the keyhole appeared to be more stable. Deeper penetration is achievable when leading with the higher power laser (16 kW) in tandem. Questions: The Secretary had difficulty hearing the questions. No paper was submitted. However, the work was recommended for consideration to be published in *Welding in the World*.

Coffee Break

Dr. Herbert Staufer, Vice Chair of Commission IV, continued as the Session Chair

13.16 XII-2084-12/212-1241-12/IV-1108-12

Characteristics of Weld Pool Behaviour in Laser Welding with Various Power Inputs

by S.W. Han, M. Sohail, S.J. Na, A. Gumenyuk and M. Rethmeier (Korea)

The advantages of both high power fiber and disc lasers were presented. The value of modeling and simulation was presented as well. This work combined experimental and analytical investigations. Marangoni flow, buoyancy and recoil pressure models were presented. The models were outlined in detail. The model results were presented as fluid flow movies – the simulated weld power was varied in the movies shown. The flow patterns were analyzed with the various combined models. A high vortex flow around the root of the weld was expected at higher powers when welding with the fiber laser. The vortex is believed to cause the root porosity. The ray path of a fiber laser was compared to the ray path of a disc laser. With an increase in welding speed, the overall shape of vortex flow pattern remains the same. The vortex was believed to be caused by more energy absorption at the bottom of the keyhole, in which the molten material at the bottom of the keyhole is difficult to move to the top of the keyhole. Questions: A question was raised about why the model separated the weld into three regions. The answer was stated that the boundary conditions may be changed, so the issue raised is valid, but difficult to describe. Since this was not a Commission IV paper, no recommendation was needed from Commission IV.

13.17 IV-1099-12/XII-2098-12/212-1258-12

Effect of Surface Conditions when Joining of Plastics with Metals using a Laser

by J.P. Bergmann and M. Stambke, (Germany)

The first part of the presentation was background and then a bit commercial. After the commercial portion of the presentation, the basics of metal/plastic joining were given. The plastic is between the laser and the metal, since the laser energy couples with the metal. Another method to join these materials has the metal on top of the plastic, with the laser heating the metal which in turn heats the plastic to melt it. The surface roughness was not found to correlate strongly with the bond shear strength. Questions: One question was raised about why the laser was used to heat the plastic rather than a different method. The author answered that the flexibility of the heat source was the major reason. This paper was recommended for publication.

13.18 IV-1098-12/XII-2097-12/212-1257-12

Cutting Quality of CFRP with Three Different Lasers and Laser Joining of CFRP and Aluminum Alloy

by K-W. Jung, Y. Kawahito, S. Katayama (Japan)

This work was a continuation of last year's presentation "IV-1056-11, High Power Laser Cutting of CFRP, and Laser Direct Joining of CFRP to Metal, by S. Katayama, Y. Abe, M. Mizutana, Y. Kawahito (Japan). This work was an overview on cutting and laser direct joining of carbon fiber reinforced plastic (CFRP). A review of the previous work with a pulsed Nd:YAG laser and continuous wave (CW) disc laser processing was given and much more information was given regarding the disc laser cutting. A single mode fiber laser was also used to cut CFRPs at 1-2 kW and 3 m/s (HAZ at 100 microns). Finally, a picosecond pulsed laser system was used to make cuts (50 W, 0.2 m/s). Macrographs were shown on the cuts showing the cut width and the HAZ. The author should consider presenting some of his cutting work to the Commission I working unit. The disc laser cutting power was varied from 2 to 5kW and variable cutting speeds were used. The disc cut at 2 to 3 kW power allowed for high speed (5 m/s) cutting with a very narrow HAZ (50 µm). Next, the welding of the CFRP materials was investigated. An overview showing plastic was joined to various metals with laser. The joining mechanisms were believed to be chemical bonding, Van der Waals force and an Anchor effect (or mechanical bonding). The CFRP was joined to 304 stainless steel. The results were found to be favorable. However, some bubbles were found to form in the joint. The results of CFRP to 5052 aluminum were given. The results were acceptable. Questions: none. No paper was submitted. As such, the work was not recommended for consideration to be published in *Welding in the World*.

13.19 An extra presentation was given about laser hybrid welding of steel. The presenter was from Japan, but the Secretary of Commission IV was unable to get his name. Weld variables and resulting mechanical properties were shown, including crack tip opening displacement. Since this was not a submitted in time and had no IIW number, no recommendation was given from Commission IV.

14.0 Adjournment – 18:00

<u>Wednesday 11 July 2011, 14:00 -18:00</u>

15.0 Continuation of Commission IV Presentations

The chair for this session was Claus Thomy (Germany).

15.1 IV-1075-12

<u>Surface Layers Formation onto Spheroidal Graphite Iron by Laser and Electron Beam</u>

by <u>Kolenic Frantisek[1]</u> ,Peter Fodrek[1], Sr., Peter Fodrek[2],Jr. and Jan Murgas[2](Slovakia)
1)

Creation of functional surface layers onto cast iron have corrosion resistance and may be decontaminated, but are susceptible to mechanical damage. Low dilution of the surface layer is needed. Ductile cast iron GGG 40 was used. The minimum tensile strength needed was 400 MPa. The composition was given, and the amounts of ferrite may be controlled by alloying and heat treatment. Filler metals (both wire and powder) were used. Powders were primarily used for flame thermal spraying and laser coating/deposition. The equipment used for laser deposition was an IPG 4.5 kW (300 µm beam diameter and 200 mm focal length). The equipment used for electron beam deposition was a low voltage EBW system (15 kW). For laser deposition, the process parameters were presented. The powders were Cr-Ni, Ni-Cr, Ni-Cu and Ni for laser deposition. Laser beam deposition also included some direct wire feeding. Deposits of Cr-Ni austenitic materials exhibited multiple cracks, but no explanation was given. Microhardness traces were taken along the deposit interfaces. Interesting micrographs were shown, with no explanation about the features. Questions: One question was asked regarding what issues were observed with multiple-deposit electron beam deposits. The presenter stated that no issues were expected. A second question was asked about why the laser was defocused rather than at sharp focus, since oxidation/cleaning may be an issue. The presenter stated that oxidation was not evident after first pass. This paper was not recommended for *Welding in the World*, since the technical content was not sufficient.

15.2 IV-1109-12 / IX-H-763-12

<u>Local Vacuum Electron Beam Welding of Fabrication of Stainless Steels and Nickel Alloys</u>

by C.S. Punshon , TWI, Cambridge (United Kingdom)

A very nice overview of why power beam processes should be used was given. A major reason was that arc welds (like SAW) may take up to 90 passes, while EBW/LBW may be performed in a single pass. The EBW penetration depth may be up to 230 mm or more. The issues with deep penetration EBW of large components were presented – a large vacuum chamber is generally needed and pumping times to high vacuum may be very long. With partial vacuum EBW, the pressure is about 1mbar in the lower column. A photo was shown of the 100kW partial vacuum EBW gun. The concept of a local vacuum used in conjunction with the partial vacuum EBW gun was presented. Sliding seals will typically be needed to ensure an acceptable weld.

According to the presenter, a local mobile vacuum concept is the “holy grail” of partial vacuum EBW. Stainless steel wire brushes help to create the local partial vacuum seal. A photo of the sliding seal EBW head was shown. The brushes were found to clean the surface as well. The vacuum level was found to be at 0.05 mbar in the weld area. A 1.7 m length, 60 mm thick weld was shown and this weld was made in 6 minutes using the local vacuum system. Mill scale was not removed in this process. High energy EBW creates x-rays, so welding was made in a lead box. The ITER fusion reactor applications were shown. A 60 mm-thick 316L stainless steel (nitrogen bearing) needs to be welded on a large scale for the ITER application. For the root pass, GTAW was used. In this application, ferrite requirements (among other requirements) are stringent. The material has 2000 ppm nitrogen, which is a challenge for EBW. Several nickel alloys were welded as well, including C-22, Alloy 740H and a 9% nickel steel (not a Ni alloy). A 38 mm-thick weld of alloy 740H was shown to have no cracking. The Ni alloy applications were for the Yucca Mountain Project. When GTAW was used to make the weld, it took 250 minutes, while reduced pressure EBW took 9 minutes. Corrosion properties were presented. Questions: One person asked about the toughness, which is critical in the thick section steels. The presenter stated that the toughness is achieved through alloy selection and pre-heating the weld joint. Another person asked about the weld positions. The presenter stated that the welding position was flat (2G). A third question was asked about the frequency of changing the wire brushes. The presenter stated that they need to be changed every 100m or so. Finally, a person asked about the equipment cost. The presenter stated that the cost of the system is roughly $2M, which is initially high, but the cost savings is realized with higher productivity. The paper was recommended for consideration to be published in *Welding in the World.*

15.3 IV-1086-12

Synthesis of Fe-Based Amorphous Coatings by High Power Diode Laser Cladding

by LI Zhuguo; HUANG Jian; ZHU Yanyan; LI Ruifeng, (China)

The presentation began with an overview of amorphous materials. For Fe amorphous alloys, they typically have high hardness and good corrosion resistance. The purpose of this study was to generate this type of coating. Fe36 Ni40B18 Si10 Nb4 and Fe36Co36B20Si4Nb4 were the materials used. The equipment used was a 3.5 kW diode laser. Laser powers were varied from 700 to100W. The travel speed was at 8 mm/s. The dilution was found to strongly influence the composition of the coating. At 600 and 700 W the dilution was similar and the least amount of dilution was found. A remelting method was investigated to drive a remelt solidification cooling rate to higher levels. Deposits made with 700 and 800 W were found to retain amorphous features. With high dilution of substrate, more crystalline material was observed. With lower powers (and, thus, temperatures), larger amounts of amorphous material resulted. The coating rate was at 17 mm/s for the second material above. This was a good presentation with good technical points. Questions: One person asked about the adhesion of the coating investigated. The presenter stated that some work has been done, but it was not presented here. Another person asked about how the powder was made. The presenter stated that it was by gas atomization. The work should be considered for publication in WiW. The paper was recommended for consideration to be published in *Welding in the World.*

15.4 IV-1092-12

Effects of PWHT on Laser Welded Joint of Mg-rare Earth Alloy Mg-3Nd-0.2Zn-0.4Zr

by Jian Huang[a], Jun Dai[a], Yixiong Wu, (China)

Laser welding was performed on the Mg alloy Mg-3Nd-0.2 Zn-0.4 Zr. An overview of the Mg alloys was given, and the rare-earth alloying additions were discussed. The alloying allows for higher mechanical properties at elevated temperatures and good corrosion resistance in the Mg materials. Solidification cracking was eliminated by controlling the heat input. The joint efficiency was found to be 85% in the weld metal and 55% in the HAZ. The material was aged to increase mechanical properties; however, no mechanism for strengthening was presented. Microstructures of the weldment were presented. The welds were solution heat treated to dissolve the second phase along the grain boundaries. This second phase was found to be only partially dissolved after low solution heat treating temperatures and shorter times. At 540° C and 6 hours, the second phase was found to completely dissolve by this time. As such, this temperature and time was chosen to perform the solution heat treatment. The chosen aging temperature was 200° C, since the peak strengthening was achieved in a reasonable time (within a few hours) at this temperature. Transmission electron microscopy (TEM) results of the aged specimen were presented. This paper contained very good metallurgical work. Questions: The secretary missed the question. The paper was not recommended for consideration to be published in *Welding in the World.*

15.5 IV-1077-12

Hybrid Laser Arc Welding of X80 and X120 Steel Grades

by M. Rethmeier, S. Gook, A. Gumenyuk, (Germany)

The purpose of this work was to determine how to improve the impact toughness of X80 and X120 welds through processing and investigate the GMA laser hybrid process *versus* the GMA welding process. Several filler metals were investigated for both materials. The first weld pass was made with the laser hybrid process and the root pass was made with the GMAW process. Photographs of the equipment were presented. Radiography showed porosity in some of the welds, but no cracks were observed. The parameters are given in the paper. Energy dispersive x-ray spectroscopy (EDX) was used to ascertain the nickel distribution in the weld metal. Micorhardness measurements at different regions of the weld were also presented. The Charpy V-Notch values were shown at a test temperature of 60° C. These values met the specifications for API 5L and the DEN EN specification. The Charpy V-notch values were compared for welds with various filler metal additions. Other mechanical properties were presented. A laser hybrid demonstrator component was made, and, with this component, the weld metal cross-section was reduced by 2.7 times of that with the GMAW process. As expected, the heat input was reduced dramatically with the laser hybrid weld process. Questions: One person stated that with this process the productivity should be improved dramatically, but the amount of testing required in Canada to qualify the laser hybrid welding process is substantial. The person then asked about the amount of testing required in Germany. The presenter stated that the process is still not in production in Germany because of the amount of testing. A second person asked about fracture toughness testing on these welds. The presenter stated that this testing was performed, just not presented here. A third person asked about why some of the Charpy V-notch values were low. The presenter stated that some notch areas were in the area where the dendrites came together in the weld, and this was expected. The paper was not recommended for consideration to be published in *Welding in the World.*

15.6 IV-1096-12

Femtosecond Laser Peening for Microweld Joint in MEMS Devices

by Tomokazu Sano[2], Takahiro Tsukada, Yutaro Isshiki, Tomoki Matsuda, Tomo Ogur Kazuto Arakawa, Masayuki Okoshi, Narumi Inoue, Kojiro F. Kobayashi[5], and Akio Hirose(Japan) ' (Japan)

An overview of laser peening was given. The welds that were made in this work were made with the friction stir welding (FSW) process. Laser peening causes the hardness to increase at the surface of the material. The residual stress in the FSW joint was found to move from tensile to compressive. A comparison between conventional and nanosecond lasers was given. Femtosecond peening was used to alleviate residual stresses on components related to microelectrical mechanical systems (MEMS) applications, in which the MEMS material selected was pure aluminum. The interaction layer of the laser shock region was less than 100 nm in this application. The purpose of this work was to investigate the femtosecond laser peening on the nanohardness of the materials used in MEMS. The nanohardness was found to increase significantly in the area of the pulse. In the cross-section of one of the tested materials, the hardness was found to decrease to base metal values at a thickness of approximately 10 µm. The microstructure was shown by using TEM, in which the dislocation densities of the material after laser peening was observed. The residual stress was found to be in compression in the affected laser peening areas. *In-situ* diffraction showed a change in microstructure in single crystal silicon, in which new streaks and dots were found in the pattern. Questions: One person stated that the different input energies of the laser peen were shown and the laser movement pattern was regular. The person followed with a question about using a random laser movement for peening. The author stated that he did consider this, but a further discussion should be held after the session. A second person noted that most of the work was with aluminum as the material to be peened, but some of the work was with silicon. He followed by asking about more extensive results with silicon. The author stated that the work with silicon is only preliminary and more extensive results are expected in the future. No paper was submitted. As such, the work was not recommended for consideration to be published in *Welding in the World*.

16.0 Coffee Break – 16:00

17.0 The Possible Reorganization of Commission IV into Subcommissions

The introduction of subcommissions was presented and discussed. The commission will be divided into three subcommissions (1) Laser, (2) Electron Beam and (3) Laser-Arc Hybrid. Vice Chair Staufer already had suggested names for subcommission chairs. The term "welding" was changed to "processing".

18.0 Resolution Concerning Publications in "Welding in the World"

The Acting Chair Staufer will be putting forth 13 papers for submission to WiW.

19.0 IIW Matters

After the break, Cecile Mayer of IIW gave a brief overview of the state of IIW, including the changes with Springer as the publisher of WiW. Changes include authors submitting the papers and they will be part of the peer-review process. The reviewer will also interact with the website for peer review.

IIW will have a public site that will post metadata only – real data will be put into private web page.

IIW Essen will be Sept 11-13, 2013.

20.0 Intermediate Meeting

Intermediate meeting discussions were held. Details are forthcoming.

21.0 Miscellaneous

Newly appointed Vice Chair Levert made a couple of announcements.

22.0 Closure of meeting