Conference Reports

Joining Ceramics, Glass and Metal in Bad Nauheim

By Graham Partridge*

The third international conference on joining ceramics, glass and metal was held from 26.–28. April 1989 in Bad Nauheim, a spa town in the Federal Republic of Germany. This is a very pleasant town (although it rained for much of the period of the conference. Normally, this could be expected in England but, somehow it is assumed that the Germans would do better, even with the weather). The conference itself was held in the Kurhaus (Congress Center) which is very well equipped for conferences of this type. Furthermore, the many hotels meant that no delegate need be more than a few minutes away from the Kurhaus.

The conference was organized by the Deutsche Gesellschaft für Metallkunde (DGM), together with the Deutsche Glastechnische Gesellschaft (DGG), the Deutsche Keramische Gesellschaft (DKG) and the Deutsche Verband für Schweisstechnik (DVS) and was the third in a series of conferences targeted at technical developments in joining ceramic, glass and metal. The conferences are held at four-yearly intervals which permits significant developments to take place in this broad, important field between meetings.

For convenience the conference was divided into four themes, namely

- Active brazing
- Diffusion bonding
- Friction welding, Reaction bonding and other joining methods
- Properties and testing

Oral papers were presented in each group, including an initial plenary paper by an appropriate expert on the particular theme. In addition, poster contributions reinforced and expanded the technological areas covered.

During the course of the conference, three short (1 h 20 m) workshops were held in parallel on the themes of

- Active brazing/Testing methods
- Diffusion bonding/Interlayers
- Design of bonded systems/Applications

A total of 232 participants were recorded as attending the conference. As would be expected, more than 50% were from the Federal Republic of Germany although the majority of the European countries were well represented and there were also participants from as far afield as Australia, China and Japan. Interestingly, no attendees from the USA were recorded.

The technical sessions were always well attended (in spite of the attractions of Bad Nauheim) and the poster area was crowded during poster discussion periods. The workshops attracted 50–60 participants each and the discussions were lively and informative.

The standard of oral presentation and of the posters was high. This presented a problem for many of the speakers and poster designers since the conference was held in English with no facilities for parallel translation. It says a great deal for those who spoke and who discussed their posters in what was not their native language that they were able to make their points well and answer questions put to them. Each oral presentation allowed time for a few questions following the paper.

Inevitably, there was some overlap in the chosen themes, for example, property determinations were presented in all sessions.

The following review covers highlights (in the author's opinion only) and does not hope to cover all the many and varied aspects of this highly stimulating international conference.

1. Active Brazing

The papers in this session were concerned with brazes which contained titanium. The presence of Ti enabled the braze to wet and bond to the ceramic surface. It was shown

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by *M. Nicholas* that wetting became progressively more difficult in the series oxide–nitride–carbide–boride although good wetting was not always essential to achieve a good bond, especially if pressure were applied across the join. Shear strengths of bonds involving ceramics were seen to be generally stronger with the strongest ceramics.

A number of presentations covered the difficulties of brazing ceramics to metals where a wide disparity in thermal expansion coefficients leads to high stress in the join and ceramic. The use of interlayers, such as Mo and Cu was shown to be beneficial in reducing stress levels and leading to strength improvements in the joins. Mo appeared to be particularly beneficial for SiC and Si_3N_4 (*E. Lugscheider* et al.) and useful for Graphite to stainless steel (*P. Jacquot* et al.). Design of the joints was important – a high ratio of ceramic to metal thickness in the join influenced residual stress in the ceramic and decreased shear strength (*Weise* et al.) and the use of a ductile metal filler was also helpful.

2. Diffusion Bonding

The diffusion bonding of ceramics to metal, resulting from interactions at the ceramic-metal interface at elevated temperatures was discussed by a number of lecturers covering a range of ceramic to metal systems. The plenary lecture was given by *J. J. Klomp* and he set the scene admirably. It is clear that diffusion bonding requiring transport of metal can lead to reaction products which may be disadvantageous. Ideal contact surfaces are not generally available and pores produced in the contact zones are removed by creep and vacancy diffusion. Bonding time and pressure are helpful in this respect (*B. Gibbesch* et al.) as applied to Nb and Cu bonds to sapphire. It was noted by *B. Derby* that joint strength and toughness had to be clearly distinguished when characterising the mechanical properties of diffusion bonds between ceramic and metal. Comparison of brazing and diffusion joins of SiC to metal was made by *Batfalsky* et al. who indicated that diffusion joins should be capable of higher temperature operation. Diffusion barriers and interlayers such as copper were often necessary (*J. Schiepers, J. P. Krugers* et al.) to enable expansion mismatches to be tolerated. Silicides which influence bond integrity were formed at the ceramic interface. The use of hot isostatic pressing for joins of Si_3N_4 to steel was shown to be advantageous (*M. Corbiere* et al.) and tungsten was the preferred "stress relieving material" adjacent to the ceramic. The use of TiH_2 powder interlayers, sintered simultaneously during Al_2O_3–Ti bonding (*S. Prech*) was interesting and further development of Cu to Al_2O_3 bonds was discussed by *W. Wlosinki* et al.

3. Friction Welding, Reaction Bonding and other Joining Methods

This section covered aspects of less well known methods for joining ceramics to metals. *D. Hann*, in his plenary address, covered a number of tasks which engineers must undertake in developing a reliable join, with particular emphasis on the problems occurring in lapped joins. As with a number of other applications discussed in other presentations, finite elemental analysis was seen to be useful in determining stresses which were strongly influenced by the geometry and thickness of the bonded parts. Shear strength testing was said to give general, relative information but other tests were also necessary to give critical information. *G. Partridge* et al. dealt with the joining of glass-ceramics directly to metals, either in bulk joining processes or by coating application and this latter aspect was amplified by *Ashcroft* et al. in a poster presentation. Generally, these forms were matched in expansion, so stresses were low. The development of unusual crystal phases in the glass-ceramic at the interface were discussed and problems arising from the competing diffusion processes of bond development (essentially via the metal oxide layer) and crystallization of the precursor glass were outlined. *W. Schaefer* et al. discussed bonding of high temperature zirconia electrochemical cells using a variety of joints (glass, welding, clamping) in the overall stack. Aluminophosphate mortars were described by *A. Hesse* et al. to join reaction bonded SiSiC and it was seen that the mortar itself was the weak link in the bonded assembly. Friction welding (*Weiss* et al.) was an unusual technique successfully used to join ceramic to metal. Initially metallization of the ceramic was seen to occur as the bond developed. The use of nickel foil, converting to nickelous oxide at the interface was shown to be a useful way of joining MgO to itself or to metals (*K. Atarashiya* et al.) and also for joining Al_2O_3 to Ti-6Al-4V alloys (*Y. Ito* et al.).

4. Properties and Testing

The plenary paper by *G. Gnirss* et al. discussed the properties of ceramic to metal joins with respect to design considerations and further looked at failure mechanisms in the joins. The general experience was that the bonding zone or adjacent ceramic were the weakest points and the lifetime of components was determined by creep and fatigue controlled sub-critical crack growth as well as temperature and time dependent degradation within the bonding zone. Optimization of the bonding process requires new bonding media, reduction of thermally induced stresses and improvement in the reproducibility of high quality ceramics. To some extent this latter might be met by improvements in powder processing and by composite developments. *M. Turwill* et al. discussed joining of ceramics to metals for various applications generally with reasonably close thermal expansion matching of the ceramic and metal parts. Finite element analysis of stresses in joins was discussed by *B. T. J. Stoop* et al. and *K. J. Ferenc* et al. It was found by *Stoop* that both tensile and shear stresses are maximum in the ceramic in the vicinity of the ceramic-metal interface. Elementary bending theory may also be used to determine residual thermal stress distributions in an asymmetrical ceramic/solder/metal plate as shown by *O. T. Iancu* et al. The determination of stress in a ceramic to metal join is not easy. Optical methods using polarized light cannot generally be used owing to lack of transparency. However, in some cases X-ray diffraction techniques (*B. Ergermann* et al.) can be employed to determine residual surface stresses and triboelectric effects or light emission under stress may also be used (*H. Teodorescue* et al.).

In many cases ceramic to metal joins may be subjected to environmental conditions likely to cause weakening. *K. Suganamu* et al. discussed stress corrosion failure, in particular, the influence of water on Si_3N_4 joins where stress corrosion of the Si_3N_4 itself can take place. However, the results obtained showed that the joins can maintain high integrity over a long period of time. Several workers addressed the bonding of copper to Al_2O_3, an important bond in the microelectronics field. Fracture toughness values of K_{ic} up to 4 MPa $m^{1/2}$ were obtained by *L. J. Bostelaar* et al. and *A. Otszyna* et al. showed that the bonds to α-Al_2O_3 were stronger than those to β-Al_2O_3. *N. Klein* et al. also showed that thermal cycling led to deterioration in the Cu to Al_2O_3 bond owing to shear stresses in the join, but control of the crystallite orientation in the Al_2O_3 could beneficially influence thermal endurance.

The majority of the papers and posters presented have been drawn together in a volume entitled "Joining Ceramics, Glass and Metal", edited by *W. Kraft* and published by the DGM.

The conference was highly successful and provided not only an excellent venue for the dissemination of research results but also the opportunity to meet fellow workers in this wide and disparate field.

Magnetic and Magneto-Optic Thin Films and Multilayers in San Diego

By Ernesto Marinero* and Takao Suzuki*

The spring meeting of the Materials Research Society (MRS) in San Diego, April 24th to 29th, 1989, was host for two major symposia dealing with magnetic and magneto-optical materials. The symposium on "Growth Characterization and Properties of Ultrathin Magnetic Films and Multilayers" comprised 11 invited talks and 42 contributed papers over three and a half days and provided a unique and interactive forum in which to discuss recent advances in low dimensional magnetism, diluted magnetic semiconductors, epitaxial overlayers and the utilization of in situ and ex situ techniques to characterize their microstructure and electronic and magnetic properties. The other symposium on "Materials for Magneto-Optic Data Storage" was the first dedicated entirely to materials aspects of the rapidly emerging magneto-optic data technology. This symposium lasted for two days and was particularly successful in providing a well balanced forum between the industrial applications of the technology and fundamental materials research. Thirty seven papers were presented, including outstanding invited lectures, which covered the entire spectrum of materials issues relating to magneto-optical recording media. This included the magneto-optic active layers, dielectric layers and substrates. Emphasis was placed, in particular, on rare earth transition metal amorphous films, such as TbFeCo, GdTbFeCo, from the fundamental as well as the applicational point of view.

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Growth, Characterization and Properties of Ultrathin Magnetic Films and Multilayers

The study of ultrathin magnetic structures is a rapidly expanding field of materials research whose growth is synergistically driven by an increasing appreciation of the degree to which the magnetic properties depend on interfacial processes and by the utilization of growth techniques which permit the fabrication of multilayer structures with novel electronic and magnetic properties. Equally important is the fact that atomic level control of the microstructure of these layers offer new opportunities to elucidate the physics of magnetism, to rigorously test theoretical models and, in some cases, to synthesize new materials.

The symposium opened with an invited talk by *Roy Richter*, General Motors (GM) who presented recent theoretical results on the temperature dependence of the spin anisotropy of a monolayer of Fe. Changes in the magnitude of the perpendicular anisotropy as a function of temperature were attributed to changes in the Fe monolayer band structure. *Mayer* and *Gutierrez* (Johns Hopkins) presented experimental results on Fe(110)/Ag(111) superlattices (SL) grown by molecular beam epitaxy (MBE). No out-of-plane magnetization was observed for this particular system. *Krebs* (NRL), on the other hand, found that Fe(001)/Ag(001) superlattice grown on thick Ag(001)/ZnSe(001) substrates exhibited strong perpendicular anisotropy for Fe layers < 3 ML. The importance of interface roughness was highlighted by *Albert Fert* (University Paris-Sud) who reported