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testing of the diffusion-bonded joint, and pointed out that each testing method had different sensitivity to the presence of microvoid at the bond interface. Is there any difference between the bonded areas estimated from fractured surfaces obtained by different test methods?

2. You did not talk so much about the bonding of dissimilar metal combination, but I think very interesting phenomena relating to the bond formation can occur at the dissimilar metal interface during the solid state bonding, such as diffusion bonding and friction bonding.

In the diffusion bonding, the bond zone is kept for a rather long time at a temperature sufficiently high for the interdiffusion of atoms to occur across the interface, and the reaction between the dissimilar metals, which is controlled chiefly by the interdiffusion, takes place almost in accordance with the equilibrium phase diagram. In contrast to this, the heating time as short as less than 1 s is necessary for the friction bonding, and so mechanical mixing as well as interdiffusion will play an important role in the reaction. It has been suggested that because of these short heating time and mechanical mixing, nonequilibrium phases are formed in the friction bonding of some dissimilar-metal combinations such as aluminum-copper and aluminum-SUS316 stainless steel. I expect that even an amorphous reaction layer can be formed by the friction bonding, if a suitable dissimilar-metal combination is selected.

Thus, the reaction mechanism at the bond interface of friction bonding is quite different from that of the diffusion bonding. So, I think it will be possible to obtain better understanding of the mechanisms of the bond formation and the reaction at the bond interface by comparing the reaction layer of diffusion bonding with that of friction bonding.

Answer (Dr. E.R. Wallach)

1. In my talk, I have reviewed different method to obtain a measure of the bonded area. Dr. Ikeuchi is right that it is difficult to use just one test and, I hope in the talk I have explained the information that each test provides and also the difficulty of obtaining information in the final stages (last 20%) of bonding. Even electrical resistance has problem in that the change in signal with increased bonding becomes extremely small as bonding nears completion (noise can be greater than the change in the signal). Also, as the voids become very small in the final stages of bonding, the microstructure and changes in, say, grain size or dislocation

density will contribute to the signal and prevent the observation of voids.

2. There is always much to be learnt from comparing the results from different joining methods. However, I do think one has to be careful when comparing a static process such as diffusion bonding with a dynamic process such as friction welding in which the relative rotation speed between the two parts being joined varies from zero (at the center) to a high speed at the periphery. Also, the metal in friction welding is under very high shear stress and can behave like a pseudoviscous fluid even though it has not melted. Thus the mechanisms of material transport will be very different. However, I do agree with Dr. Ikeuchi that for the joining of dissimilar metals, the use of both diffusion bonding and friction welding should be encouraged. It is only processes such as these that might enable satisfactory bonds to be made in the future.

Concluding Remarks

Prof. F. Matsuda

In closing this Session, I would like to express some concluding remarks. The aim and subject expected in this Session were to talk each other internationally about "New Joining Processes for Advanced Materials." Therefore, this Session was treated the wide range of welding fields as fusion welding, diffusion joining, soldering and so on.

We had three fundamental lectures of different field, the lecturers of which are invited from foreign countries as the US and England. Moreover we had also some discussers for individual lecture.

Professor D.W. Dickinson of Ohio State University reported the future trends on weldability research including new welding processes in some advanced metal and materials, and welding innovation in some advanced environments using research activities at Ohio State University.

Dr. C.J. Thwaites of International Tin Research Ind. reported the future problems and studies on soldering micro-electronic assemblies, from standpoints of solderability of surfaces, soldering process problems and quality inspection.

Professor E.R. Wallach of University of Cambridge reported the scientific and fundamental studies for diffusion bonding. The modelling of the process, mechanical testing, non-destructive test and microscopical investigations were treated.

Moreover, each discusser Dr. Tanaka of NKK, Prof. Okamoto and Dr. Ikeuchi of JWRI treated the present

state of the arts and the future trends of materials related to welding technologies.

All these lectures and discussions were very useful for future advance of welding technologies.

Concerning the future aspect of welding technology in the next decade, constructional steels and non-ferrous metals will advance to the developments for more strong, more ductile, more weldable and more anti-corrosive materials by the aid of alloying elements, purification, heat-treatment and special processes.

Moreover, development of composite material urges advance of joining technology in future. Of course, ceramics and plastics and their composite join in the ranks of welding materials. Therefore, non fusion welding and diffusion bonding technologies between special metals

and between metal and non-metal will be widely investigated and rapidly spreaded. New surface joining process with some new heat sources also be hoped to be developed.

Soldering will continue to have leadership of assembling processes of microelectronic devices, then the development of new solder and fundamental phenomena of soldering will be investigated. Robotic welding processes and automatic control process by various sensors will be widely introduced more in welding field of new advanced material.

Finally I would like to explain shortly a part of the present state of Japanese welding technologies in industrial uses for the materials used in severer environment, using Table 1 and 2.