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In this table, the initial compound thickness in eutectic solder is 1.1µm and for the silver loaded solder is 0.7µm. The difference of both values is 30% and this percentage is comparatively large. Moreover, the same percentage is recognized also for the growth rate in the table. Therefore, the pre-added effect of silver is considered to be appreciated obviously from these measured values. How about my discussion?

Secondly, a thin-foil of rubber solder which contains many solder particles of very small size in a polystyrene-butadiene rubber foil is developing at a certain Company in Japan. This solder foil is researching for wireless bonding between a VLSI and an alumina substrate, applying a similar method to flip-chip bonding method. Would you please teach us about such a solder that follows solder paste being developed newly in your Institute or in Europe, if possible?

Table 1 Materials used under severe service conditions with welding technologies

| Material | Severe Service Condition | | | | | | Industrial Example |
|--------------------------------|--------------------------|------------|-----------|-------------|---------------|---------|---|
| | Low Temp. | High Temp. | High Vac. | High Press. | High Strength | Special | |
| (1) HY-type Steel | | | | ⊙ | ⊙ | | Submarine Shell, Pressure Vessel |
| (2) Maraging Steel | | | | ⊙ | ⊙ | | Rocket Casing |
| (3) High Mn Steel | | | | | ○ | ○ | Non-magnetic Structure |
| (4) High Cr-Mo Steel | | | | | | ○ | Reactor Tube, Chemical Vessel |
| (5) Ferrite/M Stainless Steel | | ○ | ○ | | | ○ | Fusion Reactor Vessel, Chemical Plant |
| (6) Austenitic Stainless Steel | ⊙ | ○ | ⊙ | | | ○ | Low Temp., Vacuum, Chemical Plants |
| (7) Inver | ⊙ | | | | | | LNG Vessel Wall |
| (8) Ni-heat Alloy | | ⊙ | | | | ○ | JT-60 Vessel Wall, Engine, Vessel |
| (9) Al Alloy | ⊙ | | ⊙ | | | ○ | Low Temp. Vessel, Vacuum Vessel, Aircraft |
| (10) Ti Alloy | | | | ⊙ | | ○ | Submarine Shell, Aircraft, Chemical Plant |
| (11) Ta Metal | | | | | | ⊙ | Chemical Plant |
| (12) Mo Metal | | ⊙ | | | | | JT-60 Wall, Furnace |
| (13) Ceramics | | ⊙ | | | | ○ | Ultra High Temp. Material, Chemical Plant |

Answer (Dr. C.J. Thwaites)

Thank you very much, Professor Okamoto, for your questions on my presentation. I accept that in my type-script I state that there were "no significant differences" in the initial thickness of intermetallic formed, and also in the growth rate of compound, between 63-37 solder and the 62-36-2 alloy. The values obtained were on polished microsections and 80 readings were made for every heat-treatment time and the results treated statistically. For space reasons the correlation coefficients and standard deviations were not given in the tables but were such as to reflect the extremely irregular nature of the interfaces between which measurements were being made. Therefore although the 30% difference seen was statistically correct, in my opinion, for a useful decrease in leaching or compound formation rate to be seen one would be looking for perhaps a faster of 2 difference between the two solder alloy reaction rates. Also, the problem is none readily eliminated if the metallized layers were of nickel

or copper and not a precious-metal basis, and high reliability components now tend to utilize such finishes.

With regard to a foil of rubber-like material in which solder powder or particles are encapsulated, being developed in this country, I am aware of approaches such as this but do not have any details. The International Tin Research Institute is not working on such materials and I would ask in return what happens to the basis organic material at soldering temperature? Unless formulated to melt and flow away or vaporize, it must oxidize to a vicious, carbonaceous film which would interfere with wetting the substrate by the solder. Currently, there is also much work on conducting adhesives which are satisfactory for a very limited type of application but I have seen no way of using them for making 1000's of joints at one as in the reflow or wave-soldering processes.

I hope that the JWRI will continue to make more valuable contributions to soldering science in the future.

Table 2 Main welding processes used

| | Fusion Welding* | | | | | | | Pressure Welding | | | Brazing Diffusion TIP Bonding |
|-------------------|-----------------|-----------------|-------------|-------------|-------------|------------|---------------------|------------------|----------|-----------|--|
| | Manual (MMAW) | Submerged (SAW) | MIG* (GMAW) | MAG* (GMAW) | TIG* (GTAW) | Plasma arc | Electron-Beam (EBW) | Resistance | Friction | Explosion | |
| (1) HY-type | ○ | | | ○ | ○ | | ○ | | | | |
| (2) Maraging | | | | | ○ | ○ | ○ | ○ | ○ | | ○ |
| (3) High Mn | ○ | | | ○ | | | ○ | | | | |
| (4) High Cr-Mo | ○ | ○ | | ○ | | | | | ○ | | |
| (5) Fe/M Steel | ○ | ○ | | ○ | | | ○ | ○ | ○ | | |
| (6) Aust. Steel | ○ | ○ | | ○ | ○ | | ○ | ○ | ○ | | ○ |
| (7) Inver | | | | | ○ | | | ○ | | | |
| (8) Ni-heat Alloy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | | ○ |
| (9) Al Alloy | | | ○ | | ○ | ○ | ○ | ○ | | ○ | ○ |
| (10) Ti Alloy | | | ○ | | ○ | ○ | ○ | ○ | ○ | | ○ |
| (11) Ta Metal | | | ○ | | ○ | | ○ | ○ | ○ | | ○ |
| (12) Mo Metal | | | | | ○ | | ○ | ○ | ○ | | ○ |
| (13) Ceramics | | | | | | | | | ○ | | ○ |

"Progress of Diffusion Bonding of Various Materials"

Dr. E.R. Wallach

Question (Dr. K. Ikeuchi)

1. I am deeply impressed by your model calculation of the diffusion bonding which shows good agreement with experimental data. My first question is concerned with this model calculation.

You showed that the bonded area calculated by using your model was in good agreement with the experimental. My question is about the experimental method for estimating the bonded area to be compared with the calculated. I think you estimated the experimental bonded area from the fractured surface of the joint. However, you talked about several kinds of mechanical

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 pseudo-viscous 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 diffusor bonding. The modelling of the process, mechanical testing, non-destructive test and microscopical investigations were treated.

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