concentration significantly affected UTS ($p < 0.05$), while temperature did not. A significant difference was found between subgroups of different flux concentrations in the 1200 °C temperature group. For the 1200 °C group with 67% flux, the UTS obtained was 699.6 ± 30.9 MPa, which is higher than values obtained using 75% flux (602.7 ± 29.9 Mpa), as well as the one with pure flux powder (499.8 ± 126.1 MPa).

A cross-section of fractured specimens observed under SEM showed that specimens soldered at 1200 °C had a well-formed dendritic crystal structure (Fig. 6), whereas specimens soldered at 1150 °C had a poorly formed dendritic crystal structure (Fig. 7). Specimens of higher mechanical strength (1200 °C, 67% flux) had fewer flux inclusion bodies and a fewer number of as well as lower, loose dendritic patterns. On the other hand, specimens of inferior mechanical strength (1200 °C, 75% flux) had more flux inclusion bodies, and a higher percentage of crystallized dendritic patterns. In these specimens, fractures occurred along either inclusions of flux or loose dendritic crystals (Figs. 7, 8). The fractured part of the specimen soldered with flux powder had a large amount of flux powder (Fig. 9). Cracks appeared between the flux powder and solder, and decohesion took place (Fig. 10). Also, where there was flux powder, the structure of the solder was looser and less orderly in structure.

DISCUSSION

During soldering, faults in 3 main categories could be produced: soldering cracks, interior defects, and poorly formed structures. The inclusion bodies of non-soldered metals such as slags are examples of an interior defect. Therefore, the parental soldered surface should retain its non-oxidized and impurity-free status in order to form a good contact between the solder and parental soldered surface. Nevertheless, a small amount of flux can also provide appropriate protection. The use of flux can prevent surface oxidation and dissolve impurities while the solder is being heated.[5] However, using too much flux may result in inclusions in the solder joint thereby decreasing the resultant soldered strength.[5] Our results show that higher flux concentration often lead to increases in high-amplitude AE signals during the entire soldering process irrespective of soldering temperature. Also, in the frequency domain, the frequency for maximum amplitude hits during the heating period tended to decrease. During soldering, the higher the flux concentration, the greater the number of inclusion bodies the flux would contain, and the metallurgy microstructure was also looser. Therefore, it can be inferred that the high-amplitude AE signals produced in the soldering process came mainly from AE signals released from the flux under stress effects, along with high-count, high-energy AE signals produced by the high-frequency soldering machine.

Because the elastic and plastic properties of flux greatly differ from those of solder, the stress may be concentrated at the points of inclusion of flux, or at the interface between flux and solder. This may result in crack initiation and propagation around the inclusion sites, or at the solder-flux interface (decohesion). With the help of a scanning electron microscope, this experiment revealed the subtle structure of soldered parts, which shows that when a higher concentration (75%, for example, in this study) of flux was used, more flux inclusion bodies occurred, and more anomalous crystals were found in the resultant metallurgical structures. Because stress is concentrated during soldering, solidification, and tensile processes; flux inclusion bodies can easily cause slipping between crystalline lattices. On the other hand, this stress may lead to fracture or decohesion of the flux inclusion body, which causes and spreads the crack and allows it to propagate. All these are possible sources for the AE signals of the experimental specimens, and also for the AE signals produced during soldering (Fig. 3). Moreover, decreasing the fracture-resisting capacity in the plastic deformation zone can lead to a decrease in ultimate tensile strength of the soldered metal. Such processes are believed to be relatively fast and brittle crack-propagation events. That is, the faster the crack occurs, the lower the ultimate tensile strength for the greater flux-treated soldered group. Plastic behavior apparently did not occur in that group, which may reduce the generation of fracture-resisting stress, and subsequently result in a decrease in ultimate tensile strength.

In this experiment, during the isothermal and cooling periods continuous smaller-amplitude AE signals