Development of Al/Cu Dissimilar Joint by New Friction Welding Method

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Abstract

Aluminum alloy / pure copper joint has been tried to produce by the conventional welding method. However, some combination of the joints could not show high joint efficiency. The reason for this is considered to the formation of the intermetallic compound and involvement of the metal flake of joint specimens. A2017 aluminum alloy/Cu joint was examined by the new friction welding technology which has the intermediate material for friction between joint specimens. Furthermore, thermal elastic-plastic stress analysis was conducted for searching the optimum welding condition. The results are as follows. (1) 60% joint efficiency larger than that in the conventional process was obtained. (2) Intermetallic compound and involvement of the metal flake are not recognized by a micro inspection such as SEM. (3) Increase of oxygen content is recognized in Al side near the interface, however, it occurred during upset stage because oxygen content does not increase in Cu side. (4) The precise position of welding interface could be determined from the change of oxygen content near interface. (5) For producing sound joint of this combination of the materials, it is important that both materials are plastically deformed by maintaining strength balance between Al and Cu near the interface.

Keywords: friction welding, joint, aluminum alloy/Cu, intermediate material, thermal elastic-plastic stress analysis

1 Introduction

As for conventional friction welding methods[1]-[3], in general, the reason why there are the impossible cases[4] of welding for dissimilar materials is due to the direct rotating friction between the specimens. Namely, first, there is a case to generate an intermetallic compound and involvement of the other metal flake in the interface of the materials [5], [6]. Second, in the case of metals with very different melting points or flow stresses, it is hard to be welded, because only the metal with lower melting point softens and the material with higher melting point cannot decrease the flow stress so much.

Therefore, a new friction welding process has been tried to produce joints that is evaluated to be impossible to weld so far. Namely, in the new technology proposed, the friction heat can be varied and controlled to both specimens by setting the intermediate material (hereinafter called IM) for friction between the specimens.

In the friction process, IM conducts an orbital motion between the interface of the specimens. After heating and softening the interface of the specimens, IM is quickly pulled out from between the specimens. After that, the specimens are pressed to join by an upset pressure.

At the same time the thermal elastic-plastic stress analysis by the finite element method has been carried out to search the suitable friction-upset conditions.

According to the friction welding of the dissimilar joint between aluminum alloy and pure copper, aluminum alloy such as 1xxx, 5xxx and 6xxx series show relatively higher joint efficiency than 80%, while, 2xxx and 7xxx series cannot be obtained less than 30% or 50%. Such reason is due to the generation of an intermetallic compound and involvement of the other metal flake in the interface of the materials [6]. In this technology, such phenomenons do not occur because of non-contact by the specimens during friction stage.

In this study, dissimilar joint between A2017 duralumin and C1100 pure copper has been tried to produce through experiments and the thermal elastic-plastic stress analysis by the finite element method.

2 Experimental procedure

2.1 Experimental equipment

The experimental equipment is shown in **Fig. 1**. For operating IM, rotation of a servomotor (Mitsubishi Electric.HA-LFS15K2) is transferred to a small scale pulley though a flexible joint, a large scale pulley and a timing belt. In addition, rotation motion of the small scale pulley is converted to one directional translation movement through a linear guide by a crank mechanism. The orbital motion is obtained by double crank mechanism with phase difference of $\pi/2$rad by additionally setting up mechanical system mentioned above. As for equipment specification, the maximum number of rotation of IM is 6000rpm and displacement from the center of rotation for orbital motion is 0.8mm.

The maximum value of friction pressure and upset one are 70MPa and 700Mpa, respectively.

2.2 Materials used in this test

For the specimens, A2017 duralumin and C1100 pure copper were used , and for IM, S50C was used. The shape and dimensions of the specimen are shown in **Fig. 2**. The size of IM is w34×l27×t6.

The chemical composition of A2017and S50C are shown in **Table 1**. C1100 copper has 99.94%Cu and 0.05% oxygen. The thermal conductivity is 403 W/m･K for C1100, 164W/ m･K for A2017and 63.3W/m･K for S50C.

2.3 Experimental condition

The friction pressure, upset one and mode of the orbital motion are shown in **Table 2**. The temperatures of the surfaces of the specimens at the position of 2mm from the interface were measured by radiation thermometers (KEYENCEFT-H40) and thermocouples.

Table1 Chemical composition of the materials (mass%)

(a) Aluminum

Material	Si	Fe	Cu	Mn	Cr	Zn	Ti
A2017	0.37	0.31	4.3	0.50	0.02	0.10	0.15

(b) Steel

Material	C	Si	Mn	P	S	Ni
S50C	0.51	0.2	0.7	0.05	0.02	0.07

Table 2 Experimental Conditions

Friction pressure (MPa) A2017 C1100	 9-20 10-20
Friction time (sec)	1-3
Rotation number of C material (rpm)	3000-4000
Rotation radius of C material (mm)	5.8
Upset pressure (MPa)	200

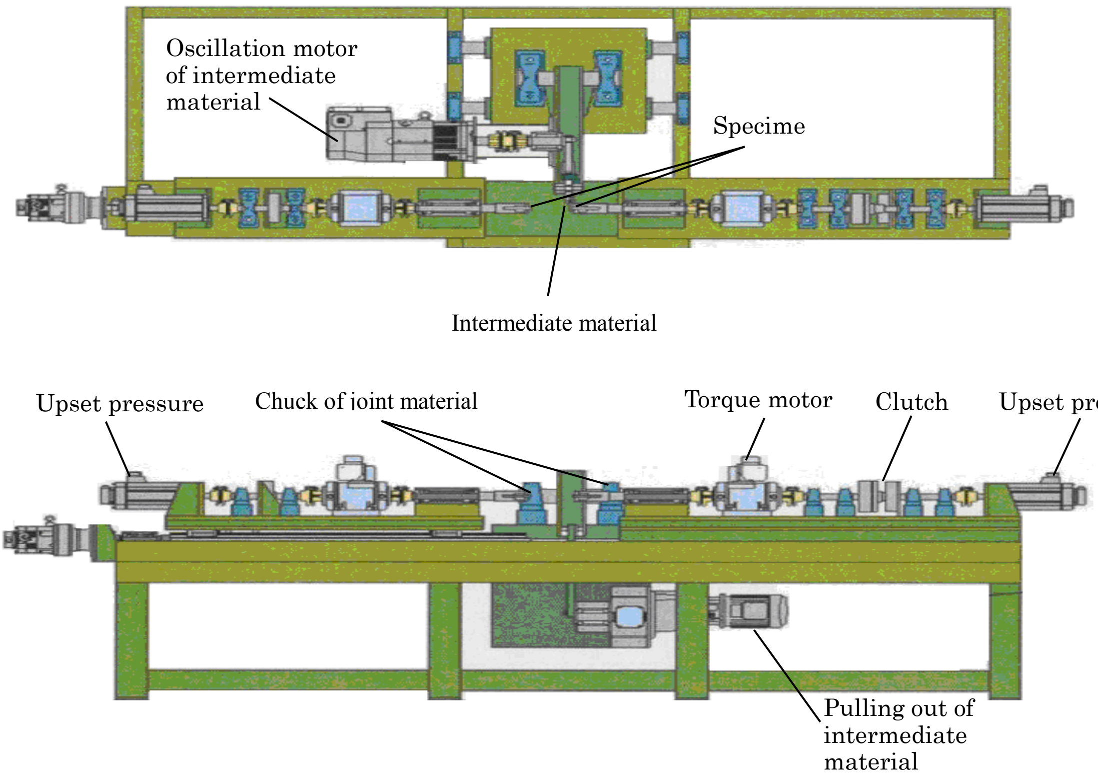

Fig. 1 Experimental equipment of new friction weld

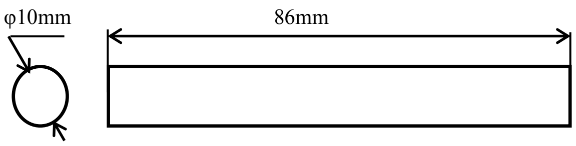

Fig. 2 Shape and dimension of the specimen

2.4 Thermal elastic-plastic stress analysis by finite element method

The thermal elastic-plastic stress analysis by the finite element method was carried out to search the suitable friction and upset conditions using ANSYS mechanical (ANSYS Inc.). Unsteady heat transfer analysis and non-linear structural analysis were coupled to obtain the solution. In this analysis, heat transfer or radiation of friction heat to the specimen, IM and atmosphere are taken into account. Details are referred in a paper [7].

Fig.3 Appearance of the welded joint

2 Experimental results

3.1 Joint efficiency

As a result of the test under the conditions in friction pressure of 20 MPa(Cu/IM) and 9MPa(Al/IM), 6s for friction time, 4000rpm for IM rotation number, 200MPa for upset pressure and 2s for upset time, 60% of joint efficiency larger than 50% of maximum value by conventional friction welding method was obtained. The appearance of the welded joint is show in **Fig. 3**.

3.2 Microscopic investigation

The result of the line scan of Al, Cu and O in the near of the interface are shown in **Figs. 4** and **5** respectively. Furthermore, SEM image of Al, Cu and O are shown in **Fig. 6**. From **Figs. 4-6**, Intermetallic compound and involved metal flake were not recognized that might be the defect of the dissimilar joint in a conventional friction welding process.

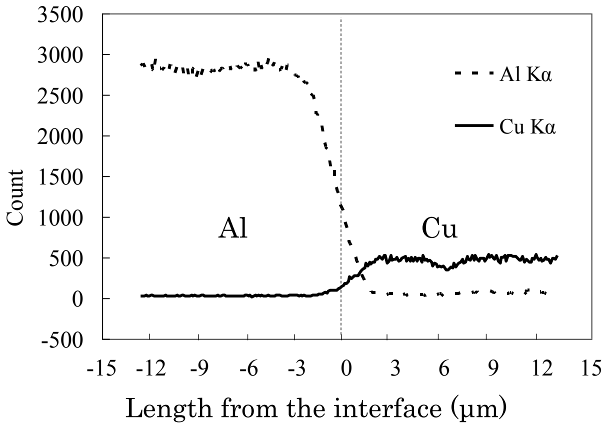

Fig. 4 Results of the line scan (Al, Cu) near the interface

Figure 5 shows that increase of oxygen content is found in the aluminum side in the interface but hardly be recognized in the copper side. As components of Al and Cu invade into other side in the near of the interface, increase of oxygen content in the aluminum side means oxidation occurs during upset process, but not in the friction process.

Judging from the change of the oxygen content in **Fig. 5**, accurate position of the interface can be is determined, which is filled for vertical dot line in **Fig. 4**.

3.3 Numerical solution method

Used software is ANSYS mechanical (ANSYS Inc.) [8]. Unsteady heat transfer analysis and non-linear structural analysis were simultaneously coupled (strong coupling) to obtain the solution. Every one side of the specimen and IM was analyzed to minimize the calculation time. The computational grids were made up of the parametric elements using mesh morphing and a total of 2828 nodes were formed for the specimens and IM. A time–step size of $\Delta t = 2.5\times10^{-2}$s was adopted to achieve a convergence in every time step. **Figure 7** shows computational grids in the analysis.

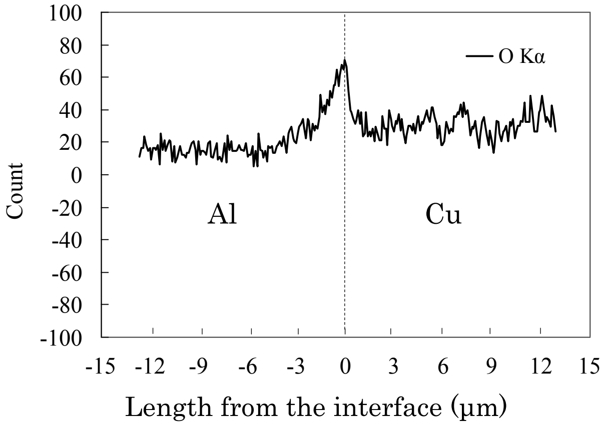

Fig. 5 Result of the line scan (oxygen) near the interface

4. Result and discussion

4.1 Change of temperature during friction stage

Figure 8 shows the calculated examples of the change of temperature and observed value in the Al specimen in the case of Al/S50C (IM).

In the **Fig. 8**, 0y0x, 0y5x, 2y5x mean the center of the specimen, the surface of the interface and surface of 2mm from the interface. The measured value corresponds to the one at 2y5x.

Figure 9 also shows the results in the case of Cu/S50C (IM).

This computation method has been confirmed to meet approximately the actual measured values.

Figures 10 and **11** show the calculated examples of the change of temperature distribution in the specimen on one side and the IM during friction stage at 1.0, 2.0, and 3.0sec during friction. This calculation was done under the condition such as friction pressure of 20MPa(Cu/IM) and 9MPa(Al/IM), 6s for friction time, 4000rpm of the orbital motion of IM, 200MPa for upset pressure and 2s for upset time that attain 60% of joint efficiency.

In the case of Al/ S50C(IM), friction generation heat is transferred from friction region with 11.8mm diameter area in the IM according to the **Fig. 10**. Moreover, the temperature of IM is slightly larger than that of Al specimen. It is because thermal conductivity of IM is lower than that of Al specimen.

On the other hand, in the case of Cu/ S50C(IM), the temperature of IM is also larger than that of Cu specimen. However the difference of the temperature between IM and the specimen is larger in the case of Cu/ S50C(IM) than in the case Al/S50C(IM).

It is because thermal conductivity of Cu is large enough to transfer the friction generation heat, which is recognized in the specimen in **Fig. 11**.

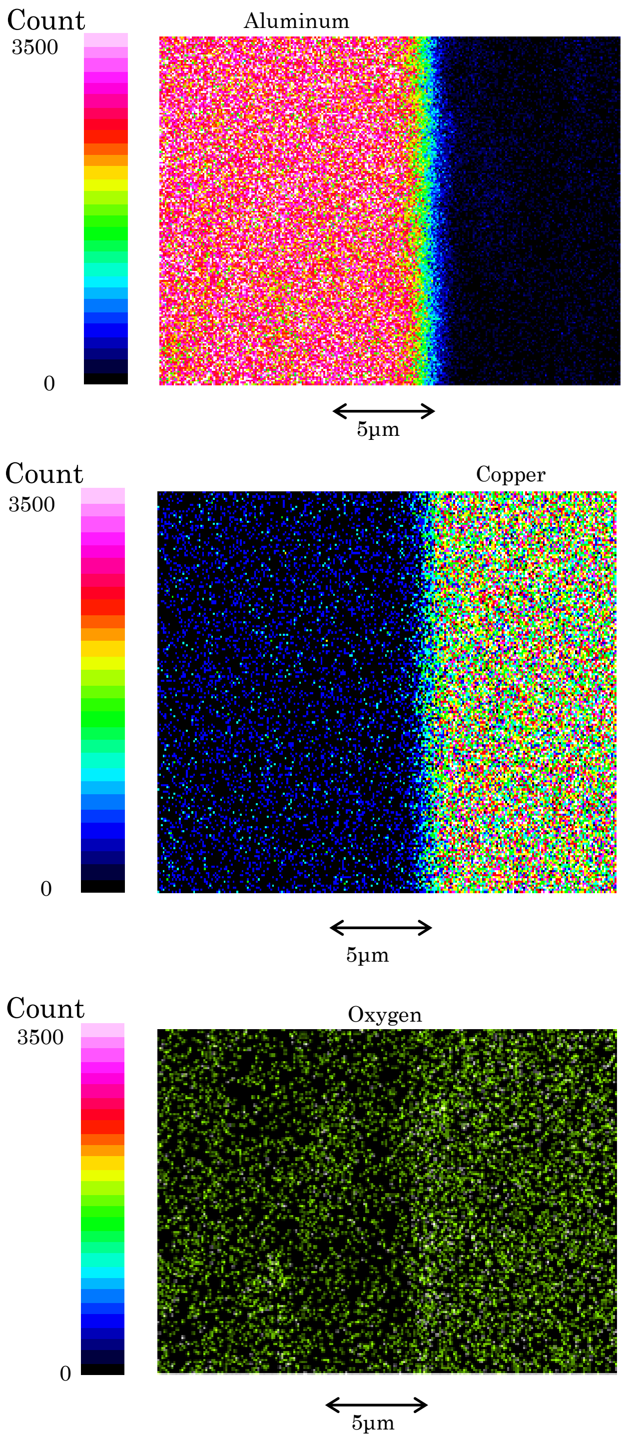

Fig. 6 Results of the SEM image near the interface

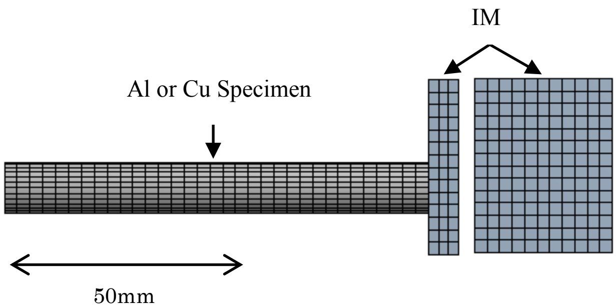

Fig. 7 Computational grids (mesh quality 0.38)

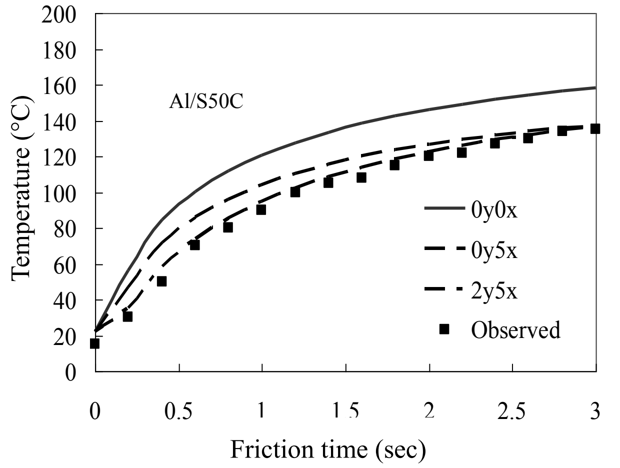

Fig. 8 Change of temperature in the specimen during friction stage（Al/S50C）

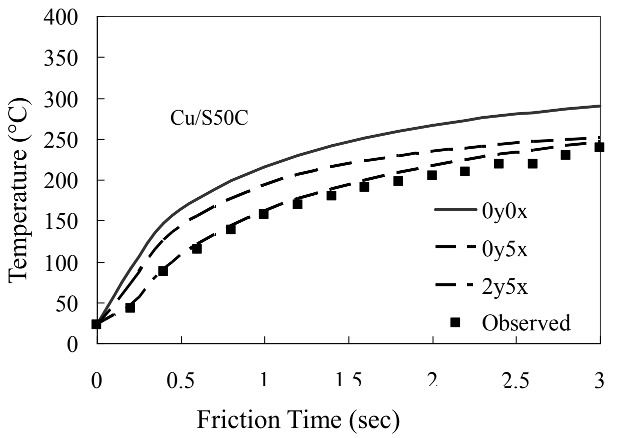

Fig. 9 Change of temperature in the specimen during friction stage（Cu/S50C）

5. Conclusions

Dissimilar joint of aluminum alloy and pure copper was tried to produce by new friction welding method. In this study, thermal elastic-plastic stress analysis was also conducted for searching the optimum welding condition. The results are as follows.

(1) 60% joint efficiency larger than that in the conventional process was obtained.

(2) Intermetallic compound and involvement of metal flake are not recognized by micro inspection such as SEM.

(3) Increase of oxygen content is recognized in Al side near the interface, however, it occurred during upset stage because oxygen content does not increase in Cu side.

(4) The precise position of welding interface could be determined from the change of oxygen content near interface.

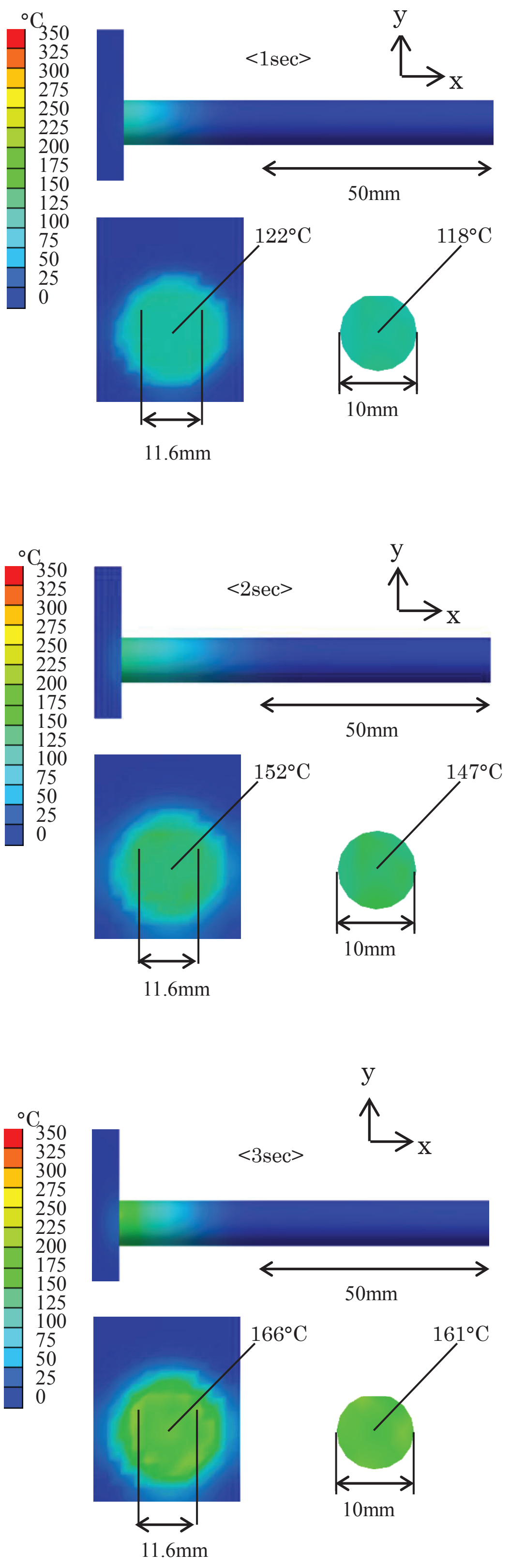

Fig. 10 Calculated temperature distribution during friction stage（Al/S50C）

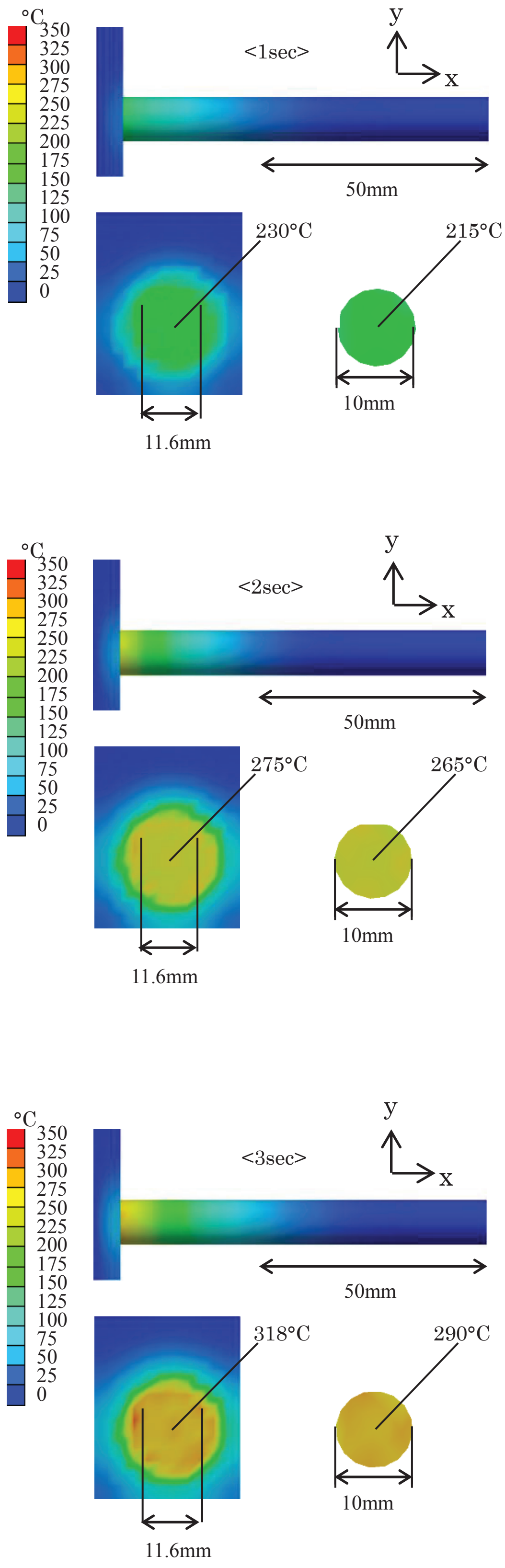

Fig. 11 Calculated temperature distribution during friction stage（Cu/S50C）

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