Geometrical Effect of Deformed Melted Polymer on Wire Insulation Burning in Microgravity

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INTRODUCTION

The most characteristic feature of wire insulation burning in microgravity is the presence of core wire with very large thermal conductivity. In our previous study [1] on an Ethylene-Tetrafluoroethylen-insulated wire, it was demonstrated that the core wire acts as both heating and cooling medium. The uncoated core wire inside of the spherical flame receives heat from the surrounding hot gas and conducts part of it to the coating to enhance gasification. On the other hand, at the station where the flame touches with the coating surface, the flame extinguishes locally due to heat loss to the core wire through the coating. It was also shown that the various properties intrinsic to wire insulation burning could be characterized by such roles of core wire.

The microgravity experimental results obtained by Fujita et al. [2] show that in the combustion of Polyethylene-insulated wire, the melted coating becomes the spheroidal shape at the center of spherical flame due to surface tension. Deformation of solid fuel surface is common problem that occasionally can be seen in the combustion of polymer material and thermally thick solid fuel. However, there are no past studies which theoretically investigate the effect of fuel surface deformation on flame spreading.

In the present study, a mathematical model is presented to describe the geometrical effect of the deformed melted coating on combustion of polyethylene-insulated wire in microgravity. Numerical results of presently developed model contribute to the further understanding of wire insulation burning in microgravity.

FLAME SPREAD MODEL

Thermal pyrolysis mechanism of polymer material is still complex and unclear. Therefore, to develop the model following assumptions are introduced.

(1) Phase change of the coating occurs at a certain melting and boiling point.

(2) The physical properties of the coating material are constant.
(3) Volume change of the coating occurs only at the instance of phase change.
(4) The lubrication theory can be applied to describe the melted coating flow.
(5) Quasi-steady heat conduction within the coating and the melted polymer occurs only in the radial direction at each station along the wire.

Since the thermal conductivity of core wire is very large, the core wire temperature doesn't change without receiving the large radial heat flux from the coating. The propagation speed of spherical flame is small. Therefore, final assumption is valid. The configuration of melted polymer, core wire temperature distribution and surrounding gas temperature distribution in Figure 1 is assumed for the modeling. The shape of melting surface is determined according to thermal inflow from the surrounding gas and the core wire. The shape of melted coating surface is determined by effect of surface tension and volume expansion at the melting surface. Numerical simulation is conducted with classifying the states of coating cross section into four. Depending on the condition, the melting of coating starts from the wire surface. Such a case is incorporated in the calculation when necessary.

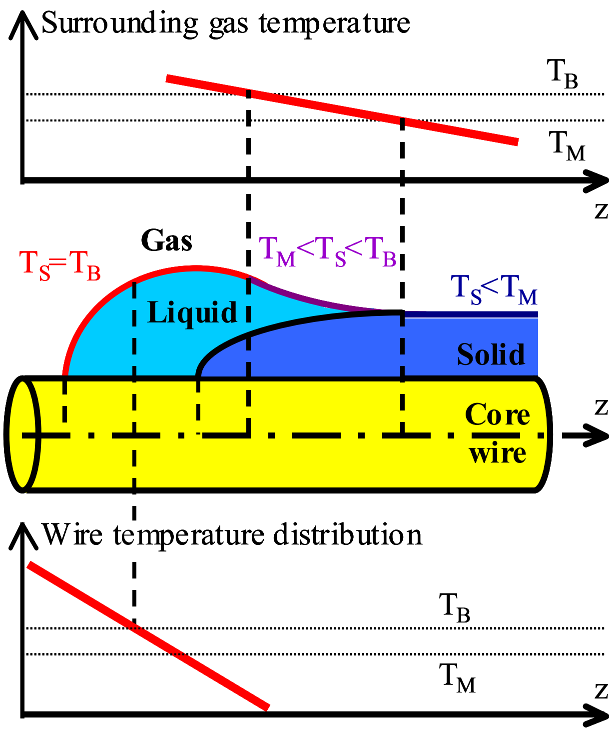

Fig.1 Configuration of melted polymer, core wire temperature and surrounding gas temperature

The core wire temperature is calculated according to one-dimensional unsteady heat conduction equation with heat loss to the coating (coated part) or circumference gas (coating burned out part). The reactive gas-phase governing equations in the low-mach-number approximation are solved using the transformed coordinates system compatible to the coating surface deformation and the SIMPLE method. An Arrhenius type of one-step reaction is applied to describe the combustion of reacting gas. The effects of radiation from the combustion gas and the solid fuel surface radiation loss are neglected, all transport properties are constant and Lewis number is unity in the gas phase. All physical properties are made dimensionless using the ambient gas properties and core wire radius.

RESULTS AND DISCUSSION

Fig.2 shows the temperature (top), fuel mass fraction (middle) and reaction rate (bottom) contours of steadily propagating flame. The figure displays that at the left hand side the flame shape is kept spherical, on the other hand, the flame is elongated to forward direction at the leading edge. This is because the coating gasification occurs at the flame leading edge location as can be seen from the fuel mass fraction contour. It is different from the results of the previous study [1] in which the coating gasifying part is restricted to the vicinity of coating burn out station. This flame shape is consistent with experimental results obtained by Fujita et al.

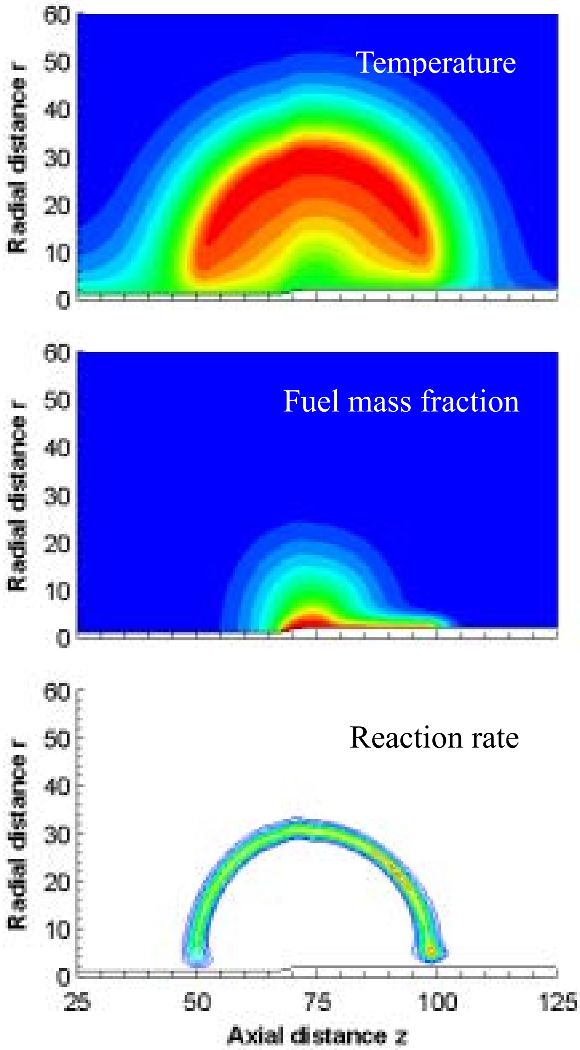

Fig.2 Temperature, fuel mass fraction and reaction rate contours of the flame in the steadily propagating state

Figure 3 and Figure 4 show the phase state of coating and temperature distribution along the wire, respectively. The figure displays that in the steadily flame propagating state, the phase state of coating cross-section along the wire is classified into four parts, (1) totally melted part, (2) two melted parts separated by a the solid phase part, (3) surface melted part, (4) totally solid phase part. Totally melted part is restricted to the vicinity of coating burn out edge and gasification speed of coating becomes the maximum at the coating burn out edge that locates near the center of the flame. Because thermal inflow from the surrounding hot gas is small compared to that from the core wire. Inside of the spherical flame the uncoated/coated wire receives heat from surrounding hot gas everywhere, however, the part of coating is cooled by the core wire. Therefore, separated two melted parts and surface melting part appear where the core wire temperature is higher than the melting temperature and where it’s lower than the melting temperature respectively. At the place where the flame contacts with coating surface, the edge of flame extinguishes locally due to heat loss to the copper wire through the melted/solid coating. Therefore, the edge of flame cannot self-propagate.

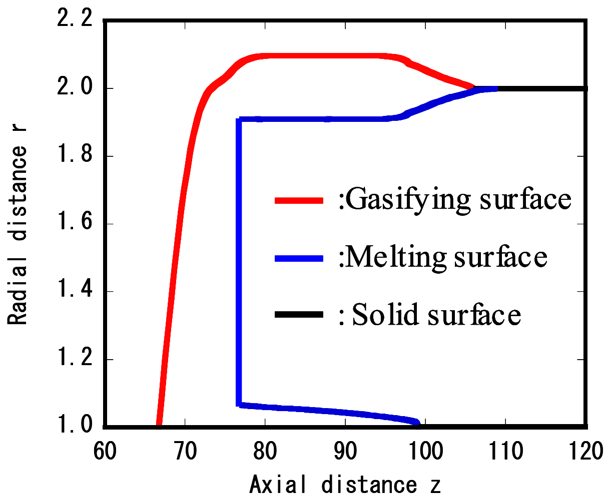

Fig.3 Phase state of coating

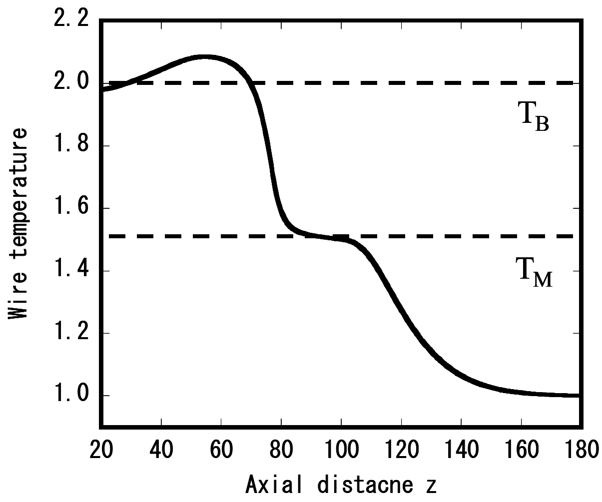

Fig.4 Temperature distribution along wire

These calculation results indicate that the core wire with very large thermal conductivity plays a crucial role in the combustion of Polyethylene-insulated wire. The bubble of melted coating occurs not only due to heating from the flame but also due to heating from the core wire. Flame shape is kept nearly spherical, because the balance between propagation speed of leading flame edge which is limited by the cooling effect of core wire and that of coating burn out station which is enhanced by the heating effect is kept.

SUMMARY

In the present study, the mechanism of Polyethylene-insulated wire combustion in microgravity is examined using deformable coating pyrolysis model. Though the flame shape and length of coating gasifying region are different from the results of the previous study, the core wire acts as both heating and cooling medium in the formation of spherical flame. The uncoated core wire inside of the flame receives heat from the flame and conducts part of it to the coating to enhance melting and gasification. At the place where the flame contacts with coated wire, the edge of flame cooled by the core wire trough the melted/solid coating.

ACKNOLEDGEMENT

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References

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[2] Fujita, O., Nishizawa, K. and Ito, K., Proc. Combust. Inst., 29, 2002, to apperar.