§33. Design Feasibility Analysis of a Dry Wall Chamber in a Fast-ignition Laser Fusion Reactor Design FALCON-D

Goto, T., Ogawa, Y. (Grad. Sch. Frontier Sci., Univ. Tokyo)

The dry wall chamber undergoes several threatening effects due to the high heat and particle load. Thus its design feasibility should be examined from diversified viewpoints. Here we adopted reduced activation ferritic steel (F82H) covered with 1mm-thick tungsten for the first wall and pressurized water for the coolant. Tungsten and F82H has been considered to be a potent candidate of the material for high heat flux components and structural material, respectively. Then there are a lot of experimental data of material properties in several extreme conditions. Ferritic steel and water coolant has good compatibility with each other and plenty of databases and experiences in nuclear power plants are available. Then the design with these materials has high engineering feasibility and reliability. That is why we select these materials.

Here we assumed 5.64 m chamber radius (coincides 2 J/cm^2 heat load per shot). First we estimated the temporal temperature evolution by solving the 1-D thermal conduction equation with temperature-dependant material properties. We considered the effect of X-ray, energetic ions, neutrons, and gamma-ray as a cause of heat generation in the material. For X-ray and energetic ions, we used the spectra obtained from the hydrodynamic simulation described in the previous section. These energy deposition profiles were estimated by the photo absorption coefficient [1] and the ion stopping range calculated by SRIM code [2]. The effect of neutron and gamma-ray was calculated by using the three-dimensional Monte Carlo N-particle transport code MCNP-4C with the nuclear data library ENDF/B-V. The water coolant with low temperature may erode the structural material due to the residual hydrogen peroxide produced by radiolysis water decomposition. Such radiolysis effect was recognized as the R&D issues in the water cooled blanket system [3]. Thus here we selected 563 K for the inlet temperature of the first wall coolant with considering the design of coolant path. Then thermal convection coefficient of the coolant water was estimated to be 86.6 kW/m^2·K.

Calculation results of the temporal temperature evolution during the first shot shows that the thin layer close to the surface undergoes large temperature elevation within short time (~2μs), whereas in deeper region quasi-steady state is achieved. In case of an irradiation with 30 Hz repetition, after 10 sec the surface temperature reaches around 1450 K. Due to small thermal diffusivity of solid breeder blanket, it takes a few minutes for the system to reach equilibrium state. However, additional temperature increase of water coolant is expected to be around 20 K and it does not so much affect the maximum temperature on the surface. Therefore, the maximum surface temperature at equilibrium state is much less than tungsten melting point (3680 K) and the threshold temperature of surface roughening (2400 K) [4].

Next we performed mechanical analysis with using this result as a temperature load. The stress-strain relation was modeled by a simple bilinear approximation. In elastic region, temperature-dependent mechanical properties of the material were considered. In plastic region, there are no reliable data and tangent modulus of tungsten was fixed to be 667 MPa. Calculation results on the stress-strain behaviour of the surface layer during the first 3 shots shows that the surface layer undergoes large plastic deformation in not only the heating phase but also the cooling phase. However, this deformation takes place in quite short time and strain rate is quite large (~10^4/s).

Under such large strain rate, many metals show higher yielding stress than quasi-static deformation. Grain size also strongly affects this yielding stress. Then a highly-engineered material, e.g., ultra fine-grained tungsten (UFG-W) [5] can be a candidate, because the yield stress of UFG-W is much higher than that of the standard tungsten because of its quite fine grain size. By taking the fast strain rate into account, the yield stress of UFG-W can reach to 3 GPa at room temperature [6], whereas ~1.2 GPa for the standard tungsten. Then the first wall design with no plastic deformation could be available.

The irradiation of energetic particles also causes other threatening effects. Especially, blistering and exfoliation due to helium accumulation is quite severe. Experimental study in the HAPL project [7] indicated blistering occurs at the helium fluence of 10^{21}/m^2 and exfoliation occurs at 10^{22}/m^2. Assuming that the layer with the thickness coincides to 3.5 MeV helium range is lost when exfoliation occurs, the loss rate of the surface layer of the FALCON-D reactor chamber can be a few millimeters or more per one year, which is totally unacceptable. Here the materials that have micro-structure [8] or fine grain can provide a solution, because it could drastically suppress the concentration of helium, resulting in the loss reduction due to the exfoliation. Experimental study showed UFG-W has high resistance to blistering [9] and it is a possible candidate for the first wall armor. UFG-W also shows high recrystallization temperature and can be attached to other material by HIP method. These properties are also favorable for this design. Though several issues remains, e.g., mass production and building large scale components, UFG-W is a probable candidate for the armor of the first wall.

[1] Henke B L *et al* 1993 *atomic data and nuclear data tables* **54** 181
[2] Ziegler J F 1999 *J. Appl. Phys.* **85** 1249
[3] Lorenzettio P *et al* 1991 *Fusion Eng. Des.* **17** 265
[4] Sethian J D *et al* 2005 *J. Nucl. Mater.* **347** 161
[5] Kurishita H *et al* 2007 *J. Nucl. Mater.* **367-370** 1453
[6] Wei Q *et al* 2006 *Acta Materialia* **54** 77
[7] Gilliam S B *et al* 2005 *J. Nucl. Mater.* **347** 289
[8] Sharafat S *et al* 2005 *J. Nucl. Mater.* **347** 217
[9] Kurishita H *et al* 2008 *J. Nucl. Mater.* **377** 34