Development of Bonding Procedure for Electrical Insulation of the KSTAR TF Magnet

K.M. Kim, H. L. Yang, H.K. Kim, S.T. Kim, J.W. Sa, N.I. Her, C.H. Choi, J.S. Bak
Korea Basic Science Institute, Nation Fusion R&D Center, 52, Yeoen-dong, Yusung-gu, Daejeon, Korea,
kyungmin@kbsi.re.kr

1. Introduction

Toroidal field magnet system of the KSTAR is composed of sixteen TF magnets. Every TF magnet contains superconducting coil, which is encased in a robust TF coil structure to withstand strong electromagnetic forces in the operation. Vertical section of the TF coil structure is 'D' shape, of which height is about 4.2 m, and of which width is about 3 m. The TF coil structure is designed as wedge shape to form a 22.5° sector. Material of the structure is stainless steel 316LN, which has good mechanical properties at cryogenic temperature.[1]

Every sixteen TF magnet is electrically isolated from each other along to toroidal direction to minimize heating from eddy current in the plasma disruption.[2] Electrical insulation material of the TF magnet is composite material, so called G10, which has excellent electrical properties at the cryogenic temperature. All of the insulation material are attached on the cover side of the TF coil structure using bonding materials.[3][4]

In this paper, detail procedures of insulation attachment including requirements, material selections of insulation and bonding, insulation attachment process, and other details are explained and summarized.

2. Bonding Experiment

2.1 Requirements

The bonding material for the insulation of the TF magnet should satisfy following requirements:

a) Available at cryogenic temperature. (4.5 K)
b) Possible to attach G10 on stainless steel.
c) Available in vacuum pressure up to $5*10^{-5}$ torr.
d) Possible to cure the bonding material at room temperature, and to completely cure in 24 hours at high curing temperature (80 °C).
e) Possible to work more than 2 hours at room temperature.

These requirements constraints the selection of bonding material as two candidates such as CTD-528 of CTD Inc.(USA), and Cryoseal(Russia) [5][6]. The two candidates have been comprehensively tested on tension strength for final selection of the bonding materials under various test conditions.

2.2 Tension Test

The tension test has been performed on the basis of ASTM D1002-94 to estimate the shear strength of bonding materials.[7] Size of the specimen is 80 mm in length, 20 mm in width, 2 mm in thickness, and 20 mm in adhesion length, respectively. The specimens were made of stainless steel 304(STS304) and G10 plate. The tension test has been carried out according to following four different conditions to compare the bonding qualities between the two bonding materials:

1) Dependence on the curing temperature : curing at room temperature for 7 days, and curing at 80 ℃ for 4 hours.
2) Application of vacuum pressure to remove voids in the bonding material : removing the void in the bonding materials under vacuum pressure up to 10^{-3} torr, and not removing the void.
3) Surface roughness : scratching surface of the stainless steel 304 with different sandpaper to make surface roughness to be 0.25a, 0.36a, and 0.60a, respectively.
4) Bonding thickness : controlling the bonding thickness by inserting glass fiber (S-glass 75 1/0) between G10 insulation and STS304 with various thickness.

2.3 Results

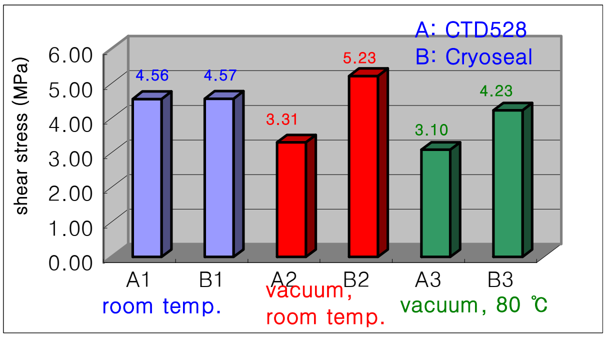

Figure 1. Shear strength according to vacuum environment and curing temperature
(surface roughness of G10 : 1.21a, surface roughness of the STS304 : 0.25a., bonding thickness of the CTD528 and the Cryoseal is 0.04 mm, and 0.06 mm, respectively)

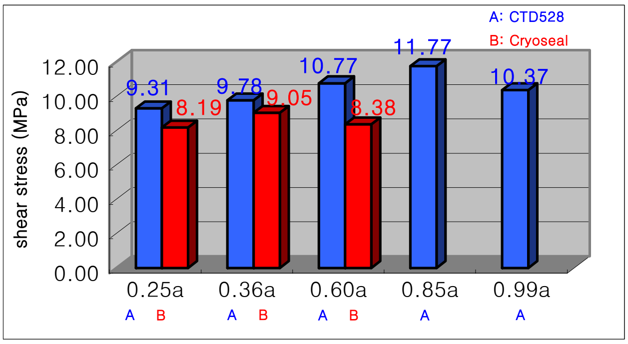

Figure 2. Shear strength according to surface roughness (Bonding thickness of the CTD-528 and the Cryoseal : 0.12 mm, and 0.11 mm, respectively. Curing temperature : 80 ℃ at the air. Surface roughness of STS304 : 0.25a, 0.36a, 0.60a, 0.85a, 0.99a. Surface roughness of the G10 : 1.21a)

Several results and graphs described above show that the bonding thickness and surface roughness mainly affect the quality in the shear strength more than curing temperature and void removing process. The result also shows that the best condition for strongest shear strength and bonding quality is 0.10 ~ 0.13 mm in bonding thickness, 0.60a ~ 0.99a in surface roughness. As a result, the CTD528, which was proved to be better in the shear strength, and to be much easier in the adhesion process than the Cryoseal under same condition, has been selected as a bonding material for insulation attachment for the KSTAR TF magnet.

3. Bonding Procedure

The procedure of the insulation attachment of the KSTAR TF magnet has been decided through comprehensive test and investment to make the bonding strength as strong as possible. The finally determined procedure is as follows :

1) Setting flatness of the TF magnet within 0.50 mm.
2) Cleaning TF magnet and insulation with solvent such as alcohol.
3) Scratching on the cover side of TF magnet each 10 times with sandpaper (#150)
4) Attaching the Kapton tape on the corner surface of the TF magnet
5) Wrapping protective cover on the Kapton tape and side of the TF magnet to prevent bonding material from attaching on the surface where insulation is not necessary.
6) Bonding insulation on the inboard side of the TF magnet.
7) Setting supplementary tools and jigs which is to clamp insulation, so called bonding clamp at the inboard side of the TF magnet.
8) Bonding insulation on the outer inter-coil structure (OIS) of the TF magnet and setting up bonding clamp.
9) Setting heating cable, and cover for the thermal insulation
10) Curing the bonding material for 10 hours with 40 ℃ of curing temperature.
11) Removing heating cable, cover, and bonding clamp.

4. Conclusion

According to the several requirements for bonding the insulations on the surface of the TF magnet, bonding materials and procedures have been tested and invested to achieve maximum shear strength of the bonding layer. The insulation material, G10 has excellent electrical and mechanical properties at cryogenic temperature. Two bonding materials to attach the G10 insulation on the surface of TF magnet were also tested through various condition and requirements.

As a result, the CTD528 was selected as bonding material due to the relatively good properties for the requirements and easy bonding process. Through the various investments for setting the optimum condition of bonding process, the final bonding procedure has been also established and this procedure is now being adopted at real situations.

References

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