Performace Improvement of Nb_3Sn strand for DTT

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Background

Divertor Tokamak Test facility (DTT) is going to be bulit in Italy, and is expected to be operated along with ITER to explore the potential solution for the power exhaust to be eventially implemented in DEMO. Two types of Nb_3Sn strand are required by DTT and total weight is 77 tons. Weight is 55 tons for type one with dominant performance requirement of I_c >280 A (4.2 K, 12 T) and hysteresis loss < 1000 mJ/cm³ (4.2 K, ±3 T). And 22 tons for type two with I_c > 260 A (4.2 K, 12 T) and hysteresis loss < 400 mJ/cm³ (4.2 K, ±3 T). These performance requirements are quite challenging in the respect of performance stability in Nb_3Sn strand production. WST has successfully developed three types of Nb_3Sn strand to meet these requirement especially for DTT. For DTT type one, considering the ultra high level of I_c, Nb and Sn volume was increased based on ITER structure. I_c >300 A (4.2 K, 12 T) and hysteresis loss < 700 mJ/cm³ (4.2 K, ±3 T) were obtained from both 164-filament structure and larger filament structure. For DTT type two, Cu split structure was selected to guarantee low hysteresis level. For 160-filament and one split structure, I_c >260 A (4.2 K, 12 T) and hysteresis loss < 400 mJ/cm³ (4.2 K, ±3 T) have been achieved. Finally all the performance of DTT Nb_3Sn strand has been accomplished by WST.

Experimental

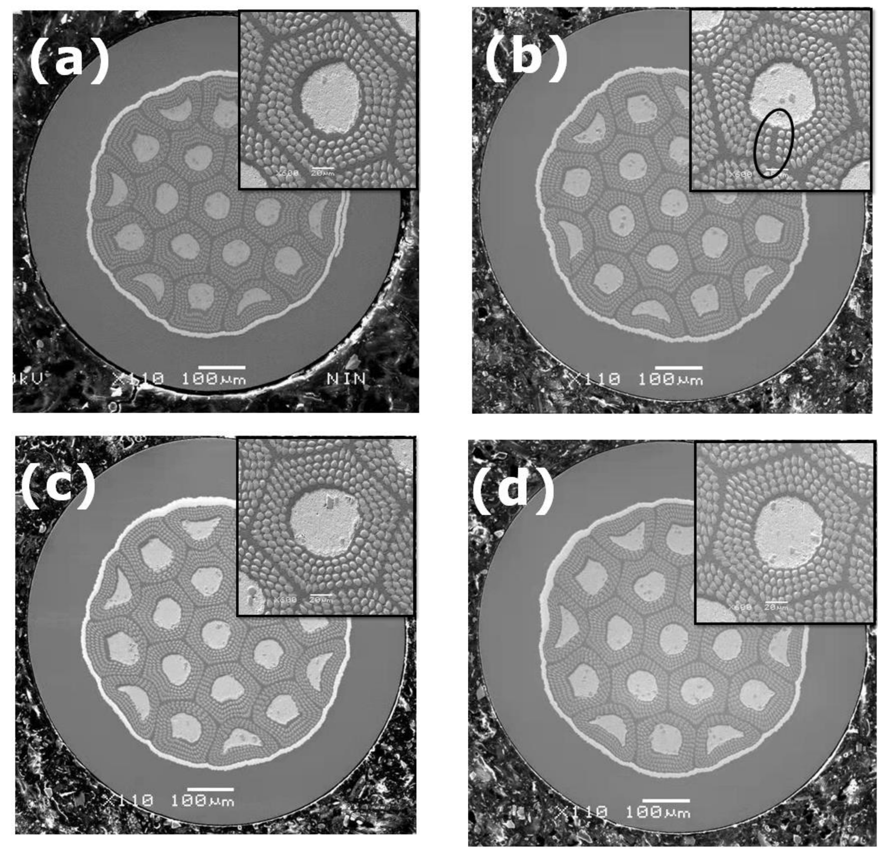

Fig. 1 Cross section of Nb_3Sn strand.

Table 1. Parameters and Structure of Nb_3Sn strands

Type	A	B	C	D
Number of filaments	3040	3040	3116	3040
Cu split	No	Yes	No	No
Nb content increase to Type A	0	0	+0.9%	+1.7%
Sn content increase to Type A	0	0	+1.7%	+1.7%

(a) Type A: Typical ITER Nb_3Sn strand.
(b) Type B: Strand with one Cu split and 156 filaments in each subelement.
(c) Type C: Strand with 164 filaments in each subelement.
(d) Type D: Strand with 160 larger filaments in each subelement.

Results and discussion

I_c and J_{cn} improvement

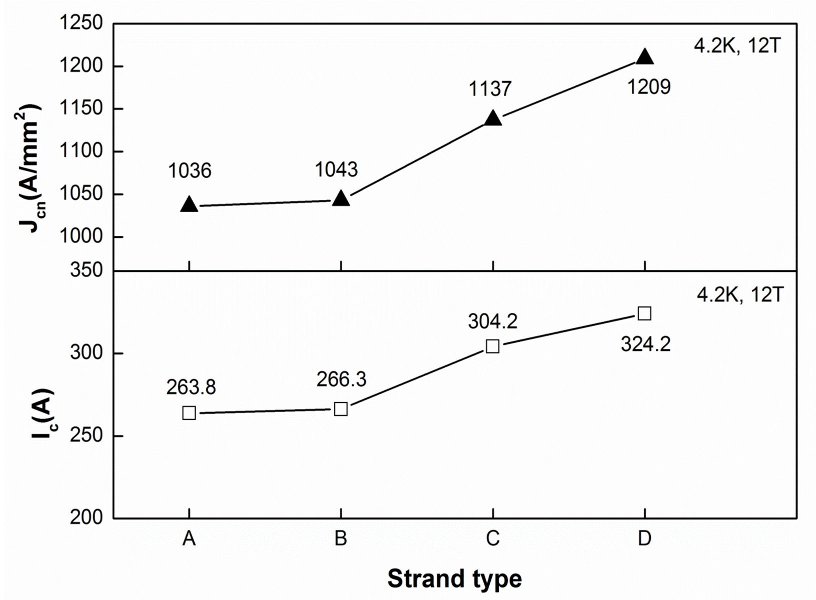

Fig. 2 I_c and J_{cn} of four type strands.

- Type A is typical ITER Nb_3Sn strand with I_c of 263.8 A/mm² , which is close to the minimum I_c of DTT type one and much lower than that of DTT type two. Therefore I_c should be improved by increasing Nb and Sn volume fraction.
- Type B strand with one Cu split and 160 filaments was designed to guarantee a low hysteresis loss level. While I_c of 266.3 A is founed to be as same level as Type A, because of the same Nb and Sn volume fraction.
- Type C strand has 164 filaments with the same filament size as Type A. Nb and Sn volume fraction are increased by 0.9% and 1.7%, respectively. Remarkable I_c improvement of 304.2 A with has been achieved, which can meet the Ic requirement of both DTT type one and type two.
- Type D strand still has 160 Nb filaments but with larger filament diameter. Nb and Sn volume fraction are both imcreased by 1.7%, which results in Ic of 324.2 A.
- Compared with Type A strand, very limited increase of Nb and Sn volume fraction could bring an I_c improvement by 15% and 23%. For clearer comparison with Type A, J_{cn} of Type C and Type D are also improved by 10% and 17%. Correspondingly Cu volume fraction is decreased and drawing ability is regarded to drop. While optimized drawing parameters ensure very few breakages in the series of experimental strands and piece length much longer than 1000 m.

Hysteresis loss improvement

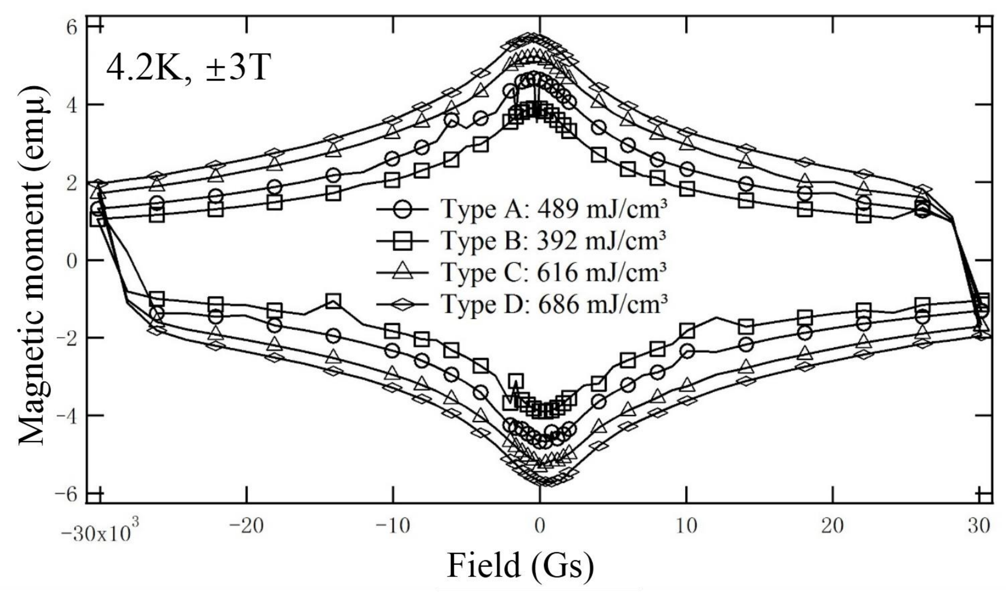

Fig.3 Magnetization plots of four type strands.

- For Type A strand, hysteresis loss is 489 mJ/cm³, which is close to the average level of ITER strand.

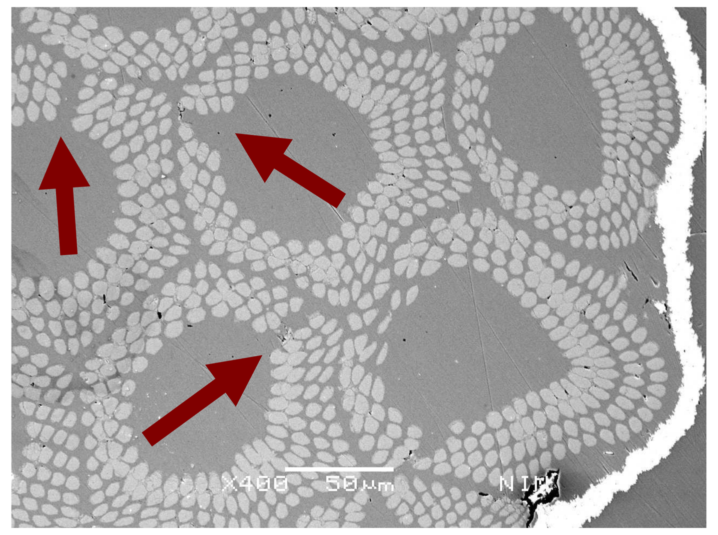

Fig.4 Magnified SEM image of reacted subelements

- For Type B strand, Cu split structure with 160 filaments could guarantee the hysteresis below 400 mJ/cm³, but much higher than that with 156 filaments, from which hysteresis loss around 300 mJ/cm³ has been obtained in our previous report. In Fig. 4, Cu splits are clearly observed in the reacted subelements. These Cu splits could break the bridging Nb_3Sn filaments to some extent. This extra increase of hysteresis loss could be attributed to more severe filament bridging from 4 more Nb filaments, even Ic remains the same level.
- Whenever for Type C with 164-filament structure or Type D with 160 larger Nb filaments, both hysteresis loss is sharply increased. In both situation, Nb and Sn volume fraction increase would lead to less Cu between filaments and easier filament bridging, based on the existed high level of hysteresis loss from Type A.
- Although hysteresis loss are 616 mJ/cm³ and 686 mJ/cm³ for Type C and Type D, respectively, they are much lower than the upper hysteresis loss limit, i.e. 1000 mJ/cm³.

Conclusion

- DTT has proposed considerably critical performance requirement, in parcular on Ic and hysteresis loss. The average performance level of Ic and hysteresis loss for ITER has been selected as the lower limit for DTT. This is remarkable risk in both performance failure and stability variation in large scale production of Nb_3Sn strand.
- For Type B strand, Cu split structure is proved efficient to decrease the hysteresis loss, but much larger than Cu split structure with 156 filaments. Finally Type B strand could meet the requirement of DTT type two with limited margin, meanwhile future work on performance optimization would be necessary.
- For Type C and Type D strand, both Ic and hysteresis loss have been sharply improved, compared with Type A strand for ITER. Both strand could meet all the requirements of DTT type one, particularly there has been sufficient performance margin for Type D.
- WST has developed three novel types of Nb_3Sn strand for DTT. All together these strand could satisfy the performance requirements of two types of DTT Nb_3Sn strand.

Presented at the MT-26, 2019 Sep. 22 – 27, Vancouvor, Canada; Poster No.: Wed-Af-Po3.21-09 [75].