Influence of high pressure hydrogen environment on tensile and fatigue properties of stainless steels at low temperatures

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A very simple and safe mechanical properties testing procedure to evaluate hydrogen environment embrittlement (HEE) in the environment of high pressure and low temperature hydrogen has been developed. In this method, 10 MPa and/or 70 MPa hydrogen environments were produced just inside the hole in the specimen. In this work, the effect of HEE on tensile and fatigue properties for stainless steels SUS304L, 316L, 430, and 630 were evaluated at low temperatures. The results of the evaluation by this testing method agreed fairly well with the results by the usual method using a high pressure chamber. The influence of HEE on the reduction of area of tensile properties for 300 series stainless steels increased with hydrogen pressure and the decrease of temperature, however, it decreased below 190 K and almost disappeared at cryogenic temperatures, below 120 K even in 70 MPa. For SUS 430 and 630, the effect decreased at low temperatures. The effect of HEE in fatigue properties was observed at higher stress level in room temperature and 190 K..

This work was carried out through "Establishment of Codes & Standards for Hydrogen Economy Society" program administrated by New Energy and Industrial Technology Development Organization (NEDO) in Japan..

Fatigue crack growth rate and fracture toughness investigations of ITER central solenoid jacket materials at 7 K

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Fatigue crack growth rate (FCGR) and fracture toughness tests of type 316LN materials machined from planned superconducting cable jacket of ITER's central solenoid magnet are investigated at 7 K. Part of the measurements was performed with specimens having undergone standard solution annealing treatment at 1040 °C - 1 h, whilst the other part with solution annealed specimens at 1100 °C - 4 h. In addition, similar jacket materials with standard solution annealing heat treatment of 1040 °C – 1 h following a compaction and aging procedure are also investigated at 7 K. All fracture toughness measurements were carried out according to ASTM standard E 1820 using the single specimen unloading compliance technique. All specimens have been tested with crack propagation and extension in longitudinal as well as in transversal orientation of the jacket. The results of the investigations show for FCGR tests for samples having undergone longer solution annealing at higher temperature a slightly higher crack propagation rate. After the FCGR tests, specimens have been directly measured with respect to J-integral. The results of these fracture toughness's in all cases were lower than with tests conducted with specimens dedicated to J-test, measured after the short pre-cracking procedure. Within this context side grooving showed almost no effect with respect to fracture toughness values. The FCGR comparison between JAEA, Japan and KIT/CEME, Germany carried out with compacted and aged samples showed a factor of 1.5 to 2 lower FCGR behavior for the measurements performed at KIT/CEME in contrast to JAEA. Contrary to this, test series conducted on the same material, however, only with a standard solution heat treatment show marginal differences of FCGR data between these two institutions.

Effect of specimen shape on elongation of 316LN jacket for ITER toroidal field coil

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Japan Atomic Energy Agency (JAEA) has a responsibility for procurement of 25% of the ITER Toroidal Field (TF) coil conductors as Japanese Domestic Agency (JADA) of the ITER project. The TF coil conductor was composed of 900 Nb_3Sn superconducting strands and 522 Cu strands protected by circular sheath tube (jacket) with the outer diameter of 43.7 mm with a thickness of 2 mm. The jacket section is a seamless tube made of modified 316LN. The ITER requires that cold worked and aged jacket satisfies 0.2% offset yield strength of more than 950 MPa and elongation (EL) of more than 20 % at 4 K. JAEA tested different types of tensile specimen (Japanese Industrial Standards (JIS) type and ASTM type) cut from jacket. ASTM type specimen has longer and wider reduced section than those of JIS type specimen. Elongation of as received condition is not dependent on specimen shape. But after cold work and aging, the elongation is deteriorated due to a sensitization and scattering of elongation is larger than that of as received condition. Fracture mode of aged jacket is “cup and cone fracture”, which have a mixture of inter granular at center area and trans-granular factures in circumference area. It is considered that initiation of fracture is more sensitive on test specimen shape with low ductility. However, the tested jacket shows elongation of more than 20%, which satisfied the ITER requirement, in different shape. In the paper, scattering of elongation in different specimen shapes is discussed.

Cold work study on 316LN modified alloy for the ITER TF coil conduit application

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In cable-in-conduit conductor (CICC) magnets, such as the ITER TF coils, the conduit is the primary structural component. This function creates requirements for strength, toughness, fatigue crack resistance, and ductility after exposure to the superconductor's reaction heat treatment. The tensile ductility of a steel is a quality factor related to fatigue and fracture resistance that can be evaluated more economically with tensile tests rather than fatigue and fracture tests. Here we subject 316LN modified base metal and welds to a range of cold work from 0% to 20% and a subsequent Nb3Sn reaction heat treatment to evaluate the effects on the tensile properties. With the addition of cold work, the 4 K yield strength increases while tensile elongation decreases in both the base metal and weld. The results are compared to previously published data on the same alloy to help appraise the use of tensile ductility parameters as a materials qualification specification in magnet design.

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Estimation of Tensile Strengths at 4K of 316LN Forging and Hot Rolled Plate for the ITER Toroidal Field Coils

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A prediction method for tensile strengths at liquid helium temperature (4K) has been developed in order to rationalize qualification tests of cryogenic structural materials used in large superconducting magnet for a fusion device. This method is to use quadratic curves which are expressed as a function of carbon and nitrogen contents and strengths at room temperature. This study shows results of tensile tests at 4K and confirmation of accuracy of prediction method for tensile strengths at 4K for large forgings and thick hot rolled plates of austenitic stainless steels, which can be used in the actual coil case and radial plates of the ITER toroidal field coils. These products are 316LN having high nitrogen from 0.09 to 0.24% and maximum thickness is 600mm. As the results, it was confirmed that the tensile strengths of these products at 4K can be predicted by using appropriate quadratic curves. And distribution of strengths for each product was estimated.

Mechanical Tensile Testing of Titanium 15-3-3-3 and Kevlar 49 at Cryogenic Temperatures

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Titanium 15-3-3-3 and Kevlar 49 are highly desired materials for structural components in cryogenic applications due to their low thermal conductivity at low temperatures. Previous tests have indicated that titanium 15-3-3-3 becomes increasingly brittle as the temperature decreases. Furthermore, little is known regarding the mechanical properties of Kevlar 49 at low temperatures, most specifically its Young's modulus. This testing investigates the mechanical properties of both materials at cryogenic temperatures through cryogenic mechanical tensile testing to failure. The elongation, ultimate tensile strength, yield strength, and break strength of both materials are provided and analyzed here.

Optimization of Cryosoaking time and its effect on wear behavior of complex alloyed M35 tool steel

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Cryogenic treatment has been used commonly to high speed tool steels in order to enhance the wear resistance of the materials. This improvement in wear property is corroborated to decrease in retained austenite and or by formation of eta-carbide. It was noted from the published literature that researcher have inadvertently used cryosoaking time for treating tool steels at cryogenic temperature without systematically optimizing for treatment cycle/sequence. In the present research work, specimens of complex alloyed high speed tool steel (M35) were hardened (1200^{o}C), triple tempered (400^{o}C) and then cryogenic treated at minus 185^{o}C for varying level of time interval starting from 4 hours to 48 hours of cryosoaking followed by soft tempering (100^{o}C) to relieve residual stresses of cold treatment and this treatment was designated as H-T-C and in another case cryogenic treatment was given immediately after hardening treatment but before triple tempering and this sequence of treatment was designated as H-C-T. Cryogenic treatment response of material was measured in terms of wear rate, bulk hardness and SEM microstructural analysis of carbide density, size and shape of the carbides. A comparative study of both treatments viz. H-C-T and H-T-C was investigated from metallurgy point of view and its implication on material properties. Based on the analysis of the data, an optimum condition for wear resistance was established.

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Differential Cryo-warming up on morphological features of the carbides in M2 tool steel

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Cryogenic treatment is known to induce metallurgical transformation / changes in metallic matrix. It has profound influence on service life of the tool steel components, many of the cases life of the HSS tool increases to many folds. This has excited researcher to relook at the microscopic changes and science of the material. In the present work on M2 tool steel, the influence of warming up rate after adequate cryosoaking was attempted. Specimens of M2 tool steel were hardened (1200^{o}C), cryogenically treated at minus 185^{o}C for 16 hours and then at the end of cryosoaking, one set of specimens were given fast warming up (FWR) by quenching in water and another set of specimens were subjected to slow warming up (SWR) in the well insulated thermocol box till the specimens attained room temperature. Both these sets of specimen were triple tempered (400^{o}C). Microstructural analysis using SEM and optical were carried out in addition to hardness and wear rate analysis using Pin-On-Disc wear machine. A qualitative correlation of carbide morphology with warming up rate was established. It was concluded that warming up rate has significant influence on density of the carbide as well as kinetics of carbide precipitation.

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Multi-Phase Inclusions in High Performance YBCO Thick Films for Coated Conductors

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High critical current densities (J_c) in $YBa_2Cu_3O_y$ (YBCO) coated conductors depend directly upon the connectivity and defect density within the films. Hence, one needs to develop methodologies for controllably introducing defect structures that are sufficient for tailoring the superconducting properties while, on the other hand, maintaining high critical current and uniformity over lengths exceeding a kilometer. A number of defect structures have been shown to be effective flux pinning centers. The most efficient structures for raising Jc across all orientations of applied fields ($J_C$min) involve two or more different secondary phases. Our work has focused on the ubiquitous Y_2O_3 and some double-perovskites, $A_2BB'O_6$ where A = Ba, B = Y or another rare-earth, and B´ = Zr, Nb, Sn, Ru, and mixtures thereof. Through changes in composition and targeted sets of additions, we show that it is possible to significantly reduce detrimental defects while precisely controlling the types and densities of pinning defects within films, leading to enhanced performance in thick YBCO films. J_c values (SF, 75.6 K) of 5 $MAcm^{-2}$ (1000 A/cm-w) have been reached in 2 micron thick films with Y_2O_3 and $BaZrO_3$ additions. Flux pinning forces of 32.3 and 122 GNm^{-3} (75.5 and 65K, respectively) have been obtained in a 0.5 micron YBCO film with Ba_2YNbO_y additions.

Correlation between self field and in-field critical currents on 700 A (cm-width)-1 coated conductors fabricated by reactive co-evaporation on IBAD substrates

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Coated conductor tapes fabricated by reactive co-evaporation of SmBaCuO on IBAD substrates have been characterized for critical current properties and uniformity along their lengths. Self field critical currents $I_c(H=0)$ between 200 and 300 A were measured at 75 K on 4 mm wide tape. These I_cs correspond to 500 - 700 A $(cm\text{-}width)^{-1}$ conductors and compare favorably to coated conductor performance as reported in the literature. A standardized power law fit to the I_c(H, Angle) data was used to investigate the anisotropic field dependence of segments cut from the two 10 m conductors. The use of the exponent from this curve fitting method allows a quantitative comparison of the field dependence between conductors over the range of angles relevant to tape microstructure. Results show the two tapes to have similar H||c-axis properties in spite of large differences in $I_c(H=0)$. A correlation was found between the $I_c(H||ab)$ (μ_0H ~0 - 1 T) and $I_c(H=0)$ that suggests a stronger link between $I_c(H=0)$ and $I_c(H||ab)$ than between $I_c(H=0)$ and $I_c(H||c)$ performance. These results will be presented along with a description of the experimental apparatus, the I_c and n-value data analysis, and a comparative microstructural analysis contrasting the two conductors for a determination of the structure-property-chemistry relationship in these high performance coated conductors.

Visualizing current limiting obstacles in YBCO coated conductors deposited on clad-type textured substrate

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Current limiting obstacles in coated conductors on clad-type textured substrate have been investigated by using spatially resolved measurements on flux flow dissipation and grain structure. Tape architecture adopting Ni-alloy textured substrate is promising approach to realize low cost and high performance RE-123 coated conductors. Sumitomo Electric Industries, Ltd., has succeeded to develop clad-type textured substrate to reduce the amount of Ni-alloy significantly, therefore can solve the problems of 1) magnetization losses and 2) mechanical strength in the substrate. Critical current density, J_c, of the tape has reached more than 2 $MAcm^{-2}$ at 77 K, self-field. In this study, in order to investigate the feasibility of higher J_c, we have visualized local flux flow dissipation and grain structure simultaneously by using low temperature laser scanning microscopy and laser induced thermoelectric effect imaging, respectively. Comparing these two images, we have identified a few current blocking grain boundaries. While the transport J_c is limited by the lowest J_c region, other region can carry 20 % higher transport current than the apparent J_c value in the four probe measurements.

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Systematic Study of Flux Pinning of Y-Ba-Cu-O Superconductor with Nanoparticle Additions

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Methods to enhance the flux pinning and critical current density (J_c) of Y-Ba-Cu-O superconductor by addition of varying nanosize defects have been studied by many research teams in recent years. Thus far, J_c was optimized for additions typically at 2-10 Vol%, which is different from low-temperature superconductors such as NbTi where additions up to 25 Vol% correlate with increasing J_c. Herein we present systematic studies on nanoparticle additions, particularly focusing on how to increase and optimize the volume percentage. Only select nanoparticle phases were chosen, including M = Y_2O_3, $BaZrO_3$, $BaSnO_3$, and Y_2BaCuO_5 (Y211). Thin films of (YBCO+M) were deposited on single-crystal substrates by pulsed-laser deposition, and processing parameters were varied to optimize J_c(H,T) include deposition temperature from 775°C to 840°C, additions from 0 to 20 Vol%, and different methods including $(M/YBCO)_N$ multilayer and $(YBCO)_{1-x}M_x$ single-target methods. The processing conditions and microstructures that maximize J_c for varying regimes of operation temperature from 5K to 77K and magnetic field and orientation were studied. We have found that several phases, including Y211 and $BaSnO_3$ can achieve much higher additions > 15 Vol% without reducing T_c or J_c(77K,self-field) significantly; whereas other common phases such as Y_2O_3 had surprisingly serious degradation for only > 8Vol%. The comparisons for the different systematic studies will be shown and discussed.

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Effects of bulk pinning and applied field on edge barrier pinning in superconducting thin films

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The sample edge of a superconductor can provide a barrier to magnetic flux delaying its penetration into the sample thus enhancing the critical current density (J_c) of the sample. Edge barrier enhancements are commonly neglected, but recent work by our group has demonstrated that the bridge width is as critical as bridge thickness for J_c measurements. The work here provides additional theoretical and experimental information to further quantify this effect. The J_c enhancement can be effected by many different parameters including applied field and added bulk pinning centers within the sample. Analysis of how these parameters affect edge barrier pinning will be provided.

Critical temperature enhancement (T_c=21K) by biaxial compressive strain in $FeSe_{0.5}Te_{0.5}$ thin films

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High purity epitaxial $FeSe_{0.5}Te_{0.5}$ thin films with different thickness were grown by Pulsed Laser Ablation on different substrates. By varying the film thickness, T_c up to 21K were observed, 5K higher than the bulk value. Structural analyses indicated that the a axis changes significantly with the film thickness and is linearly related to T_c. The latter result indicates the important role of the compressive strain in enhancing T_c: the compressive strain derive from the Volmer Veber growth of the films. STM images confirm this hypothesis. The critical temperature is also related to both the Fe-(Se,Te) bond length and angle, suggesting the possibility of further enhancement. These high quality thin films present a huge, nearly isotropic, critical field value (around 60T) and critical current density greater than 10^5 A/cm^2 with a weak field dependence. All this characteristics make this material appealing for applications.

Correlation between enhanced T_c, orthorhombicity and AC magnetic shielding in argon preheated high T_C superconductor $(Y_{1-x}Sm_x)(SrBa)Cu_3O_{6+z}$

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We report here on the preparation, X rays diffraction, AC magnetic susceptibility measurements and effect of heat treatments in $(Y_{1-x}Sm_x)(SrBa)Cu_3O_{6+z}$. Each sample was subject to two types of heat treatment: oxygen annealing [O] and argon annealing followed by oxygen annealing [AO]. For each x, the [AO] treatment increases the orthorhombicity $\varepsilon = (b-a)/(b+a)$ (for $0 \leq x \leq 1$), T_c (for $x \geq 0.4$) and the distance d[Cu(1)-(Sr/Ba)] for x< 0.5 and decrease it for x> 0.5. When x increase from 0 to 1, ε decreases with T_c[O]. However, T_c[AO] decreases with ε until x = 0.2 and after it increases by 6 K to 85 K for x =1 [AO]. A remarkable improvement in the shielding effect S, in the case of the samples [AO] at all $T < T_c$ and for any applied field, was observed for x > 0.5 indicating an improvement in the pinning properties. Remarkable correlation was observed**.** A combination of several factors such as decrease in d[Cu(1)-(Sr/Ba)]; increase in cationic and chain oxygen ordering; p_{sh} and in-phase purity for the [AO] samples may account for the observed data.

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The Injector Cryomodule for e-Linac at TRIUMF

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The e-Linac project at TRIUMF, now funded, is specified to accelerate 10mA of electrons to 50MeV using 1.3GHz multi-cell superconducting cavities. The linac consists of three cryomodules; an injector cryomodule with one cavity and two accelerating modules with two cavities each. The injector module is being designed and constructed in collaboration with VECC in Kolkata. The design utilizes a unique box cryomodule with a top-loading cold mass. A 4K phase separator, 2K-4K heat exchanger and Joule-Thompson valve are installed within each module to produce 2K liquid. The design and status of the development will be presented.

Mechanical Properties of RRR Nb from the Heavily Worked to Fully Annealed Condition

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The mechanical properties of highly pure (RRR) Nb are dependent on the type, level of impurities, and microstructure. Substantial plastic deformation of annealed Nb often leads to localized non-uniform strains which manifests as shear banding. This circumstance leads to non-uniform deformation behavior in the material, and is cause for concern when hydroforming Nb tube into SRF cavities. However, plastic strain combined with periodic recrystallization decreases the tendency for shear banding, and the situation improves as the number of strain-annealing cycles increases. This is because the recrystallized microstructure becomes more uniform as the number of strain-annealing cycles increases. The authors hypothesize that shear bands form in Nb after recrystallization and subsequent deformation because of localized differences in grain size, texture, or chemistry. In order to fabricate SRF cavities to relatively high geometric tolerances by deformation methods, the Nb must deform uniformly in the available strain space. The current report presents mechanical property results on bulk high RRR grade Nb at various stages of thermo-mechanical processing, namely: a) as received, b) as worked, c) partially recrystallized, d) fully recrystallized to a fine grain size, and e) fully recrystallized to a larger grain size. This information gives us an increased understanding of RRR Nb formability under different microstructural conditions and could be useful in designing a processing methodology for successful SRF cavity fabrication by hydroforming.

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Microstructure and Mechanical Properties of RRR Nb Tube Processed by Severe Plastic Deformation

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Singer and co-workers, and scientists at KEK have successfully fabricated RRR Nb superconducting radio frequency (SRF) cavities by hydroforming. The key microstructural characteristics desired for hydroforming include: fine grain size, favorable texture, and uniformity. This is a significant challenge because tube making often involves steps that encourage a non-uniform microstructure, and because microstructure and formability are dependent on precursor microstructure and thermo-mechanical processing (strain path and heat treatment), convergence to a uniform microstructure is difficult. The authors have previously shown that thermo-mechanical processing steps involving severe plastic deformation (SPD) via equal channel angular extrusion (ECAE) can breakdown highly non-uniform microstructures in pure Nb to yield a uniform fine grain material. In the current work we examine the microstructure and mechanical properties of 38 mm diameter 2.9 mm wall thickness seam-welded RRR Nb tubes given multi-pass ECAE processing.   Microstructure (grain size, texture, and uniformity), and mechanical property (strength, hardening, ductility, and anisotropy) results are reported for tubing at different stages of annealing following SPD processing.   Emphasis is given to material characteristics relevant for hydroformability.

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The Role of Heat Treatment Temperature on the Thermal Conductivity of Superconducting Niobium

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High purity niobium is used to fabricate superconducting magnets and superconducting radio frequency cavities. During operation of magnets and cavities, localized heating at material imperfections can cause the niobium to become normally conducting and suffer a thermal quench. The thermal conductivity k of superconducting niobium decreases as the niobium cools below its 9.25 K critical temperature, due to the decreasing population of normally conducting electrons. A local minimum in k occurs at about 3 K, where most of the electrons have formed Cooper pairs, and k then increases several fold compared with the minimum until about 1.8 K, where there is a local maximum in k due to phonon transport. The material processing history significantly influences k for $T < 9.25$ K by introducing dislocations and other imperfections. The unknown variation of k with these parameters adds significant uncertainty in predicting the thermal performance of any device.

Measured values of k for $1.6 \text{ K} < T < 4.6 \text{ K}$ are reported for several specimens with various crystal and bi-crystal orientations and having different process histories. The experiments use steady state temperature profiles and results are analyzed using a novel parameter estimation method that incorporates a theoretically based model for k of superconductors. The temperature dependence of k is reported for the several specimens that were cut from ten large-grain ingots having tantalum contents between 500 – 1350 ppm. The effects of heat treatments at $600\ °\text{C} < T < 1200\ °\text{C}$ are also investigated, showing that the magnitude of k at the phonon peak increases with the heat treatment temperature. The thermal conductivity is correlated with the heat treatment parameters, crystal direction, and tantalum content.

Electropolishing of Niobium to Obtain Defect Free Surface

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Pure niobium is used for making Superconducting Radio Frequency (SRF) cavities. The SRF cavities are used in particle accelerators for high energy physics applications to study the nature of elementary particles. These cavities need to have a good surface finish to achieve maximum performance. Surface defects like grain boundaries and pits seriously affect their performance. Electropolishing (EP) in hydrofluoric/sulfuric acid is commonly used as a final process to give a good surface finish to the niobium surface. However the optimum EP conditions have not been fully explored. To further study the parameters necessary for an optimum surface finish, an electrolytic cell made of 99.999% pure Al has been designed. Pure Al is resistant to HF and it also can be used as the counter electrode in the niobium EP process, as the CE is usually pure Al. Acid concentration, stirring, and temperature are the parameters expected to affect the surface finish and their effect is studied using flat Nb specimens. The electrolyte used is a mixture of HF (48%) and H_2SO_4 (96%). The proportion of HF and H_2SO_4 is also critical to the surface finish obtained. The effect of the above parameters on the level of surface finish is studied. Optical microscope, SEM, AFM and optical profilometer is used to characterize the level of surface finish obtained. There is also a strong dependence of performance on the oxide layer that forms on the surface of SRF cavities. XPS with depth profiling and SIMS is planned to study the chemical composition of the surface in order to further optimize the electropolishing parameters.

Annealing to mitigate pitting in electropolished niobium coupons and SRF cavities

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Prevention of weld pits is an unsolved problem nagging the development of superconducting radio-frequency (SRF) cavities. Several research groups have noted a strong correlation between cavity quench location and the location of weld pits in poorly performing cavities. To understand this problem on a fundamental level, we recently explored electropolishing (EP) of niobium coupons that simulate cavity welds under conditions very close to those used to process (SRF) cavities [*IEEE Trans. Appl. Supercond.* **15**, to appear]. Significantly higher tendencies for pitting were found for many combinations of EP variables when the niobium metal was in a cold-worked state than when it was in an annealed state. Since all SRF cavities are welded and then processed by chemical etching and EP without recovering the cold work due to forming, stress corrosion is a plausible mechanism for the formation of weld pits. Here, we report recent work at Fermilab to remove stress corrosion by returning the material to a recovered state prior to EP. Coupons were annealed in a high-vacuum furnace using different combinations of time and temperature, and hardness measurements were used to gauge recovery. For single-cell cavities, annealing is being applied after the forming of half-cells and prior to electron-beam welding. The results of coupon topography, roughness, and pitting in response to different EP parameters will be presented. Also, the status of single-cell cavity experiments will be reported.

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Recently developed techniques combining images of the inner surface of SRF cavities with temperature mapping, show that grain boundaries (GBs) in 9-cell prototype SRF Nb cavities are strongly associated with local quenching of surface superconductivity in high RF field mode. Using magneto-optical (MO) imaging, we found that GBs in high purity SRF-quality Nb bi-crystals can preferentially admit flux when the plane of a GB is aligned parallel or close to parallel to the vector of the external magnetic field. In DC transport in the superconducting state, we found preferential flux flow (FF) at the GB of BCP'ed niobium and detected a transition from single to multiple rows of vortex flow. In addition, we quantified the angular dependent GB flux flow of a BCP'ed bi-crystal by performing *V-I* transport characterization while rotating the plane of the GB against the vector of the external magnetic field. In order to relate our findings from DC characterization to RF properties, we are extending this study to Nb thin films grown on MgO substrates at TJNAF; these thin film measurements should enable us to obtain the grain boundary depairing current density, $J_{b,gb}$, which is an important parameter for determining the thermodynamic limitation of SRF niobium properties.

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Studies on thin film MgB_2 and other superconductors for applications to RF structures for particle accelerators

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In order to overcome the limitation of Nb associated with its theoretical RF critical magnetic field of ~200 mT, which corresponds to ~50 MV/m of accelerating gradient for electron accelerators, studies of coating thin superconductors such as MgB_2 have been carried out. The magnetic fields at which vortices start to penetrate into the superconductor (B_{pen}) have been measured in DC at LANL. Low-field RF properties and quench fields at high fields have been measured using 11.4 GHz high-power RF pulses at SLAC. It has been found that the B_{pen} for thin film MgB_2 is significantly higher than bulk Nb, e.g., a 300 nm film showed a B_{pen} of ~ 215 mT compared to ~145 mT of a Nb rod at 4.5 K. RF measurements, however, have shown low quenching fields of ~25 mT for the identical sample. This discrepancy is being investigated.

Numerical and experimental studies for ac losses in IBAD and RABiTS YBCO coils

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In this presentation, numerical and experimental approaches were employed to investigate several ways for reducing AC losses in high temperature superconducting (HTS) coils wounded from YBCO tapes with RABiTS or IBAD template. For the computational approach, 2D finite element models implemented in COMSOL Multiphysics were used. The field and angular dependences of critical current density measured on short sample tapes were taken into account in simulations for better calculation accuracy. In simulations for RABiTS coils, the nonlinear field dependences of the magnetic permeability and ferromagnetic loss of the substrate were also taken into account. In order to understand the effect the conductor striation on AC losses of a YBCO coil, the studies were carries out on two 43 turn IBAD coils with identical dimensions, but one wound from original (unstriated) tape and the other wound from striated tape. The simulation models, after being validated against experiments, were also used to understand the effect of the orientation of ferromagnetic substrate on AC losses in several RABiTS coils wound from back-to-back (substrate-to-substrate) or front-to-front (YBCO-to-YBCO) stacks of two RABiTS tapes. These studies are important to suggest an effective way to reduce AC loss in YBCO coils.

Quench propagation velocity studies in HTS using small bifilar coils

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Quench propagation velocity studies are necessary for HTS high field magnet applications at low temperatures. As a part of this R&D, small 10-turn bifilar coils (OD =60.1mm, ID=54.6mm) are being wound with second generation (2G) HTS tapes. Kapton tape is used for turn to turn insulation. These coils are instrumented with voltage taps and quench initiation heaters. Critical current and quench propagation velocities will be measured at 4.2 K in background fields ranging from 0 to 8T, parallel to the wide face of the conductor. Details of these measurements as a function of current and field will be presented.

Variable temperature transport AC loss measurement in 2G superconducting pancake coil

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Transport AC loss measurements in High Temperature Superconducting (HTS) coils or complex stacks and bundles of superconducting tapes are needed to estimate heat load in applications involving AC transport current and/or AC magnetic field. AC loss data at variable temperature provides insight into the dependence of AC losses on critical current density. This paper presents transport AC loss measurements on 2G HTS pancake coils at 77 K and lower temperatures down to 68 K. Details of the electrical technique for transport AC loss measurements in coils and data on several pancake coils as well as comparison of the data on coils wound with single tape and stacked tape bundles will be presented.

* U.S. Department of Energy
** Center for Advanced Power Systems at Florida State University

AC losses in coils made of 2G tape

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We present measurements of AC losses in multi-pancakes and on solenoidal coils with different geometries made of YBCO-tapes. Measurements were performed at temperatures 47-77 K at frequencies ranging from 50 to 800 Hz by electric and calorimetric methods. The results of electric and calorimetric measurements show very good coincidence. We observed decreasing with decreasing of the losses with decrease of the temperature The losses are found to depend strongly on coil configuration and linearly increase with increasing frequency. The central pancakes in the coils exhibit larger AC losses than pancakes situated at the ends. Also, AC losses within pancakes depend on adjacent pancakes, even if kept in an open circuit state. Introducing a gap between pancakes/double pancakes can be used as a means of decreasing AC losses in multi-pancakes HTS coils.

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Influence of Alternative Insulation Materials on Three-Dimensional Quench Propagation in YBCO Coated Conductors and Coils

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To increase the integrity in YBCO coated conductor coil configurations, it is necessary to develop effective approaches for quench detection and protection. While quench behavior is affected on a micro-scale by conductor architecture and the constituent property, a macroscopic-scale effect is introduced by the selection of the insulation material. Using an electrically insulating, thermally conducting insulation results in radial turn-to-turn thermal diffusion for one/two mixed-dimensional modeling. In this study, the effect of insulation properties on quench propagation in a two/three mixed-dimensional YBCO coil model is investigated. Thin layers are approximated as a 2-D surface or using contact resistance to pair the 2-D and 3-D surfaces. Using COMSOL, a commercial finite element analysis program, the variance in several quench indicators is determined. In particular, the effects on multi-dimensional propagation and key quench protection parameters such as peak voltage, peak temperature and peak temperature gradient, are studied.

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Experimental study of magnetic field effects on the stability margin and quench propagation velocity of wind-and-react $Bi_2Sr_2CaCu_2O_x$ coils

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As part of the VHFSMC effort aimed at the development of high field superconducting magnet technologies for high energy physics, the 2-D and 3-D quench behavior of $Bi_2Sr_2CaCu_2O_x$ (Bi2212) coils is investigated in a magnetic field up to 20 T. In particular, this study focuses on the field-dependence of the minimum quench energy and normal zone propagation velocities. Multi-layer coils are constructed from Bi2212 strand and fitted with an array of thermocouples and voltage taps located relative to a heater attached to the coil. Preliminary results show that a thermally induced quench is more likely to occur when a voltage pulse is delivered to the heater in the presence of a magnetic field. The transport current in the coil, and thus Joule heating, however, act as the primary drivers for in-field quench propagation. These results lay the groundwork for a comprehensive study of quench generation, propagation and detection for protection of high field magnet systems.

Fault Current Limiting Properties of a coil wound non-inductively using a superconducting wind-and-react MgB_2 cable

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We have investigated via experiment and computation a model FCL coil made from magnesium diboride cable. The triplet cable was wound non-inductively into a coil, modeling a part of the winding of an element in a resistive superconducting fault current limiter. Using an ac pulsed power system, which could deliver a fixed number of AC cycles to mimic a fault, we tested a quench development along the cable in the coil. Experiments have been carried out in vacuum with conduction cooling provided by a cryocooler. The MgB_2 strand used for the cable was a multifilamentary wire with monel outer sheath and Nb barriers. A number of voltage taps spaced at about a half-turn intervals, were used to assess the effect of inhomogeneity and temperature gradient in the winding. Temperature distributions were measured by distributed thermo-couples along the cable in the winding. The current limiting properties of the coil were measured using ac current pulses and a sensitive real time DAQ system operated via LabView.