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# Challenges in Long-Length Scale Up of High Ic RABiTS$^{TM}$/MOD-YBCO-based Coated Conductors

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***Abstract*—The RABiTS$^{TM}$/MOD-YBCO route has been identified as a low-cost manufacturing process for high performance 2G wire. AMSC has used this approach to design a full-scale production line based on a "wide-strip" manufacturing process. The current production-scale equipment is designed to process strips with a width up to 10 cm and length up to 1 km; however, the initial operation of the equipment uses a 4-cm wide strip. As with any new manufacturing technology, a number of start-up issues were experienced during the commissioning of the production line. This paper describes some of the successes in addressing these issues, as well as ongoing efforts to improve processing yield.**

## I. INTRODUCTION

Second generation (2G) high temperature superconducting (HTS) wires (AMSC's laminated architecture is called "344 superconductors") have moved out of the laboratory and are now being produced in the quantity, and with the performance required for large-scale commercial application demonstrations. The initial production of 2G wire is being carried out in a production-scale manufacturing facility brought on-line by American Superconductor (AMSC) at the end of 2007. In this paper, we describe the general approach to develop and commission the 2G manufacturing process. We also discuss a few of the issues encountered during the initial commissioning of AMSC's 2G manufacturing line and the successes in addressing them.

## II. SCALE-UP OF 2G WIRE MANUFACTURING

The development and scale up of the 2G wire process at AMSC involved three stages: (1) an R&D stage, (2) a pilot stage and (3) a full-scale manufacturing line. Each of these stages focused on different aspects of the technology, but each was critical to addressing issues related to final performance, yield and cost of the process

***R&D Stage:*** The R&D stage focused on evaluating various technologies for both the template and HTS layers in terms of technical feasibility, inherent performance and manufacturability. This initial work identified the RABiTS/MOD-YBCO technology as the best selection for high performance, low-cost process based on a "wide-strip" roll-to-roll manufacturing process. The R&D efforts then focused on designing and testing reel-to-reel processing technologies compatible with the RABiTS/MOD processes. This stage culminated on the demonstration of the RABiTS/MOD-YBCO process in R&D scale, reel-to-reel equipment designed to process 1-cm wide strips up to a few meters in length.

***Pilot Stage:*** The primary focus of the pilot stage was developing and testing the key processing technologies and reel-to-reel machines required for the "wide-strip" technology. A major requirement was designing equipment capable of replicating the R&D processes while achieving the same level of performance in a continuous, high-rate "wide-strip" process.

The work focused on testing and evaluating various manufacturing technologies and machine designs, and selecting the specific processes based on a variety of factors including performance, deposition rates, line speeds, manufacturability, capital cost, operating costs, etc. A primary goal throughout this stage was insuring that the processes and machines were capable of achieving the target cost and yield metrics required for a commercial 2G wire. Throughout this stage, work also focused on qualifying vendors and establishing their capability for supplying materials in production quantities. This stage concluded with the demonstration of a pilot line capable of processing a 4-cm wide strip in lengths up to 100 meters. The 344 superconductors produced from this process achieved critical currents of ~100 A as shown in Fig. 1 [1].

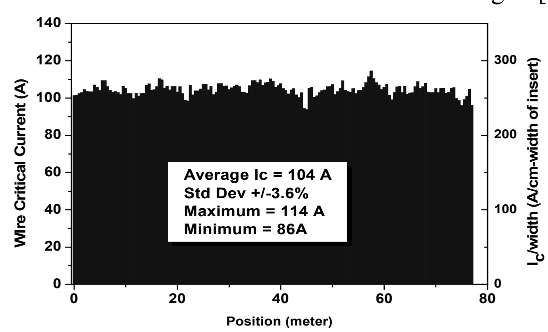


Fig. 1. Benchmark performance ($I_c$ at 77K, self-field) of a 344 superconductors produced AMSC's in pilot manufacturing line (0.8 µm $Y(Dy_{0.5})Ba_2Cu_3O_y$ layer) [1].

***Production Stage:*** The Production stage focused on designing, building and commissioning production-scale machines capable of processing strips up to 10-cm in width and lengths to 1 km. Once each machine was delivered to AMSC, it underwent extensive testing during the commissioning and qualification process. A major area of concern was verifying the uniformity of the process over the width of the wide strip and establishing the stability of the process over length. In addition, significant effort was devoted to refining the reel-to-reel transport systems to eliminate damage during the numerous process steps.

## III. Optimization of 2G Production

The initial operation of the production line resulted in 344 superconductors with a lower performance than the benchmark performance achieved in the pilot line. Thus once all the production-scale machines were commissioned, the focus of the scale up effort shifted to evaluating the performance of the individual processes against the benchmark performance of the pilot processes, establishing the stable processing windows and optimizing interactions between the process steps.

Root cause analyses identified a number of critical differences in the operation of the production machines compared to the pilot machines. One process that was particularly challenging to analyze and correct was the $Y_2O_3$ ('seed') buffer deposition. In this process, a previously unseen secondary texture, identified as $Y_2O_3$<100> || NiW<110> texture where the $Y_2O_3$ has a single axis epitaxy, was observed at high deposition temperatures favorable for enhancing the epitaxial growth of the $Y_2O_3$ on the Ni-W substrate [2, 3]. Optimization of the process required maximizing the primary texture while suppressing the development of the secondary texture by adjusting the various process parameters.

Similar optimizations were carried out on other process steps to both improve the operation of the individual machines and to optimize the interactions between processes.

The root cause analyses also identified subtle quality changes in raw materials as an additional source of the initially low performance of the 2G wire. This was observed in a number of cases as vendors modified their processes to increase the batch size from the pilot to production quantities.

One example was the quality of the NiW material. The transition from pilot to production-scale manufacturing required increasing the Ni5at%W batch size from approximately 300 lb to 5,000 lb. Analysis of the initial production-scale NiW lot showed it met all the material metrics; however, the final substrate had a reduced percent cube texture compared the smaller pilot scale lots. Detailed studies of the material identified subtle differences in the early manufacturing process at the vendor that necessitated changes in the rolling and annealing conditions to form the final substrate. The solution was to adjust the process at the vendor to insure that the same material is consistently delivered and is compatible with the standard deformation and annealing procedures in AMSC's production line.

Similar optimizations were carried out with materials from other vendors resulting in improved material specifications insuring a consistent quality in the material supply.

Once the initial optimizations were complete, the inherent performance of the 344 superconductors produced in the production line was equal to, or in many cases exceeded, that of the pilot wire. A result at the upper end of the present distribution of production is shown in Fig. 2 [1]; this gives an indication of the potential for this process, and we continue to optimize to tighten the distribution toward this high level.

Further improvements in the 2G manufacturing process are focused on identifying the root cause of local dips in the critical current of individual 344 superconductor wire such as shown in Fig. 3 [4]. In general, these are associated with mechanical defects including particulates, scratches and handling damage. Eliminating these mechanical-based defects is resulting in increased $I_c$ uniformity and piece length.

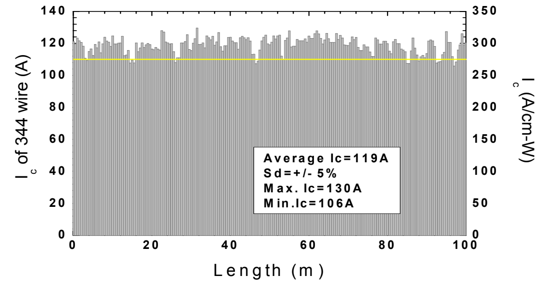


Fig. 2. Performance ($I_c$ at 77K, self-field) of a 344 superconductors produced in the production-scale manufacturing line (0.8 μm $Y(Dy_{0.5})Ba_2Cu_3O_y$ layer) [1].

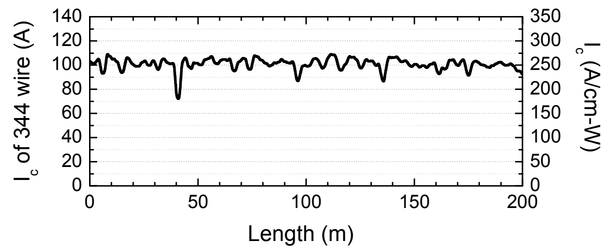


Fig. 3. Ic performance (top) of a 200 meter long 344 superconductors produced in AMSC's production scale manufacturing line [4]

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## References

[1] M.W. Rupich, U. Schoop, D.T. Verebelyi, C.L.H. Thieme, D. Buczek, X. Li, W. Zhang, T. Kodenkandath, Y. Huang, E. Siegal, W. Carter, N. Nguyen, J. Schreiber, M. Prasova, J. Lynch, D. Tucker, R. Harnois, C. King, D. Aized, *IEEE Trans. on Applied Superconductivity*, vol 17, No. 2, pp. 3379-82. 2007.

[2] C. Cantoni, A. Goyal, E. Specht, X. Li, M. Rupich, *J. Mater Res*, in press.

[3] A. Malozemoff, M. Rupich, A. Santamaria, "Scale-up of 2G HTS Wire Manufacturing at American Superconductor," Dept. of Energy High Temperature superconductivity Program Peer Review, Arlington, VA, July 29-13, 2008. Available at: http://www.energetics.com/supercon08/pdfs/presentations/tuesday/joint/joint_2_scale_up.pdf.

[4] X. Li, M.W. Rupich, C.L.H. Thieme, M. Teplitsky, S. Sathyamurthy, E. Thompson, E. Siegal, D. Buczek, J. Schreiber, K. DeMoranville, D. Hannus, J. Lynch, J. Inch, D. Tucker, R. Savoy, S. Fleshler, *IEEE/CSC & ESAS European Superconductivity News Forum*, No 6, October 2008 (ASC Preprint 3MA02).: Available at: http://www.ewh.ieee.org/tc/csc/europe/newsforum/pdf/LiX_3MA02.pdf.