ORNL/TM-2005/xx

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Prepared for

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ACRONYMS

ASTM	American Society for Testing and Materials
BB	bend bar
CEA	Commissariat à l'Energie Atomique, France
CVD	chemical vapor deposition
CVI	chemical vapor infiltration
CYL	cylindrical sample
DOE	The Department of Energy
GFR	gas-cooled fast reactor
HNLS	Hi-Nicalon™ Type-S
ID	identification number
INL	Idaho National Laboratory
LCAC Mo	Low Carbon Arc Cast Molybdenum
LPS	Liquid-phase sintering
NITE	Nano-Infiltration and Transient Eutectic-Phase Process
ORNL	Oak Ridge National Laboratory
PIE	post-irradiation examination
PNNL	Pacific Northwest National Laboratory
PyC	pyrolytic carbon
R&D	research and development
R&H	Rohm & Haas Advanced Materials
SiC/SiC	SiC-fiber-reinforced SiC-matrix ceramic composite
TDD	thermal diffusivity disk
TEM	transmission electron microscopy
Tpi	tows per inch
TySA	Tyranno™-SA
UBE	Ube Industries, Ltd.

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Executive Summary

The *FUTURIX-MI* is a international collaboration program between U.S. Department of Energy (DOE) and French Commissariat à l'Energie Atomique (CEA) for materials irradiation in Phenix fast reactor in France in support of gas fast reactor (GFR) materials and fuel R&D effort. ORNL Generation IV Materials Program provides selected silicon carbide ceramics (SiC) and composites (SiC/SiC) and molybdenum alloys for the evaluation of effect of neutron irradiation in a GFR-relevant condition. Projected irradiation condition in this program is to a fast neutron fluence of ~$1x10^{27}$ n/m^2 (E>0.1MeV) at a temperature of ~1000°C. The irradiation is scheduled to start in early 2007 and continue for 2 operation cycles of the Phenix reactor. This report compiles the details of specimen matrix, materials, and post-irradiation examination (PIE) plans for the part of contribution from ORNL. Also, a potential R&D item which is recommended as a preparatory work for PIE is identified.

1. Overview

This document describes technical details, primarily regarding the planning of matrix and fabrication and characteristics of the materials, of the ORNL contribution to a U.S. Department of Energy (DOE) – Franch Commissariat à l'Energie Atomique (CEA) collaborative FUTURIX-MI program for materials irradiation in Phenix fast reactor in France in support of gas fast reactor (GFR) materials and fuels R&D effort. ORNL Generation IV Materials Program provides selected silicon carbide (SiC) ceramics and composites and molybdenum alloys for evaluation of the effect of neutron irradiation in a GFR-relevant condition. Projected irradiation condition in this program is to a fast neutron fluence of ~$1x10^{27}$ n/m^2 (E>0.1MeV) at a temperature of ~1000°C. The irradiation is scheduled to start in early 2007 and continue for 2 operation cycles of the Phenix reactor.

Document ('FUTURIX-MI Status Aug-04.doc') containing general information of the FUTURIX-MI experiment is appended as Attachment 1. Note that the specimen matrix plan in Attachment 1 has been outdated.

2. Key Schedule

The schedule revised in March, 2005, is as below.

Delivery of ORNL specimen to INL	May 2, 2005
Delivery of US specimens to CEA	May 31, 2005
Capsule fabrication	June 2005~
Start of irradiation	Early 2007

Post-irradiation examination (PIE) follows as soon as the irradiated samples are transferred to ORNL and made available for testing, in year 2008 or later.

3. ORNL Specimen Matrix

ORNL specimen matrix plan is shown in Table 1. The matrix plan is in accordance with the Futurix-MI entire matrix plan Version Final-01, as of 03/08/05, found in Microsoft Excel worksheet entitled 'FUTURIX-MI composition 2005-03-08.xls,' prepared by Dr. Jian Gan at INL.

Table 1 – ORNL specimen quantity for materials listed in irradiation matrix of Final-01.

Material, Manufacturer (Supplier)	Disc 8dx2h			TEM 3dx0.15t			Cylinder 3dx10h			Beam 25x2x1.5		
	Irrad	Ctrl	Total	Irrad	Ctrl	Total	Irrad	Ctrl	Total	Irrad	Ctrl	Total
SiC/SiC NITE, UBE (ORNL)	10	10	20	20	10	30	1	1	2	6	6	12
SiC/SiC CVI, ORNL	10	10	20	20	10	30	1	1	2	12	12	24
LCAC Mo Alloy, ORNL	5	5	10	20	10	30	1	1	2	6	6	12
MoZrB, ORNL	5	5	10	20	10	30				6	6	12

3.1 Silicon Carbide Ceramics and Composites

(1) Matrix Details

The detailed matrix plan for SiC/SiC composites and monolithic SiC to be provided by or through ORNL is listed in Table 2. Descriptions of individual materials are given in Table 3. All the composite materials consist of near-stoichiometric SiC fibers and matrices and therefore the neutron tolerance greatly improved over the conventional SiC/SiC composites is expected [1-4]. The CVI composites are the reference SiC/SiC

Table 2 – Matrix plan for SiC/SiC composites provided by ORNL.

File: FUTURIX-MI_US_SiC_Matrix_050314 Sheet: Matrix Summary Printed 4/14/2005

Numbers of ORNL Silicon Carbide Specimens for FUTURIX-MI Experiment

Category	Material	Mater ID	For Irradiation					Control					Total				
			BB	TDD	CYL	TEM1	TEM2	BB	TDD	CYL	TEM1	TEM2	BB	TDD	CYL	TEM1	TEM2
			54	60	6	84	16	54	60	6		4	108	120	12	84	20
NITE	TySA-NITE	18	6	3	1			6	3	1			12	6	2		
	LPS-SiC	4		3		10			3		10			6		20	
	CVD-SiC R&H	1		2					2					4			
	Hybrid-CVI	17		2					2					4			
	Subtotal		6	10	1	10		6	10	1	10		12	20	2	20	
	Assignment		6	10	1	20		6	10	1	10		12	20	2	30	
CVI	TySA-CVI-Ref	11		2					2					4			
	TySA-CVI-TI	12		2					2					4			
	TySA-CVI-TF	13		2					2					4			
	HNLS-CVI-Ref	14	6	2				6	2				12	4			
	HNLS-CVI-TI	15	6	2	1			6	2	1			12	4	2		
	CVD-SiC R&H	1				12					8					20	
	SC-SiC	3					8					2					10
	Subtotal		12	10	1	12	8	12	10	1	8	2	24	20	2	20	10
	Assignment		12	10	1	20		12	10	1	10		24	20	2	30	

composites for nuclear applications [4,5], whereas the NITE composite is a new class of SiC/SiC composite that potentially provides superior baseline properties and acceptable irradiation performance [5-11]. The monolithic SiC materials are either matrix materials for the composite materials or high-quality reference materials for studying the fundamental irradiation effects in SiC.

Table 3 – Details of ORNL SiC and SiC/SiC materials

Material	Fiber Fabric	Interphase	Matrix
CVD-SiC R&H	Roam and Haas Advanced Materials, CVD-SiC, Standard Resistivity Grade (lot #9130)		
SC-SiC	Hoya Advanced Semiconductors Technologies, Inc., Single Crystal 3C-SiC, n-type (lot SBG13AK)		
LPS-SiC	Matrix material for TySA-NITE, supplied by Kyoto University, Japan, proprietary		
TySA-NITE	Tyranno™-SAK 7.5 micron, Uni-Directional	PyC, 500nm nominal	NITE-SiC, proprietary
TySA-CVI-Ref	Tyranno™-SA Grade-3 7.5 micron (SA3-S1I16PX), 2D Plain Weave (PSA-S17I16PX), 17x17 tpi	PyC, 150nm nominal	Beta-SiC, Isothermal CVI
TySA-CVI-TI	Tyranno™-SA Grade-3 7.5 micron (SA3-S1I16PX), 2D Plain Weave (PSA-S17I16PX), 17x17 tpi	PyC, 50nm nominal	Beta-SiC, Isothermal CVI
TySA-CVI-TF	Tyranno™-SA Grade-3 10 micron (SA3-S1F08PX), 2D Plain Weave (PSA-S17F08PX), 17x17 tpi	PyC, 150nm nominal	Beta-SiC, Isothermal CVI
HNLS-CVI-Ref	Hi-Nicalon™ Type-S 900denier (#383213), 2D Plain Weave (HNS9P2424), 24.25x25 tpi	PyC, 150nm nominal	Beta-SiC, Isothermal CVI
HNLS-CVI-TI	Hi-Nicalon™ Type-S 900denier (#383213), 2D Plain Weave (HNS9P2424), 24.25x25 tpi	PyC, 50nm nominal	Beta-SiC, Isothermal CVI

Bend bar specimens

The specimen type BB in Table 2 represents bend bar with dimensions of 25mm (length) x 2.5mm (width) x 2mm (thickness). With this small specimen width, uni-directionally reinforced composites or 2-dimensional composites with thread count >20 tpi (tows-per-inch) have to be selected. This is because the composite strength tends to deviate from the systematic specimen width dependence unless 2 or more fiber tows are accommodated in each fabric layer of the 2-dimensional composite [12]. Two Hi-Nicalon™ Type-S (HNLS) chemically vapor infiltrated (CVI) composites, which had been fabricated for this program, are 2D plain-weave fabric composites with 24 - 25 tpi tread counts instead of ~16 tpi for other 2D SiC fiber composites in standard specifications. The Tyranno™-

SA (TySA) NITE composite is uni-directionally reinforced. The reference-interphase (with the '-Ref' suffix) is nominally 150nm-thick pyrocarbon (PyC) while the thin-interphase ('-TI') is nominally 50nm-thick PyC. The effect of PyC interphase thickness on non-irradiated mechanical properties of SiC/SiC composites in this class has been studied in detail [13,14]. A major microstructural modification and mechanical property degradation in carbon materials during neutron irradiation have been reported [15-18], however, the influence of such irradiation effects in thin interphases on macroscopic properties of SiC/SiC composites has not been made clear. It is general speculation that the thinner PyC interphase composites are supposed to be more resistant to neutron damage. It is expected that the Futurix-MI experiment answers these questions.

Thermal diffusivity specimens

The specimen type TDD in Table 2 represents a type of thermal diffusivity disc. Specimens of CVD-SiC R&H and Hybrid-CVI have been added to the NITE category, because the total of only 12 TDD specimens of NITE composites and matrix material (LPS-SiC) had been supplied by Kyoto University while 20 TDD specimens had been requested. CVD-SiC R&H samples are also provided by PNNL and included in the European matrix. 2 duplicate specimens each for 5 different composites are assigned for irradiation in CVI category. This combined specimen matrix should provide sufficient comprehensive understanding of post-irradiation thermal conductivity in CVI and NITE SiC/SiC composites and contributions from the composite constituents in the irradiation condition of Futurix-MI [19-22].

TEM specimens

The standard TEM specimen (with a round disc-shape) is designated type TEM1. Type TEM2 with a flat edge section was introduced for material identification. All the TEM specimens of CVD-SiC R&H and LPS-SiC are of type TEM1, whereas all the SC-SiC specimens are of type TEM2.

Specimen identification

Individual ID's were not engraved onto the SiC and SiC/SiC specimens. This is because ID's engraved on the textured surface of small composite specimens may not be readable, whereas the specimen-to-specimen variations in surface features (or 'fingerprint') should give sufficient information that enables the specimen identification by visual inspection. Also, the CVI and NITE composites are easily distinguishable from the difference in surface features. The surface features consist of the fabric texture and pore distributions unique to individual specimen. These features will not change during the reactor irradiation for a long term. A set of photographs of the machined samples is provided for future identification.

(2) PIE Plan

Irradiated samples will be shipped to and tested at ORNL.

It is highly preferred to test the type BB specimens in tension instead of in flexure, although they have been designed for flexural test. The type BB specimens are most likely to fail in a mode of interlaminar shear if tested in flexure, because they will have a support span-to-depth ratio of ~10:1. The minimum span-to-depth ratios recommended in ASTM Standard C1341 are 16:1 and 32:1 in three-point and four-point-1/4 configurations, respectively, in order to avoid the interlaminar failure. The interlaminar shear fracture strength is correlated primarily with the matrix fracture toughness and features of the pore that happened to be a crack initiation site. On the other hand, the mechanical properties of fibrous composites are determined by various properties of fiber, interphase, and matrix. Therefore, if interlaminar shear is going to be the primary failure mode, the effect of irradiation on composite properties can not be evaluated. Since the type BB specimens are smaller than typical miniature tensile specimens for neutron irradiation studies, it is recommended that an appropriate and reliable testing technique is developed in FY2006 – 2007.

The type TDD specimens will be used for evaluation of thermal diffusivity at temperatures ranging from ambient to the irradiation temperature (1000°C).

The TEM samples will be used for microstructural examination by transmission electron microscopy, hardness / modulus evaluation by nano-indentation, and fracture toughness evaluation by micro-indentation.

3.2 ORNL Molybdenum Alloys

(1) Alloys and Specimens

ORNL molybdenum alloys consist of a newly developed weldable molybdenum alloy (MoZrB) and a reference material (LCAC). The MoZrB material, named Alloy-6 in the alloy development program, was selected for irradiation because it showed most promising mechanical properties before irradiation among new alloys. Chemical compositions of the two alloys are given in Table 4. The hot-rolled coupons are heat-treated in vacuum before machining specimens.

Table 4. Chemical compositions (wt.%) of molybdenum alloys

Mater	Mo	C	Zr	B	Fe	Ni	Al	O	Si
MoZrB	Bal.	0.0087	0.0028	0.0017			0.0006	0.0017	
LCAC	Bal.	0.014			0.0031	<0.001		0.0006	0.0013

As listed in Table 1, 20 disk specimens (8 mm dia.), 60 TEM specimens, 2 cylinders, and 24 small beam specimens were prepared for irradiation or as control specimens.

(2) PIE Plan

TEM specimens – After irradiation the TEM specimens will be used for two purposes: transmission electron microscopy (TEM) and measuring microhardness. Through the TEM work characteristics of small radiation-induced defects and large voids will be examined. The microhardness testing on the TEM specimens will supply irradiation hardening information for the alloys.

8 mm Disks – The disks will be used for ball indentation tests to measure deformation properties and temperature dependencies. Ball indentation testing method using a small ball of 1 mm diameter or smaller has been established in ORNL and other places.

Beam specimens – The small beams will be deformed in three point bend jigs to obtain bending deformation properties. Some physical properties such as density and electrical resistivity will be measured. Alternatively, it will be tried to measure fracture mechanics parameters from those specimens if they can be notched.

The cylinder specimen – It is considered as backup material for any applications.

4. References

[1] L. L. Snead, Y. Katoh, A. Kohyama, J. L. Bailey, N. L. Vaughn and R. A. Lowden, Journal of Nuclear Materials 283-287 (2000) 551-555.

[2] Y. Katoh, A. Kohyama, L.L. Snead, T. Hinoki and A. Hasegawa, "Neutron Tolerance of Advanced SiC-Fiber / CVI-SiC Composites," Proceedings of the 19th IAEA Fusion Energy Conference, IAEA-CN-94 (International Atomic Energy Agency, 2002) FT/P1-03.

[3] T. Hinoki, L.L. Snead, Y. Katoh, A. Hasegawa, T. Nozawa and A. Kohyama, Journal of Nuclear Materials 307-311 (2002) 1157-1162.

[4] Y. Katoh, A. Kohyama, T. Hinoki and L.L. Snead, Fusion Science & Technology 44 (2003) 155.

[5] R. Naslain, "Design, preparation and properties of non-oxide CMCs for application in engines and nuclear reactors: an overview," Composites Science and Technology 64 (2004) 155–170.

[6] Y. Katoh, A. Kohyama, S.M. Dong, T. Hinoki and J-J. Kai, "Microstructure and Properties of Liquid Phase-Sintered SiC/SiC Composites," Ceramic Engineering and Science Proceedings, Volume 23, Issue 3 (2002) 363-370.

[7] Y. Katoh, S.M. Dong and A. Kohyama, "A Novel Processing Technique of Silicon Carbide-Based Ceramic Composites for High Temperature Applications," Ceramic Transactions, Vol.144 (2002) 77-86.

[8] Y. Katoh, S.M. Dong and A. Kohyama, "Thermo-Mechanical Properties and Microstructure of Silicon Carbide Composites Fabricated by Nano-Infiltrated Transient Eutectoid Process," Fusion Engineering and Design 61-62 (2002) 723-732.

[9] S.M. Dong, Y. Katoh, and A. Kohyama, "Preparation of SiC/SiC Composites by Hot Pressing, Using Tyranno-SA Fiber as Reinforcement," Journal of the American Ceramic Society, Vol. 86, No. 5 (2003) 26-32.

[10] T. Hino, T. Jinushi, Y. Hirohata, M. Hashiba, Y. Yamauchi, Y. Katoh and A. Kohyama, "Helium Gas Permeability of SiC/SiC Composite Developed for Blanket Component," Fusion Science and Technology, Volume 43 (2003) 184-190.

[11] Y. Katoh, A. Kohyama, T.Nozawa, M. Sato, "SiC/SiC Composites through Transient Eutectic-phase Route for Fusion Applications," Journal of Nuclear Materials, Volumes 329-333 (2004) 587-591.

[12] T. Nozawa, T. Hinoki, Y. Katoh, A. Kohyama and E. Lara-Cruzio, Small Specimens Test Techniques: Fourth Volume (ASTM STP 1418, M.A. Sokolov, J.D. Landes and G.E. Lucas, Eds., ASTM International, West Conshohocken, PA, 2002) 294-305.

[13] Y. Katoh , T. Nozawa, L.L. Snead, T. Hinoki, A. Kohyama, N. Igawa, T. Taguchi, Materials Transactions, 46 (2005) 527-535.

[14] Y. Katoh , T. Nozawa, and L.L. Snead, "Mechanical Properties of Thin PyC Interphase SiC-Matrix Composites Reinforced with Near-Stoichiometric SiC Fibers," Journal of the American Ceramic Society, in printing.

[15] B.T. Kelly, Physics of Graphite, Applied Science Publishers, London (1981).

[16] G.B. Engle and W.P. Etherly, Irradiation behavior of graphite at high temperature, High Temperatures – High Pressures 4 (1972) 119-158.

[17] R.J. Price, "High temperature neutron irradiation of highly oriented carbons and graphites," Carbon 12 (1974) 159-169.

[18] B.T. Kelly and T.D. Burchell, "Structure-related property changes in polycrystalline graphite under neutron irradiation," Carbon 32 (1994) 499-505.

[19] L.L. Snead, S.J. Zinkle, and D.P. White, "Thermal conductivity degradation of ceramic materials due to low temperature, low dose neutron irradiation," Journal of Nuclear Materials 340 (2005) 187–202.

[20] T. Nozawa, Y. Katoh, and L.L. Snead, "Tensile and thermal properties of chemically vapor-infiltrated silicon carbide composites with various high-modulus fiber reinforcements," Ceramic Engineering and Science Proceedings, Vol. 26 (2005).

[21] T. Nozawa, Y. Katoh, L.L. Snead, T. Hinoki, and A. Kohyama, "Characterization of chemically vapor infiltrated silicon carbide composites reinforced by various high modulus fibers: I. Thermal conductivity," Fusion Materials Semiannual Report, DOE/ER-0313/37 (2005) 11-16.

[22] Y. Katoh, T. Nozawa, L.L. Snead, T. Hinoki, and A. Kohyama, "Property tailorability for advanced CVI silicon carbide composites for fusion," submitted to Fusion Engineering and Design.

Attachment 1

Futurix-MI Status Report as of 08/04/2004

(from Mitchell Meyer, August 2004)

1.1 Background

The Gas-cooled Fast Reactor (GFR) is an attractive candidate for future deployment as a fourth generation nuclear power system. Both the U.S.D.O.E. and the French CEA have interest in studying the technical feasibility of the GFR. Joint work in the fuels area began in FY02 as an effort funded at a small level under the I-NERI project 'Development of Gen IV Advanced Gas-Cooled Reactors with Hardened/Fast Neutron Spectrum' by defining fuel requirements, proposing fuel concepts to meet these requirements, and modeling the in-reactor behavior of these concepts. During this work, it became clear almost immediately that very few materials were available that both met GFR neutronic requirements and could withstand postulated core loss-of-coolant accident conditions without melting or restructuring. These materials generally fall into the class of monocarbide and mononitride ceramic compounds.

There is very little materials property and irradiation data on these materials to support evaluation of their use as GFR fuel materials. U.S. efforts to obtain this data include ion irradiation studies and the GFR-F1 irradiation in the ATR (Advanced Test Reactor); however this irradiation is limited to low dose due to the low fast flux in the thermal spectrum ATR. Both DOE and CEA agreed from early on in the I-NERI program that fast spectrum testing to damage levels representative of GFR fuel was required in order to complete a representative assessment of the potential of these materials for service as GFR fuel matrix and cladding materials.

Three coordination meetings were held between U.S. and CEA technical staff during this fiscal year. The first meeting was an informal discussion held in conjunction with the GLOBAL 2003 meeting in New Orleans (November 2003). Here general discussion focused on the structure of the project and the potential for U.S. collaboration and partial funding of FUTURIX-MI. The second meeting was held at ANL-E in Chicago in February of 2004 in conjunction with the CEA/DOE coordination meeting. This second meeting focused on further details of U.S. participation in FUTURIX-MI and details related to the financing of the experiment. The third meeting was held in August at CEA Cadarache in conjunction with the FUTURIX-FTA coordination meeting to finalize experiment plans and to delegate responsibilities for sample preparation.

This report updates the status of this potential collaborative experiment and highlights progress made during FY-2004.

1.2 Objectives of FUTURIX-MI

GFR performance goals require fuels with high heavy metal density, high thermal conductivity, low irradiation induced swelling, melting temperatures exceeding 2000°C, and low parasitic neutron absorption. Based on GFR reference core design, two types of fuel have been identified that are most likely to meet GFR goals. These are refractory clad pin-type fuels and refractory matrix dispersion fuels.

Based on postulated GFR behavior during normal and accident conditions, a set of general criteria for fuel matrix and cladding materials has been derived. Based on these criteria, the class of high-temperature moncarbides and mononitrides appear most likely to meet GFR goals as fuel matrix materials; specifically SiC, TiC, ZrC, TiN, and ZrN have been identified. Pin-type cladding materials include SiC composites and Nb-based refractory alloys. The response of these GFR candidate fuel materials to fast neutron damage levels in the range required for GFR operation at high temperatures is not known. Assessment of fuel feasibility requires determination of basic fuel and material properties through irradiation testing and assessment.

The FUTURIX-MI irradiation is devoted to the behavior of inert matrix materials under GFR conditions with temperatures of ~1000°C and fast neutron fluence on the order of $1.0 \times 10^{27} n.m^{-2}$ (E>0.1MeV). Specimens of candidate fuel matrix and cladding materials will be irradiated in a special device in Phénix in order to provide specimens for postirradiation characterization. Postirradiation examination will focus on the measurement of thermal properties, mechanical properties, and microstructural analysis of the irradiated materials.

Where possible, non-fuel related high-temperature structural materials were considered for irradiation in the FUTURIX-MI experiment.

Postirradiation examination responsibilities will be shared between CEA and DOE. CEA estimates the total cost of this experiment to be 4.270 M€. DOE and the National Technical director for AFCI fuels have tentatively agreed to fund this experiment at 1.25 M€, to provide specimens of mutual interest to both parties, and to share in the duties of postirradiation examination and reporting.

1.3 Overview of the FUTURIX-MI Experiment

The configuration of the FUTURIX-MI experiment is shown in Fig. 1. Material test specimens are mounted in a specially designed SiC sample holder. The sample holder is in turn encapsulated in a metal alloy heating capsule and a stainless steel outer can. The cans are stacked inside of a standard Phénix KMI irradiation capsule.

Table 1 and Fig. 2 provide details on general sample types and specific geometry. Specimens are provided for measurement of thermal expansion, thermal diffusivity, mechanical property testing, density, electrical resistivity, and examination by transmission microscopy. In order to provide for the as-designed heating rates, all specimen cavities are to be filled with specimens.

In addition to the materials test specimens, two types of temperature monitors are included in the SiC sample holders. These are SiC thermal expansion monitors, which are located near the edges of the sample holder and metal fuse temperature monitors located in the center of the SiC capsule.

Table 1. Types of FUTURIX-MI specimens

Sample	Purpose	Dimensions
8 mm disc	Thermal diffusivity measurement	8 mm dia. x 2 mm thick
3 mm rod	Thermal expansion, density, backup TEM	3 mm dia. x 5 mm of 10 mm long, electrical resistivity
3 mm disk	TEM specimens	3 mm dia. x 0.15 mm thick, small punch test
Bend bars	Mechanical testing	2.0 x 2.5 x 25 mm

The experiment matrix as of August 2004 is shown in Table 2. The experiment stackup consists of 8 cans. Two types of mutually compatible specimens can be placed in each can, as indicated in the table. Provision of specimens is divided roughly equally between CEA and DOE.

Table 2. FUTURIX-MI experiment matrix as of August 2004

(Table 2 needed update; deleted by Katoh)

The eight cans are loaded in a Phénix KMI capsule. The KMI capsule will be located near the center of the Phénix core for irradiation, as shown in Fig. 3, where it will reside for two cycles totaling 240 effective full power days for a goal fast neutron fluence (E>100 KeV) of $8x10^{26}$ n/m^2.

CEA has requested that a backup matrix be formulated in case samples listed in Table 2 cannot be provided by June of 2004. Note that some of the materials in the current matrix are 'placeholders' that are commercially available materials offered where CEA was not able to provide novel materials as originally intended. The Cercom TiN in capsule 6 and the Cercom ZrC in capsule 7 fall into this category. Additional Mo alloys can be added as TEM and small beam specimens as indicated in capsule 8. Nb-Zr alloys could be consolidated into one-half of capsule 2 if appropriate PWC-11 specimens can't be fabricated, leaving space for multiple samples, preferably metallic. The backup matrix should be defined by the end of September 2004.

1.4 Current Status

I-NERI agreements were written during the second quarter of FY04 and are currently in place with ITU and CEA for GFR fuel development. Collaboration under the new I-NERI agreements is scheduled to begin with the start of the 2005 fiscal year. The I-NERI agreement with CEA includes tasks associated with the FUTURIX-MI experiment.

An 'implementation agreement' based on the FUTURIX-FTA model has been drafted and is awaiting action by DOE.

During the February meeting, the possibility of the addition of 8 additional capsules containing materials of general interest to Gen IV was discussed. Our understanding was that CEA agreed to this in principal, but insisted that DOE shoulder all of the costs associated with these additional capsules and provide a definite list of materials by April. CEA did not provide a cost estimate, however, despite repeated inquiries in February through May. ANL provided repeated expressions of interest during this time frame, and a list of additional specimens for the eight capsules was provided to CEA in April of 2004. During a DOE/CEA GFR INERI meeting in Idaho Falls in May of 2004, the CEA lead for GFR fuel development, including FUTURIX-MI, referred inquiries about the status of the additional capsules to CEA management. Attempts were made to arrange a face-to-face meeting between the AFCI Fuels NTD and the CEA manager in June, but a meeting did not occur due to scheduling conflicts. During the August FUTURIX coordination meeting, CEA was not willing to add additional capsules to the FUTURIX–MI experiment, stating that it was too late in the planning; the technical report having been completed in May without provision for the additional capsules.

1.5 Schedule and deliverables

Both the Presentation Report, which formally proposes the irradiation test to the Phénix reactor, and the Technical Report, which provides detailed calculations of the irradiation performance of the experiment have been completed by CEA and submitted to Phénix for review in May. Final technical specifications for the experiment will be based on this review, and specimen specifications will be sent to ANL for dissemination to affected parties.

The schedule for major U.S. milestones and/or deliverables associated with the FUTURIX-FTA fuels collaboration is shown in Table 3.

Data required for specimen characterization reports supplied with specimens are listed in Table 4.

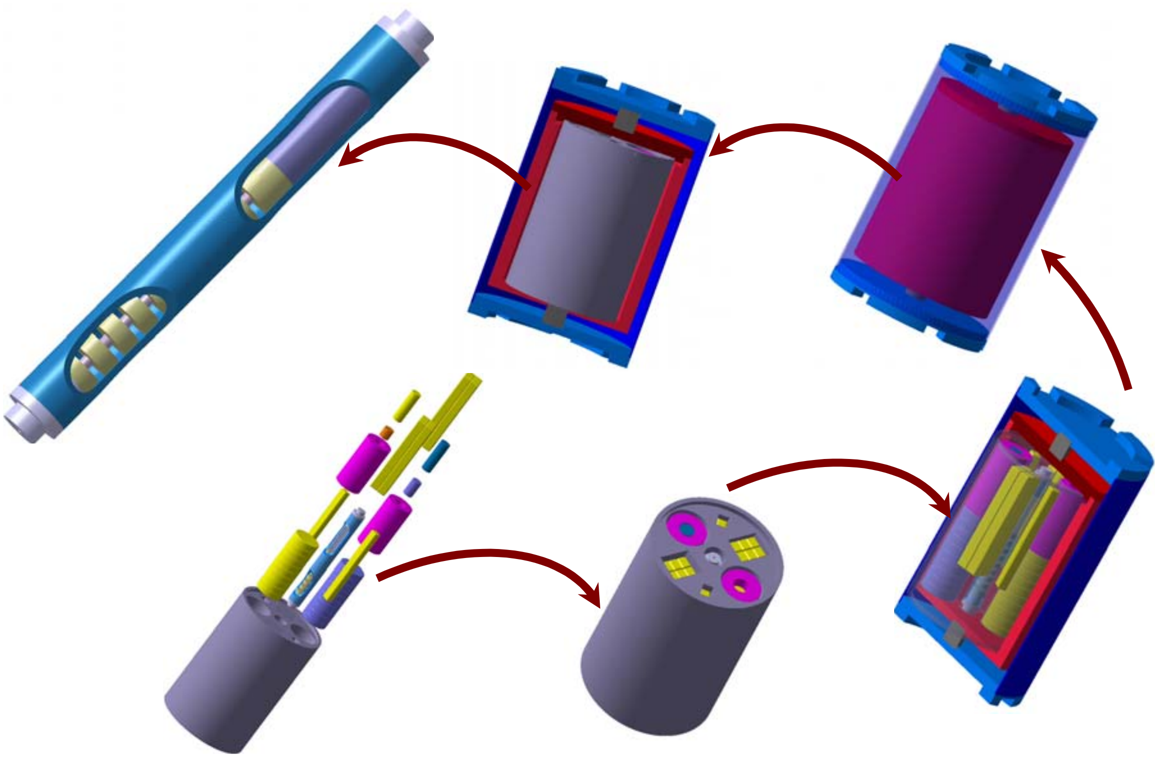
Table 3. Schedule outline, milestones and deliverables related to FUTURIX-MI.

(Table 3 needed update; deleted by Katoh)

Table 4. Characterization data for FUTURIX-MI specimens.

Characteristic	**Example**
Fabrication method, and method of controlling repeatability	Fabrication procedures if not proprietary, method s of ensuring sample-to-sample uniformity
Composition and impurity content (required)	Fe, Ni, Co, Cl, F, O, C, N, Hf (Hf for Zr-based materials)
Composition and impurity content (if possible)	Cu, Zn, Mo, Mn, Cd, S
Metallography	Grain size, pore fraction and morphology, micro-chemical analysis of inclusions
Crystal structure	XRD, TEM if practical
Stoichiometry	If possible
Details of fiber reinforcement	Type, size, heat treatment
Geometry	Sample dimensions, cracks, chips, discoloration, etc.
Dimensional stability to 1200°C	If possible
Physical properties	Measurement of properties on the same batch of materials (if practical on the actual FUTURIX-MI specimens) before mid-2005: Thermal conductivity: Thermal diffusivity Thermal expansion Heat capacity Others if possible: Hemispherical total emittance Shear modulus, eleastic modulus Poisson’s ratio Fracture toughness Tensile yield stress Thermal creep
Chemical compatibility	With respect to SiC and Na

Figure 1. FUTURIX-MI SiC sample holder and assembly



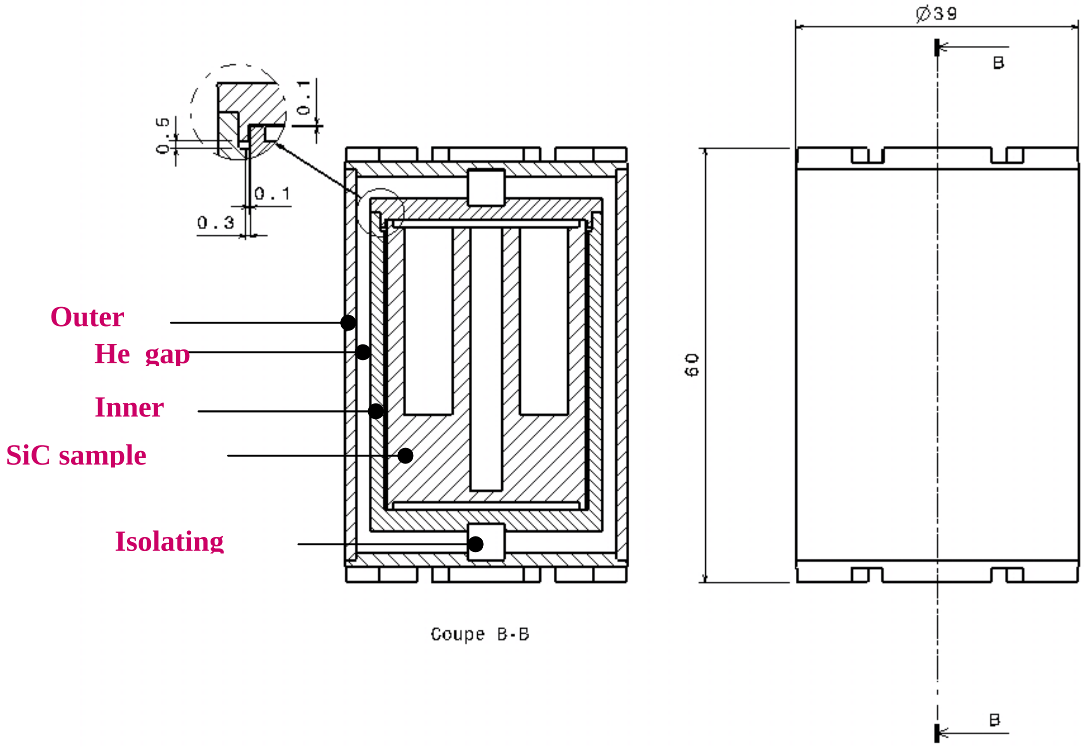

Ø39
B
0.5
0.1
0.1
0.3
Outer
He gap
Inner
SiC sample
Isolating
60
Coupe B-B
B

Figure 2. FUTURIX-MI sample dimensions

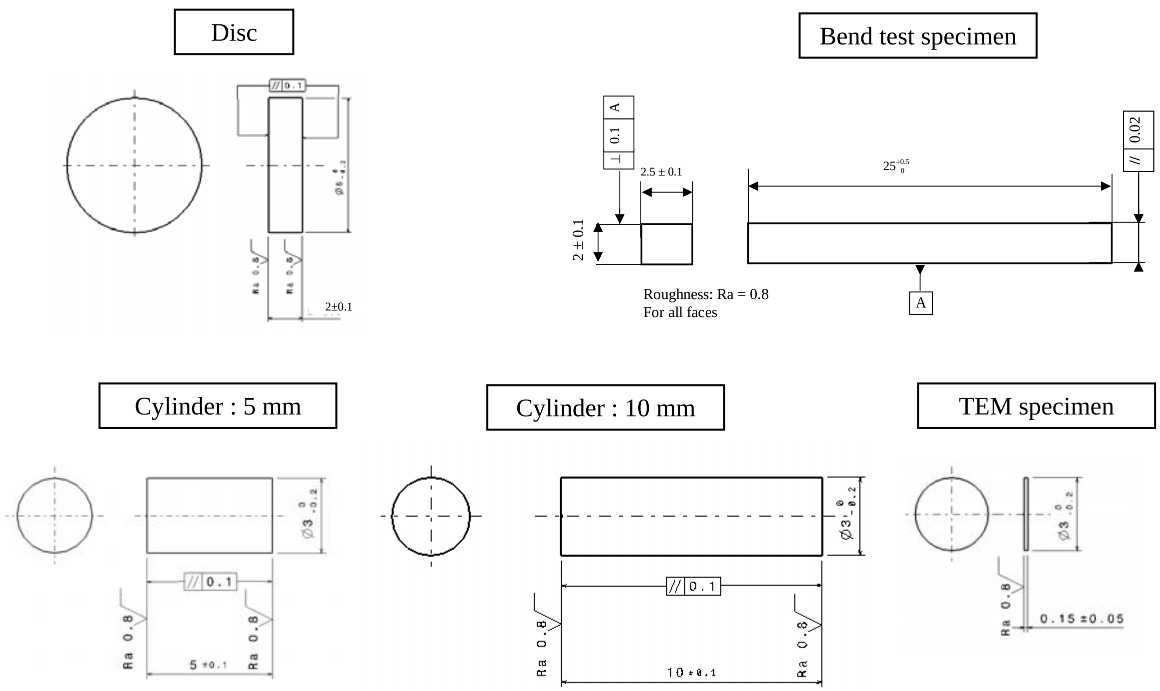
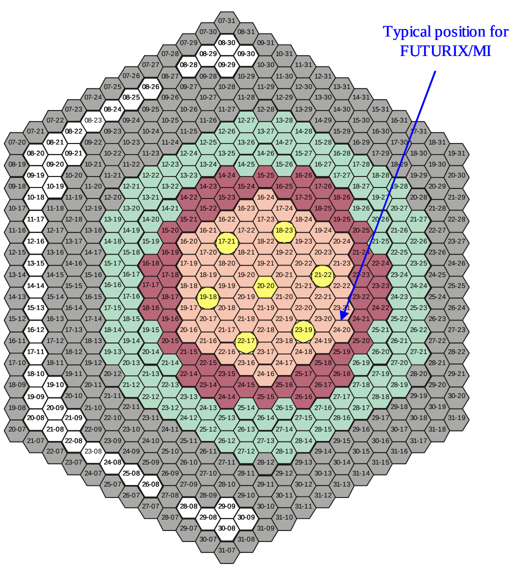


Figure 3. FUTURIX-MI location in Phénix core (tentative).

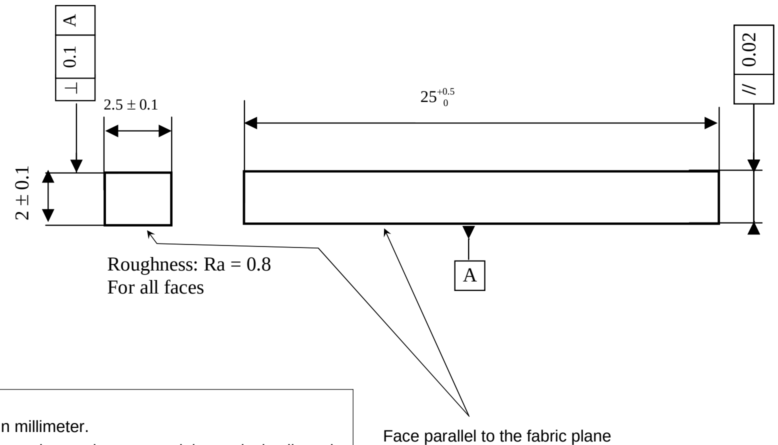


Attachment 2

Drawings for Specimen Machining

BB: 2.5mm-wide Bend-Bar of Ceramic Composites

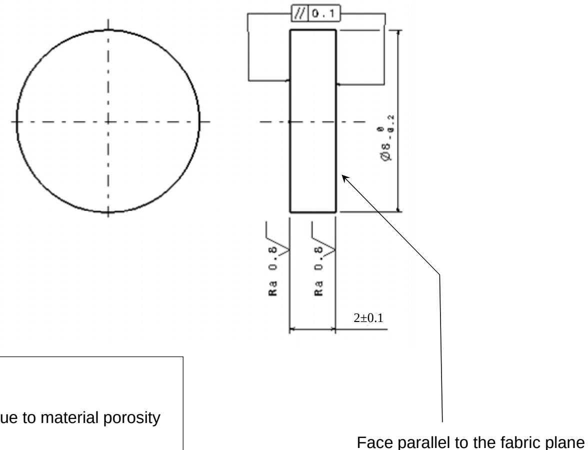
Dimensions are in millimeter unless otherwise noted.



NOTE:
1. Dimensions are in millimeter.
2. Limited surface smoothness due to material porosity is allowed.
3. The 2.5mm-wide faces are parallel to the fabric plane, i.e., the thickness (2mm) along the fabric stacking direction.
4. Follow general guideline in ASTM Standard C1161-02c Section 7.2.4
5. All grinding in parallel to the longitudinal direction.

TDD: 8mm-diameter Thermal Diffusivity Disc of Ceramics Composites

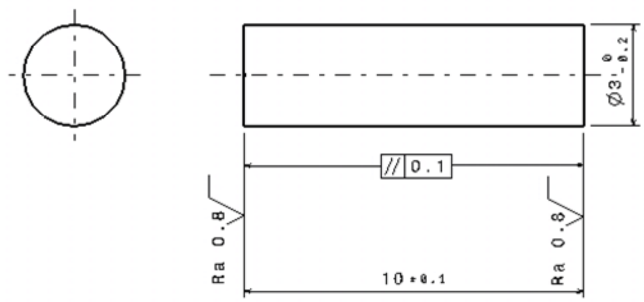
Dimensions are in millimeter unless otherwise noted.



NOTE:
1. Dimensions are in millimeter.
2. Limited surface smoothness due to material porosity is allowed.
3. The round faces are parallel to the fabric plane, i.e., the thickness (2mm) along the fabric stacking direction.

CYL: 10mm-Long Cylindrical Rod of Ceramic Composite

Dimensions are in millimeter unless otherwise noted.

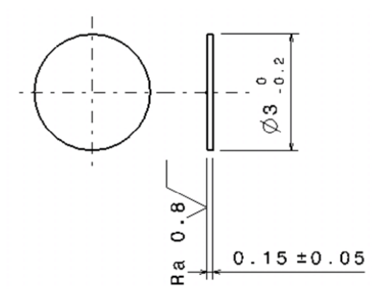


NOTE:
1. Dimensions are in millimeter.
2. Limited surface smoothness due to material porosity is allowed.
3. The longitudinal direction is parallel to the fabric plane.

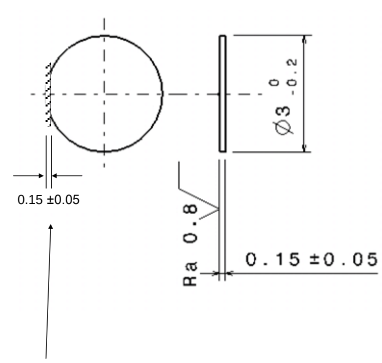
TEM1 and TEM2: TEM Disc of Monolithic Ceramics

Dimensions are in millimeter unless otherwise noted.

TEM-1 (circular)



TEM-2 (truncated)



Remove 0.15mm from the edge
for material identification

Attachment 3

Materials Characterization Data Forms

Characterization Data for Futurix-MI Experiment

Material	ORNL LCAC (Low Carbon Arc Cast) Molybdenum
Fabrication method, and method of controlling repeatability	- Vacuum arc-cast, vacuum arc-remelting, extrusion, and rolling - Specimens were machined in as-stress relieved condition
Composition and impurity content	0.014 at-% C, 0.0031% Fe, <0.001% Ni, 0.0006% O, 0.0013% Si, balance Mo.
Metallography	- Elongated, fine grain microstructure - No second phase inclusion / precipitation has been found
Crystal structure	Body-centered cubic
Stoichiometry	Not applicable
Details of fiber reinforcement	Not applicable
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- No experimental data with regard to irradiated dimensional stability
Physical properties	- Mass density of 10.2 g/cm^3 (>99% theoretical density) - Thermal conductivity: 138 W/m-K (at 20°C) - Thermal diffusivity: 5.4×10^{-5} m^2/s (at 20°C) - Thermal expansion: 5.1×10^{-6} K^{-1} (20-1000°C) - Specific heat: 250 J/kg-K (at 20°C) - Tensile yield stress: 796 MPa (at 20°C, L-direction)
Chemical compatibility	- Limited reactivity with SiC at >~850°C -

Characterization Data for Futurix-MI Experiment

Material	ORNL MoZrB Alloy
Fabrication method, and method of controlling repeatability	- Vacuum arc-cast, vacuum arc-remelting, extrusion, and rolling - Specimens were machined in as-stress relieved condition
Composition and impurity content	0.0087 at-% C, 0.0028% Zr, 0.0017% B, 0.0006% Al, 0.0017% O, balance Mo.
Metallography	- Elongated, fine grain microstructure - No second phase inclusion / precipitation has been found
Crystal structure	Body-centered cubic
Stoichiometry	Not applicable
Details of fiber reinforcement	Not applicable
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- No experimental data with regard to irradiated dimensional stability
Physical properties	- Mass density of 10.2 g/cm^3 (>99% theoretical density) - Thermal conductivity: 138 W/m-K (at 20°C) - Thermal diffusivity: 5.4 x 10^{-5} m^2/s (at 20°C) - Thermal expansion: 5.1 x 10^{-6} K^{-1} (20-1000°C) - Specific heat: 250 J/kg-K (at 20°C) - Tensile yield stress: 803 MPa (at 20°C, L-direction)
Chemical compatibility	- Limited reactivity with SiC at >~850°C -

Characterization Data for Futurix-MI Experiment

Material	ORNL CVI SiC/SiC Composites (TySA-CVI-Ref / TI / TF)
Fabrication method, and method of controlling repeatability	- Reinforcement with Tyranno™-SA Grade-3 near-stoichiometric silicon carbide fiber. - Interphase coating with pyrolytic carbon (50-150nm thickness) onto the fiber surface prior to matrix infiltration. - Deposition of stoichiometric silicon carbide matrix by isothermal / isobaric chemical vapor infiltration.
Composition and impurity content	0.2 mass-% Al, 0.15% O, 0.05% N, 0.06% Cl, 3.3 mass-ppm Fe, 2.2ppm Ni, 28ppm Zr, 0.5ppm Hf, 5 mass-ppb Co, 5.8% excess-C, balance SiC
Metallographic feature	- Porosity due to three types of matrix pores; bundle intersections (Type I), fabric mesh (Type II), interlaminar (Type III) - Inclusion / precipitation of phases other than SiC or carbon has been found
Crystal structure	Beta-SiC in fiber and matrix, glassy carbon in interphase
Stoichiometry	- The matrix is stoichiometric beta-SiC - The fiber consists primarily of beta-SiC - The fiber contains small amount (~5%) of carbon that is present at multi-grain junctions of SiC
Details of fiber reinforcement	- [0/90°] lay-up of two-dimensional plain-weave fabric of Tyranno™-SA Grade-3 near-stoichiometric silicon carbide fiber produced by Ube Industries, Ltd (Ube, Japan) - Fabric type / lot: PSA-S17F08PX / #4000030981
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, these materials undergo lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom, in a way very similar to monolithic crystalline silicon carbide. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density of 2.68 g/cm^3 (~86% theoretical density) - Thermal conductivity (in-plane): 45 / 18 W/m-K (at 20 / 1000°C) - Thermal conductivity (through-thickness): 23/10 W/m-K (at 20/1000°C) - Thermal expansion: 4.5 x 10^{-6} K^{-1} (20-1000°C) - Specific heat: 670 J/kg-K (at 20°C)
Chemical compatibility	- Compatible with SiC at all temperatures

<u>**Characterization Data for Futurix-MI Experiment**</u>

Material	**ORNL CVI SiC/SiC Composites (HNLS-CVI-Ref / TI)**
Fabrication method, and method of controlling repeatability	- Reinforcement with Hi-Nicalon™ Type S near-stoichiometric silicon carbide fiber. - Interphase coating with pyrolytic carbon (50-150nm thickness) onto the fiber surface prior to matrix infiltration. - Deposition of stoichiometric silicon carbide matrix by isothermal / isobaric chemical vapor infiltration.
Composition and impurity content	0.42% O, 0.05% N, 0.06% Cl, 4.6 mass-ppm Fe, 6.0ppm Ni, 0.13ppm Co, 6.6% excess-C, balance SiC
Metallographic feature	- Porosity due to three types of matrix pores; bundle intersections (Type I), fabric mesh (Type II), interlaminar (Type III) - Inclusion / precipitation of phases other than SiC or carbon has been found
Crystal structure	Beta-SiC in fiber and matrix, glassy carbon in interphase
Stoichiometry	- The matrix is stoichiometric beta-SiC - The fiber consists primarily of beta-SiC - The fiber contains small amount (~7%) of carbon that is present at multi-grain junctions of SiC
Details of fiber reinforcement	- [0/90°] lay-up of two-dimensional plain-weave fabric of Hi-Nicalon™ Type S near-stoichiometric silicon carbide fiber produced by Nippon Carbon Co (Tokyo, Japan). - Fabric type / lot: HNS9P2424 / #AP3711A-01-I8-01
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, these materials undergo lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom, in a way very similar to monolithic crystalline silicon carbide. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density of 2.52 g/cm^3 (~82% theoretical density) - Thermal conductivity (in-plane): 28 / 14 W/m-K (at 20 / 1000°C) - Thermal conductivity (through-thickness): 17 / 9 W/m-K (at 20/1000°C) - Thermal expansion: 4.5 x 10^{-6} K^{-1} (20-1000°C) - Specific heat: 670 J/kg-K (at 20°C)
Chemical compatibility	- Compatible with SiC at all temperatures

Characterization Data for Futurix-MI Experiment

Material	ORNL CVI SiC/SiC Composites (Hybrid-CVI)
Fabrication method, and method of controlling repeatability	- Reinforcement with Tyranno™-SA Grade-3 near-stoichiometric silicon carbide fiber and Thornel™ P-120S pitch-based graphite fiber. - Interphase coating with pyrolytic carbon (50-150nm thickness) onto the fiber surface prior to matrix infiltration. - Deposition of stoichiometric silicon carbide matrix by isothermal / isobaric chemical vapor infiltration.
Composition and impurity content	0.2 mass-% Al, 0.15% O, 0.05% N, 0.06% Cl, 3.3 mass-ppm Fe, 2.2ppm Ni, 28ppm Zr, 0.5ppm Hf, 5 mass-ppb Co, ~20% C, balance SiC
Metallographic feature	- Porosity due to matrix pores typical for orthogonal three-dimensional fiber architecture - Inclusion / precipitation of phases other than SiC or carbon has been found
Crystal structure	Beta-SiC in Tyranno™-SA fiber and matrix, graphitic carbon in P-120S fiber, glassy carbon in interphase
Stoichiometry	- The matrix is stoichiometric beta-SiC - The Tyranno™-SA fiber consists primarily of beta-SiC - The Tyranno™-SA fiber contains small amount (~7%) of carbon that is present at multi-grain junctions of SiC
Details of fiber reinforcement	- Orthogonal three-dimensional fabric of Tyranno™ SA Grade-3 near-stoichiometric silicon carbide fiber, produced by Ube Industries, Ltd (Ube, Japan), and Thornel™ P-120S pitch-based graphite fiber, produced by (Cytec Engineered Materials, Inc., Anaheim, CA). - X:Y:Z = 1:1:1 - Tyranno™-SA fiber in in-plane (X and Y) directions - P-120S fiber in trans-thickness (Z) direction
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, this material undergoes lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom, in a way very similar to monolithic crystalline silicon carbide. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density of 2.21 g/cm^3 (~75% theoretical density) - Thermal conductivity (in-plane): 37 / 16 W/m-K (at 20 / 1000°C) - Thermal conductivity (through-thickness): 51 W/m-K (at 20°C) - Thermal expansion: 4.5 x 10^{-6} K^{-1} (20-1000°C) - Specific heat: 640 J/kg-K (at 20°C)
Chemical compatibility	- Compatible with SiC at all temperatures

Characterization Data for Futurix-MI Experiment

Material	NITE SiC/SiC Composites (TySA-NITE)
Fabrication method, and method of controlling repeatability	- Reinforcement with Tyranno™-SA Grade-3 near-stoichiometric silicon carbide fiber. - Interphase coating with pyrolytic carbon (500nm thickness) onto the fiber surface prior to matrix sintering. - Densification of stoichiometric silicon carbide matrix by the proprietary NITE (nano-infiltration and transient eutectic-phase) process.
Composition and impurity content	0.65 mass-% Al, 2.5% Y, 2.1% O, 0.05% N, 0.06% Cl, 3.3 mass-ppm Fe, 2.2ppm Ni, 28ppm Zr, 0.5ppm Hf, 5 mass-ppb Co, 0.8% excess Si, 9.6% excess C, balance SiC
Metallographic feature	- Porosity due to finely and uniformly distributed matrix pores - The matrix contains oxide phases; primarily $Y_3Al_5O_{12}$, other oxide phases consist of Al, Y, Si, and O.
Crystal structure	Primarily beta-SiC in fiber and matrix, glassy carbon in interphase
Stoichiometry	- The matrix SiC is stoichiometric beta-phase - The matrix contains <10% of oxide phases which are present at multi-grain junctions of SiC and between the matrix SiC grains and interphases - SiC in the fiber is stoichiometric beta-phase - The fiber contains small amount (~5%) of carbon that is present at multi-grain junctions of SiC
Details of fiber reinforcement	- Uni-directional reinforcement with proprietary Tyranno™-SAK near-stoichiometric silicon carbide fiber produced by Ube Industries, Ltd (Ube, Japan)
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, this material undergoes lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom, in a way very similar to monolithic crystalline silicon carbide. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density: 2.99 g/cm^3 (~97% theoretical density) - Thermal conductivity (through-thickness): 74 W/m-K (at 20°C) - Thermal expansion: 4.5 x 10^{-6} K^{-1} (20-1000°C) - Specific heat: 660 J/kg-K (at 20°C)
Chemical compatibility	- Compatible with SiC at all temperatures

Characterization Data for Futurix-MI Experiment

Material	Rohm and Haas CVD SiC
Fabrication method, and method of controlling repeatability	- Standard resistivity grade of ultra-high purity CVD (chemically vapor deposited) SiC produced by Rohm and Haas Advanced Materials (Woburn, MA, USA)
Composition and impurity content	>99.9995% SiC
Metallographic feature	- Crystal grains elongated along the CVD growth direction
Crystal structure	- Beta-SiC
Stoichiometry	- This material is stoichiometric
Details of fiber reinforcement	Not applicable
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, these materials undergo lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density: 3.21 g/cm^3 (100% theoretical density) - Thermal conductivity: 333 / 78 W/m-K (at 0 / 1000°C) - Thermal expansion: 4.5 x 10^{-6} K^{-1} (20-1000°C) - Specific heat: 574 / 1251 J/kg-K (at 0 / 1000°C)
Chemical compatibility	- Compatible with SiC at all temperatures

Characterization Data for Futurix-MI Experiment

Material	HAST Single-Crystal 3C-SiC
Fabrication method, and method of controlling repeatability	- Standard resistivity grade of monocrystalline CVD (chemically vapor deposited) 3C-SiC produced by HAST; Hoya Advanced Semiconductor Technologies Co., Ltd. (Sagamihara, Japan)
Composition and impurity content	~10 at.ppm N, balance SiC
Metallographic feature	Not applicable
Crystal structure	- Beta-SiC, {100} surface orientation
Stoichiometry	- This material is stoichiometric
Details of fiber reinforcement	Not applicable
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, these materials undergo lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density: 3.21 g/cm^3 (100% theoretical density)
Chemical compatibility	- Compatible with SiC at all temperatures

Characterization Data for Futurix-MI Experiment

Material	NITE LPS-SiC
Fabrication method, and method of controlling repeatability	- Matrix material for NITE SiC/SiC composite in a form of monolithic SiC ceramic - Produced through liquid-phase sintering (LPS); the process condition is proprietary
Composition and impurity content	1.5 mass-% Al, 3.0% Y, 3.9% O, 1.6% excess-Si, balance SiC
Metallographic feature	- Porosity due to finely and uniformly distributed pores - Grain sizes are 200-1000 nm. - The matrix contains oxide phases; primarily $Y_3Al_5O_{12}$, other oxide phases consist of Al, Y, Si, and O.
Crystal structure	- Beta-SiC
Stoichiometry	- This material is primarily stoichiometric beta-phase SiC - The material contains <10% of oxide phases which are present at multi-grain junctions of SiC
Details of fiber reinforcement	Not applicable
Geometry	- Dimensions and mass of individual specimens are listed in a separate table. - Appearance of specimens is found in a separate set of photographs.
Dimensional stability to 1200°C	- During neutron irradiation, these materials undergo lattice swelling, which exhibits negative correlation with temperature and tends to saturate by a neutron fluence of a few displacement-per-atom. The expected magnitude of saturated swelling at 1000°C is ~0.5% volumetric.
Physical properties	- Mass density: 3.08 g/cm^3 (~96% theoretical density)
Chemical compatibility	- Compatible with SiC at all temperatures

Attachment 4

List of ORNL Silicon Carbide Specimens

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
BB	NITE SiC	TySA-NITE	NT01	BB25-01	Irradiation	25.17	2.49	2.00	-	0.3704
BB	NITE SiC	TySA-NITE	NT02	BB25-02	Irradiation	25.17	2.49	2.00	-	0.3727
BB	NITE SiC	TySA-NITE	NT03	BB25-03	Irradiation	25.18	2.48	2.00	-	0.3760
BB	NITE SiC	TySA-NITE	NT04	BB25-04	Irradiation	25.20	2.49	2.00	-	0.3783
BB	NITE SiC	TySA-NITE	NT05	BB25-05	Irradiation	25.20	2.49	2.00	-	0.3770
BB	NITE SiC	TySA-NITE	NT06	BB25-06	Irradiation	25.20	2.50	2.01	-	0.3781
BB	NITE SiC	TySA-NITE	NT07	BB25-07	Control	25.20	2.48	2.00	-	0.3800
BB	NITE SiC	TySA-NITE	NT08	BB25-08	Control	25.20	2.48	2.01	-	0.3794
BB	NITE SiC	TySA-NITE	NT09	BB25-09	Control	25.22	2.50	2.01	-	0.3756
BB	NITE SiC	TySA-NITE	NT10	BB25-10	Control	25.20	2.49	2.00	-	0.3785
BB	NITE SiC	TySA-NITE	NT11	BB25-11	Control	25.19	2.49	2.01	-	0.3767
BB	NITE SiC	TySA-NITE	NT12	BB25-12	Control	25.18	2.50	2.01	-	0.3802
CYL	NITE SiC	TySA-NITE	NT21	CYL-01	Irradiation	10.04	-	-	2.95	0.1995
CYL	NITE SiC	TySA-NITE	NT22	CYL-02	Control	10.03	-	-	2.94	0.1974
TDD	NITE SiC	TySA-NITE	NT31	TD8-01	Irradiation	-	-	2.01	7.88	0.2935
TDD	NITE SiC	TySA-NITE	NT32	TD8-02	Irradiation	-	-	2.01	7.91	0.2963
TDD	NITE SiC	TySA-NITE	NT33	TD8-03	Irradiation	-	-	2.00	7.89	0.2983
TDD	NITE SiC	TySA-NITE	NT34	TD8-04	Control	-	-	2.00	7.88	0.2943
TDD	NITE SiC	TySA-NITE	NT35	TD8-05	Control	-	-	2.00	7.87	0.2948
TDD	NITE SiC	TySA-NITE	NT36	TD8-06	Control	-	-	2.00	7.88	0.2914
TDD	NITE SiC	NITE Matrix SiC	LP31	TD8-07	Irradiation	-	-	1.94	7.91	0.2839
TDD	NITE SiC	NITE Matrix SiC	LP32	TD8-01	Irradiation	-	-	1.94	7.89	0.2809
TDD	NITE SiC	NITE Matrix SiC	LP33	TD8-09	Irradiation	-	-	1.95	7.90	0.2813
TDD	NITE SiC	NITE Matrix SiC	LP34	TD8-10	Control	-	-	1.94	7.86	0.2807
TDD	NITE SiC	NITE Matrix SiC	LP35	TD8-11	Control	-	-	1.93	7.89	0.2841
TDD	NITE SiC	NITE Matrix SiC	LP36	TD8-12	Control	-	-	1.94	7.87	0.2822
TDD	NITE SiC	CVD SiC R&H	CD31	TD8-13	Irradiation	-	-	2.01	7.88	0.3121
TDD	NITE SiC	CVD SiC R&H	CD32	TD8-14	Irradiation	-	-	2.00	7.88	0.3127
TDD	NITE SiC	CVD SiC R&H	CD33	TD8-15	Control	-	-	1.94	7.83	0.3032
TDD	NITE SiC	CVD SiC R&H	CD34	TD8-16	Control	-	-	1.95	7.88	0.3025
TDD	NITE SiC	Hybrid-CVI	HC31	-	Irradiation	-	-	1.98	7.93	0.2260
TDD	NITE SiC	Hybrid-CVI	HC32	-	Irradiation	-	-	2.01	7.94	0.2100
TDD	NITE SiC	Hybrid-CVI	HC33	-	Control	-	-	2.04	7.93	0.2180
TDD	NITE SiC	Hybrid-CVI	HC34	-	Control	-	-	2.02	7.94	0.2250

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
TEM	NITE SiC	NITE Matrix SiC	LP41	TE3-01	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP42	TE3-02	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP43	TE3-03	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP44	TE3-04	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP45	TE3-05	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP46	TE3-06	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP47	TE3-07	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP48	TE3-08	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP49	TE3-09	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP50	TE3-10	Irradiation	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP51	TE3-11	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP52	TE3-12	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP53	TE3-13	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP54	TE3-14	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP55	TE3-15	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP56	TE3-16	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP57	TE3-17	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP58	TE3-18	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP59	TE3-19	Control	-	-	0.150	2.97	0.0032
TEM	NITE SiC	NITE Matrix SiC	LP60	TE3-20	Control	-	-	0.150	2.97	0.0032

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm) L	W	T	Dia.	Mass (g)
BB	ORNL SiC	HNLS-CVI-Ref	SR01	-	Irradiation	25.00	2.50	2.01	-	0.2950
BB	ORNL SiC	HNLS-CVI-Ref	SR02	-	Irradiation	24.99	2.50	2.00	-	0.2890
BB	ORNL SiC	HNLS-CVI-Ref	SR03	-	Irradiation	25.01	2.49	2.01	-	0.2920
BB	ORNL SiC	HNLS-CVI-Ref	SR04	-	Irradiation	25.00	2.50	2.01	-	0.2890
BB	ORNL SiC	HNLS-CVI-Ref	SR05	-	Irradiation	25.00	2.49	2.01	-	0.2960
BB	ORNL SiC	HNLS-CVI-Ref	SR06	-	Irradiation	25.00	2.49	2.00	-	0.2920
BB	ORNL SiC	HNLS-CVI-Ref	SR07	-	Control	25.00	2.50	2.00	-	0.2920
BB	ORNL SiC	HNLS-CVI-Ref	SR08	-	Control	25.00	2.48	2.01	-	0.2940
BB	ORNL SiC	HNLS-CVI-Ref	SR09	-	Control	24.99	2.50	2.01	-	0.2880
BB	ORNL SiC	HNLS-CVI-Ref	SR10	-	Control	24.99	2.48	2.00	-	0.2990
BB	ORNL SiC	HNLS-CVI-Ref	SR11	-	Control	24.99	2.50	2.00	-	0.2870
BB	ORNL SiC	HNLS-CVI-Ref	SR12	-	Control	25.00	2.49	2.01	-	0.2900
BB	ORNL SiC	HNLS-CVI-TI	ST01	-	Irradiation	25.00	2.48	2.01	-	0.2910
BB	ORNL SiC	HNLS-CVI-TI	ST02	-	Irradiation	25.00	2.48	2.00	-	0.2860
BB	ORNL SiC	HNLS-CVI-TI	ST03	-	Irradiation	25.00	2.50	2.00	-	0.2820
BB	ORNL SiC	HNLS-CVI-TI	ST04	-	Irradiation	25.00	2.49	2.00	-	0.2790
BB	ORNL SiC	HNLS-CVI-TI	ST05	-	Irradiation	25.00	2.49	1.96	-	0.2700
BB	ORNL SiC	HNLS-CVI-TI	ST06	-	Irradiation	25.00	2.50	2.00	-	0.2790
BB	ORNL SiC	HNLS-CVI-TI	ST07	-	Control	24.99	2.50	2.00	-	0.2810
BB	ORNL SiC	HNLS-CVI-TI	ST08	-	Control	25.00	2.50	2.01	-	0.2920
BB	ORNL SiC	HNLS-CVI-TI	ST09	-	Control	25.00	2.50	2.00	-	0.2920
BB	ORNL SiC	HNLS-CVI-TI	ST10	-	Control	24.99	2.49	2.01	-	0.2910
BB	ORNL SiC	HNLS-CVI-TI	ST11	-	Control	25.00	2.48	2.00	-	0.2840
BB	ORNL SiC	HNLS-CVI-TI	ST12	-	Control	25.00	2.49	2.00	-	0.2890
CYL	ORNL SiC	HNLS-CVI-TI	ST21	-	Irradiation	9.97	-	-	2.99	0.1740
CYL	ORNL SiC	HNLS-CVI-TI	ST22	-	Control	9.99	-	-	2.94	0.1630
TDD	ORNL SiC	TySA-CVI-Ref	TR31	-	Irradiation	-	-	2.03	7.94	0.2660
TDD	ORNL SiC	TySA-CVI-Ref	TR32	-	Irradiation	-	-	2.04	7.93	0.2660
TDD	ORNL SiC	TySA-CVI-Ref	TR33	-	Control	-	-	2.02	7.93	0.2670
TDD	ORNL SiC	TySA-CVI-Ref	TR34	-	Control	-	-	2.00	7.93	0.2700
TDD	ORNL SiC	TySA-CVI-TI	TT31	-	Irradiation	-	-	2.07	7.92	0.2540
TDD	ORNL SiC	TySA-CVI-TI	TT32	-	Irradiation	-	-	1.98	7.93	0.2680
TDD	ORNL SiC	TySA-CVI-TI	TT33	-	Control	-	-	2.02	7.93	0.2800
TDD	ORNL SiC	TySA-CVI-TI	TT34	-	Control	-	-	2.01	7.92	0.2750
TDD	ORNL SiC	TySA-CVI-TF	TF31	-	Irradiation	-	-	2.01	7.93	0.2630
TDD	ORNL SiC	TySA-CVI-TF	TF32	-	Irradiation	-	-	2.02	7.92	0.2690
TDD	ORNL SiC	TySA-CVI-TF	TF33	-	Control	-	-	2.01	7.92	0.2610
TDD	ORNL SiC	TySA-CVI-TF	TF34	-	Control	-	-	2.02	7.92	0.2590
TDD	ORNL SiC	HNLS-CVI-Ref	SR31	-	Irradiation	-	-	2.05	7.92	0.2540
TDD	ORNL SiC	HNLS-CVI-Ref	SR32	-	Irradiation	-	-	2.03	7.92	0.2550
TDD	ORNL SiC	HNLS-CVI-Ref	SR33	-	Control	-	-	2.03	7.93	0.2490
TDD	ORNL SiC	HNLS-CVI-Ref	SR34	-	Control	-	-	2.05	7.93	0.2490
TDD	ORNL SiC	HNLS-CVI-TI	ST31	-	Irradiation	-	-	2.04	7.95	0.2600
TDD	ORNL SiC	HNLS-CVI-TI	ST32	-	Irradiation	-	-	2.04	7.93	0.2570
TDD	ORNL SiC	HNLS-CVI-TI	ST33	-	Control	-	-	2.03	7.93	0.2500
TDD	ORNL SiC	HNLS-CVI-TI	ST34	-	Control	-	-	2.06	7.93	0.2550

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
TEM	ORNL SiC	CVD SiC R&H	CD41	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD42	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD43	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD44	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD45	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD46	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD47	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD48	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD49	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD50	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD51	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD52	-	Irradiation	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD53	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD54	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD55	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD56	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD57	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD58	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD59	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	CVD SiC R&H	CD60	-	Control	-	-	0.13	2.92	0.0028
TEM	ORNL SiC	SC-SiC	SX41	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX42	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX43	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX44	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX45	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX46	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX47	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX48	-	Irradiation	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX49	-	Control	-	-	0.27	2.90	0.0056
TEM	ORNL SiC	SC-SiC	SX50	-	Control	-	-	0.27	2.90	0.0056

Attachment 5

List of ORNL Molybdenum Specimens

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
TEM	ORNL Mo	LCAC Moly	L1	-	Irradiation	-	-	0.171	2.991	0.012
TEM	ORNL Mo	LCAC Moly	L2	-	Irradiation	-	-	0.182	2.992	0.012
TEM	ORNL Mo	LCAC Moly	L3	-	Irradiation	-	-	0.179	2.994	0.012
TEM	ORNL Mo	LCAC Moly	L4	-	Irradiation	-	-	0.181	2.991	0.012
TEM	ORNL Mo	LCAC Moly	L5	-	Irradiation	-	-	0.183	2.992	0.012
TEM	ORNL Mo	LCAC Moly	L6	-	Irradiation	-	-	0.181	2.981	0.012
TEM	ORNL Mo	LCAC Moly	L7	-	Irradiation	-	-	0.179	2.990	0.012
TEM	ORNL Mo	LCAC Moly	L8	-	Irradiation	-	-	0.186	2.987	0.012
TEM	ORNL Mo	LCAC Moly	L9	-	Irradiation	-	-	0.180	2.985	0.012
TEM	ORNL Mo	LCAC Moly	L10	-	Irradiation	-	-	0.191	2.994	0.012
TEM	ORNL Mo	LCAC Moly	L11	-	Irradiation	-	-	0.175	2.984	0.012
TEM	ORNL Mo	LCAC Moly	L12	-	Irradiation	-	-	0.178	2.983	0.012
TEM	ORNL Mo	LCAC Moly	L13	-	Irradiation	-	-	0.181	2.992	0.012
TEM	ORNL Mo	LCAC Moly	L14	-	Irradiation	-	-	0.189	2.977	0.012
TEM	ORNL Mo	LCAC Moly	L15	-	Irradiation	-	-	0.177	2.990	0.012
TEM	ORNL Mo	LCAC Moly	L16	-	Irradiation	-	-	0.168	2.982	0.012
TEM	ORNL Mo	LCAC Moly	L17	-	Irradiation	-	-	0.180	2.984	0.012
TEM	ORNL Mo	LCAC Moly	L18	-	Irradiation	-	-	0.171	2.982	0.012
TEM	ORNL Mo	LCAC Moly	L19	-	Irradiation	-	-	0.172	2.988	0.012
TEM	ORNL Mo	LCAC Moly	L20	-	Irradiation	-	-	0.178	2.984	0.012
TEM	ORNL Mo	LCAC Moly	L21	-	Control	-	-	0.178	2.984	0.012
TEM	ORNL Mo	LCAC Moly	L22	-	Control	-	-	0.162	2.984	0.012
TEM	ORNL Mo	LCAC Moly	L23	-	Control	-	-	0.181	2.988	0.012
TEM	ORNL Mo	LCAC Moly	L24	-	Control	-	-	0.176	2.972	0.012
TEM	ORNL Mo	LCAC Moly	L25	-	Control	-	-	0.185	2.981	0.012
TEM	ORNL Mo	LCAC Moly	L26	-	Control	-	-	0.177	2.985	0.012
TEM	ORNL Mo	LCAC Moly	L27	-	Control	-	-	0.183	2.978	0.012
TEM	ORNL Mo	LCAC Moly	L28	-	Control	-	-	0.172	2.988	0.012
TEM	ORNL Mo	LCAC Moly	L29	-	Control	-	-	0.183	2.979	0.012
TEM	ORNL Mo	LCAC Moly	L30	-	Control	-	-	0.180	2.978	0.012
TEM	ORNL Mo	LCAC Moly	L31	-	Control	-	-	0.174	2.986	0.012
TEM	ORNL Mo	LCAC Moly	L32	-	Control	-	-	0.181	2.979	0.012

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
TEM	ORNL Mo	Mo-alloy 6	M1	-	Irradiation	-	-	0.144	2.974	0.012
TEM	ORNL Mo	Mo-alloy 6	M2	-	Irradiation	-	-	0.175	2.976	0.012
TEM	ORNL Mo	Mo-alloy 6	M3	-	Irradiation	-	-	0.167	2.984	0.012
TEM	ORNL Mo	Mo-alloy 6	M4	-	Irradiation	-	-	0.184	2.971	0.012
TEM	ORNL Mo	Mo-alloy 6	M5	-	Irradiation	-	-	0.172	2.980	0.012
TEM	ORNL Mo	Mo-alloy 6	M6	-	Irradiation	-	-	0.178	2.975	0.012
TEM	ORNL Mo	Mo-alloy 6	M7	-	Irradiation	-	-	0.174	2.977	0.012
TEM	ORNL Mo	Mo-alloy 6	M8	-	Irradiation	-	-	0.173	2.971	0.012
TEM	ORNL Mo	Mo-alloy 6	M9	-	Irradiation	-	-	0.174	2.972	0.012
TEM	ORNL Mo	Mo-alloy 6	M10	-	Irradiation	-	-	0.184	2.971	0.012
TEM	ORNL Mo	Mo-alloy 6	M11	-	Irradiation	-	-	0.171	2.961	0.012
TEM	ORNL Mo	Mo-alloy 6	M12	-	Irradiation	-	-	0.171	2.992	0.012
TEM	ORNL Mo	Mo-alloy 6	M13	-	Irradiation	-	-	0.171	2.971	0.012
TEM	ORNL Mo	Mo-alloy 6	M14	-	Irradiation	-	-	0.175	2.971	0.012
TEM	ORNL Mo	Mo-alloy 6	M15	-	Irradiation	-	-	0.177	2.974	0.012
TEM	ORNL Mo	Mo-alloy 6	M16	-	Irradiation	-	-	0.172	2.975	0.012
TEM	ORNL Mo	Mo-alloy 6	M17	-	Irradiation	-	-	0.175	2.973	0.012
TEM	ORNL Mo	Mo-alloy 6	M18	-	Irradiation	-	-	0.165	2.976	0.012
TEM	ORNL Mo	Mo-alloy 6	M19	-	Irradiation	-	-	0.174	2.974	0.012
TEM	ORNL Mo	Mo-alloy 6	M20	-	Irradiation	-	-	0.182	2.972	0.012
TEM	ORNL Mo	Mo-alloy 6	M21	-	Control	-	-	0.178	2.977	0.012
TEM	ORNL Mo	Mo-alloy 6	M22	-	Control	-	-	0.172	2.964	0.012
TEM	ORNL Mo	Mo-alloy 6	M23	-	Control	-	-	0.172	2.976	0.012
TEM	ORNL Mo	Mo-alloy 6	M24	-	Control	-	-	0.175	2.977	0.012
TEM	ORNL Mo	Mo-alloy 6	M25	-	Control	-	-	0.175	2.973	0.012
TEM	ORNL Mo	Mo-alloy 6	M26	-	Control	-	-	0.178	2.980	0.012
TEM	ORNL Mo	Mo-alloy 6	M27	-	Control	-	-	0.174	2.975	0.012
TEM	ORNL Mo	Mo-alloy 6	M28	-	Control	-	-	0.172	2.971	0.012
TEM	ORNL Mo	Mo-alloy 6	M29	-	Control	-	-	0.177	2.974	0.012
TEM	ORNL Mo	Mo-alloy 6	M30	-	Control	-	-	0.177	2.976	0.012
TEM	ORNL Mo	Mo-alloy 6	M31	-	Control	-	-	0.178	2.975	0.012
TEM	ORNL Mo	Mo-alloy 6	M32	-	Control	-	-	0.178	2.974	0.012

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm) L	W	T	Dia.	Mass (g)
BB	ORNL Mo	LCAC Moly	LB1	-	Irradiation	25.110	2.508	2.009	-	1.283
BB	ORNL Mo	LCAC Moly	LB2	-	Irradiation	25.095	2.504	2.038	-	1.284
BB	ORNL Mo	LCAC Moly	LB3	-	Irradiation	25.118	2.508	2.016	-	1.281
BB	ORNL Mo	LCAC Moly	LB4	-	Irradiation	25.136	2.506	2.007	-	1.283
BB	ORNL Mo	LCAC Moly	LB5	-	Irradiation	25.089	2.504	2.006	-	1.282
BB	ORNL Mo	LCAC Moly	LB6	-	Irradiation	25.099	2.513	2.006	-	1.278
BB	ORNL Mo	LCAC Moly	LB7	-	Control	25.175	2.506	2.011	-	1.283
BB	ORNL Mo	LCAC Moly	LB8	-	Control	25.114	2.511	2.008	-	1.280
BB	ORNL Mo	LCAC Moly	LB9	-	Control	25.108	2.501	2.008	-	1.280
BB	ORNL Mo	LCAC Moly	LB10	-	Control	25.125	2.502	2.015	-	1.281
BB	ORNL Mo	LCAC Moly	LB11	-	Control	25.102	2.505	2.012	-	1.280
BB	ORNL Mo	LCAC Moly	LB12	-	Control	25.079	2.508	2.006	-	1.271
BB	ORNL Mo	Mo-alloy 6	MB1	-	Irradiation	25.155	2.499	2.000	-	1.269
BB	ORNL Mo	Mo-alloy 6	MB2	-	Irradiation	25.135	2.502	2.013	-	1.280
BB	ORNL Mo	Mo-alloy 6	MB3	-	Irradiation	25.144	2.498	2.003	-	1.278
BB	ORNL Mo	Mo-alloy 6	MB4	-	Irradiation	25.137	2.499	2.008	-	1.272
BB	ORNL Mo	Mo-alloy 6	MB5	-	Irradiation	25.155	2.501	2.009	-	1.284
BB	ORNL Mo	Mo-alloy 6	MB6	-	Irradiation	25.154	2.502	2.005	-	1.275
BB	ORNL Mo	Mo-alloy 6	MB7	-	Control	25.170	2.506	2.005	-	1.281
BB	ORNL Mo	Mo-alloy 6	MB8	-	Control	25.147	2.503	2.005	-	1.280
BB	ORNL Mo	Mo-alloy 6	MB9	-	Control	25.151	2.506	2.000	-	1.270
BB	ORNL Mo	Mo-alloy 6	MB10	-	Control	25.142	2.504	2.010	-	1.278
BB	ORNL Mo	Mo-alloy 6	MB11	-	Control	25.150	2.498	2.018	-	1.275
BB	ORNL Mo	Mo-alloy 6	MB12	-	Control	25.145	2.499	2.009	-	1.271

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
CYL	ORNL Mo	LCAC Moly	LC1	-	Irradiation	10.018	-	-	2.985	0.713
CYL	ORNL Mo	LCAC Moly	LC2	-	Control	9.991	-	-	2.971	0.704
CYL	ORNL Mo	LCAC Moly	LC3	-	Control	9.988	-	-	2.985	0.710

Type	Material Category	Material	ID	Alternate ID	Use	Dimensions (mm)				Mass (g)
						L	W	T	Dia.	
TDD	ORNL Mo	LCAC Moly	LA1	-	Irradiation	-	-	2.023	7.964	1.020
TDD	ORNL Mo	LCAC Moly	LA2	-	Irradiation	-	-	2.016	7.980	1.018
TDD	ORNL Mo	LCAC Moly	LA3	-	Irradiation	-	-	2.021	7.967	1.021
TDD	ORNL Mo	LCAC Moly	LA4	-	Irradiation	-	-	1.989	7.967	1.007
TDD	ORNL Mo	LCAC Moly	LA5	-	Irradiation	-	-	2.032	7.965	1.014
TDD	ORNL Mo	LCAC Moly	LA6	-	Control	-	-	2.008	7.964	1.016
TDD	ORNL Mo	LCAC Moly	LA7	-	Control	-	-	2.028	7.944	1.020
TDD	ORNL Mo	LCAC Moly	LA8	-	Control	-	-	2.007	7.978	1.019
TDD	ORNL Mo	LCAC Moly	LA9	-	Control	-	-	2.033	7.965	1.021
TDD	ORNL Mo	LCAC Moly	LA10	-	Control	-	-	2.020	7.973	1.018
TDD	ORNL Mo	LCAC Moly	LA11	-	Control	-	-	2.022	7.960	1.022
TDD	ORNL Mo	LCAC Moly	LA12	-	Control	-	-	2.018	7.956	1.012
TDD	ORNL Mo	Mo-alloy 6	MA1	-	Irradiation	-	-	2.043	7.967	1.028
TDD	ORNL Mo	Mo-alloy 6	MA2	-	Irradiation	-	-	2.006	7.952	1.008
TDD	ORNL Mo	Mo-alloy 6	MA3	-	Irradiation	-	-	2.050	7.960	1.022
TDD	ORNL Mo	Mo-alloy 6	MA4	-	Irradiation	-	-	2.042	7.965	1.025
TDD	ORNL Mo	Mo-alloy 6	MA5	-	Irradiation	-	-	1.993	7.979	1.005
TDD	ORNL Mo	Mo-alloy 6	MA6	-	Control	-	-	2.067	7.990	1.034
TDD	ORNL Mo	Mo-alloy 6	MA7	-	Control	-	-	2.047	7.961	1.023
TDD	ORNL Mo	Mo-alloy 6	MA8	-	Control	-	-	2.010	7.953	1.012
TDD	ORNL Mo	Mo-alloy 6	MA9	-	Control	-	-	1.998	7.947	1.000
TDD	ORNL Mo	Mo-alloy 6	MA10	-	Control	-	-	1.976	8.000	0.998
TDD	ORNL Mo	Mo-alloy 6	MA11	-	Control	-	-	2.041	7.958	1.019
TDD	ORNL Mo	Mo-alloy 6	MA12	-	Control	-	-	2.019	7.956	1.008

Attachment 6

Photographs of ORNL Specimens

Photo#:	00033	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT01 - 06 (left to right), side 1/4				

Photo#:	**00034**	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT01 - 06 (left to right), side 2/4				

Photo#:	00035	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT01 - 06 (left to right), side 3/4				

Photo#:	00036	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT01 - 06 (left to right), side 4/4				

Photo#:	00038	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT07 - 12 (left to right), side 1/4				

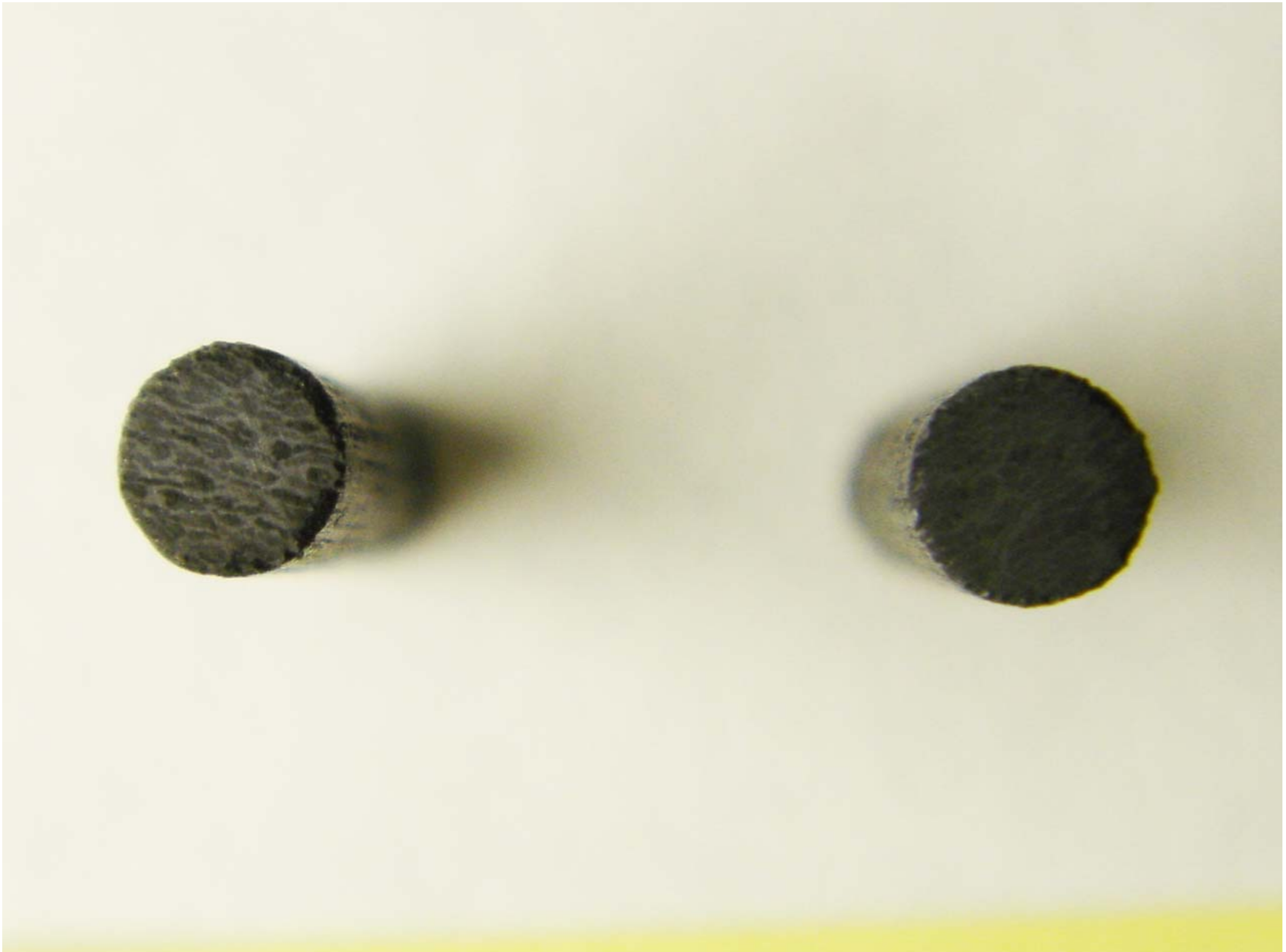
Photo#:	00039	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT07 - 12 (left to right), side 2/4				

Photo#:	00040	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT07 - 12 (left to right), side 3/4				

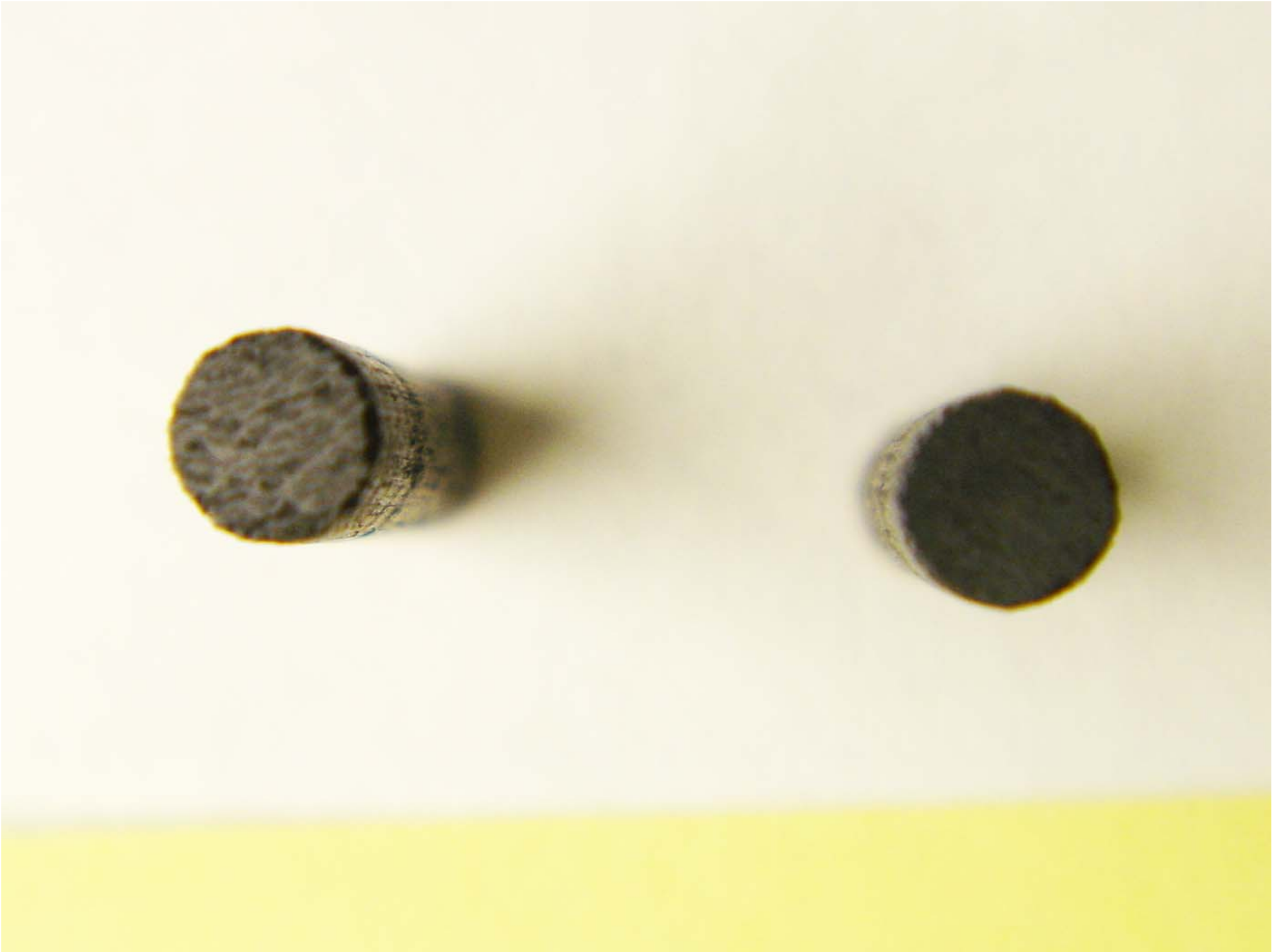
Photo#:	00041	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT07 - 12 (left to right), side 4/4				

Photo#:	00043	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT21 - 22 (left to right), side 1/3				

Photo#:	00044	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT21 - 22 (left to right), side 2/3				



Photo#:	00045	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT21 - 22 (left to right), side 3/3				



Photo#:	00047	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT31 - 36 (top left to top right, then bottom left to bottom right), side 1/2				

Photo#:	00048	Date:	3/14/05	Equip.:	DSC-T1
Note:	NT31 - 36 (top left to top right, then bottom left to bottom right), side 2/2				

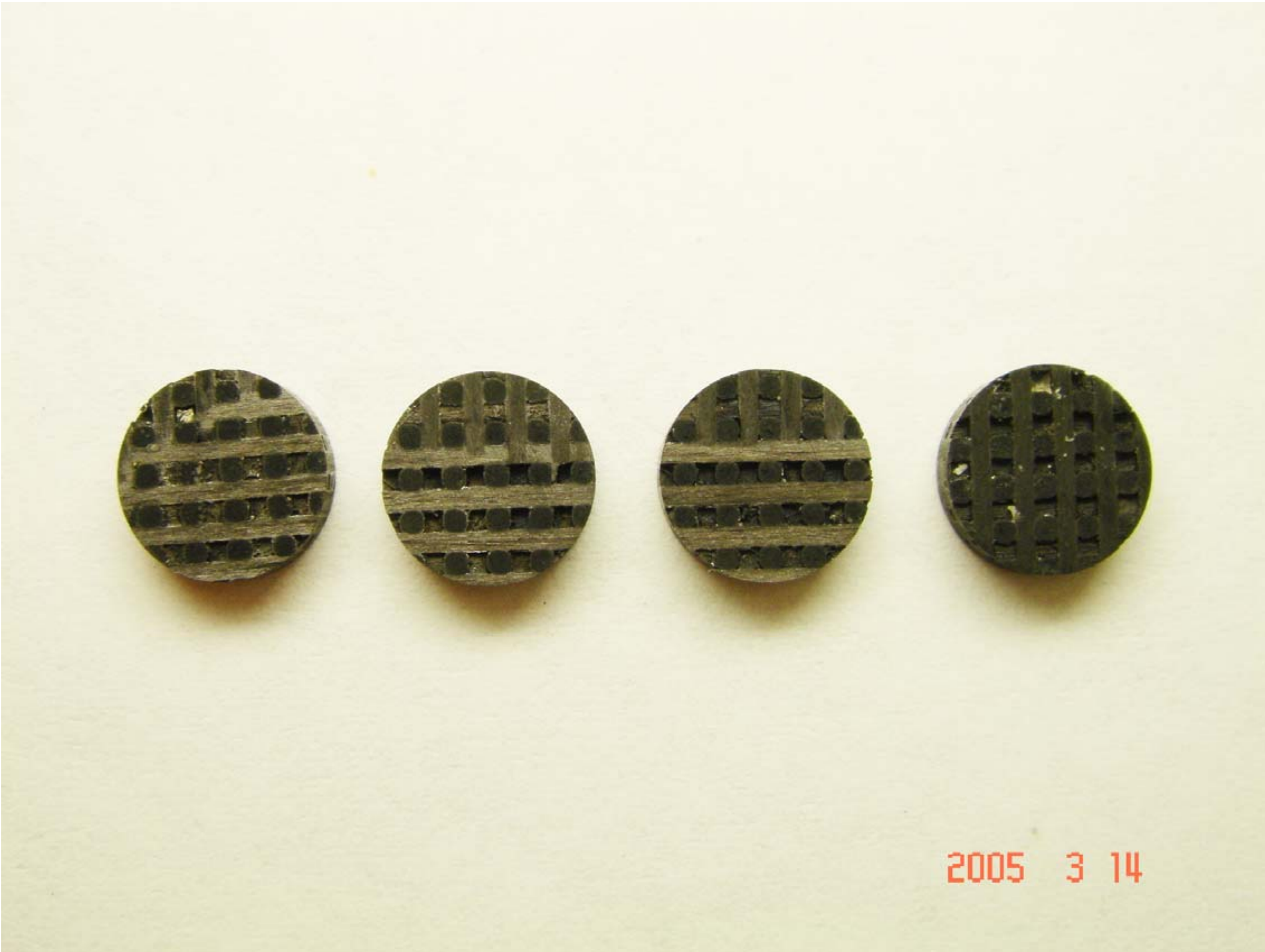
Photo#:	00050	Date:	3/14/05	Equip.:	DSC-T1
Note:	LP31 - 36 (top left to top right, then bottom left to bottom right), side 1/2				

Photo#:	00051	Date:	3/14/05	Equip.:	DSC-T1
Note:	LP31 - 36 (top left to top right, then bottom left to bottom right), side 1/2				

Photo#:	00053	Date:	3/14/05	Equip.:	DSC-T1
Note:	CD31 - 34 (left to right), side 1/2				

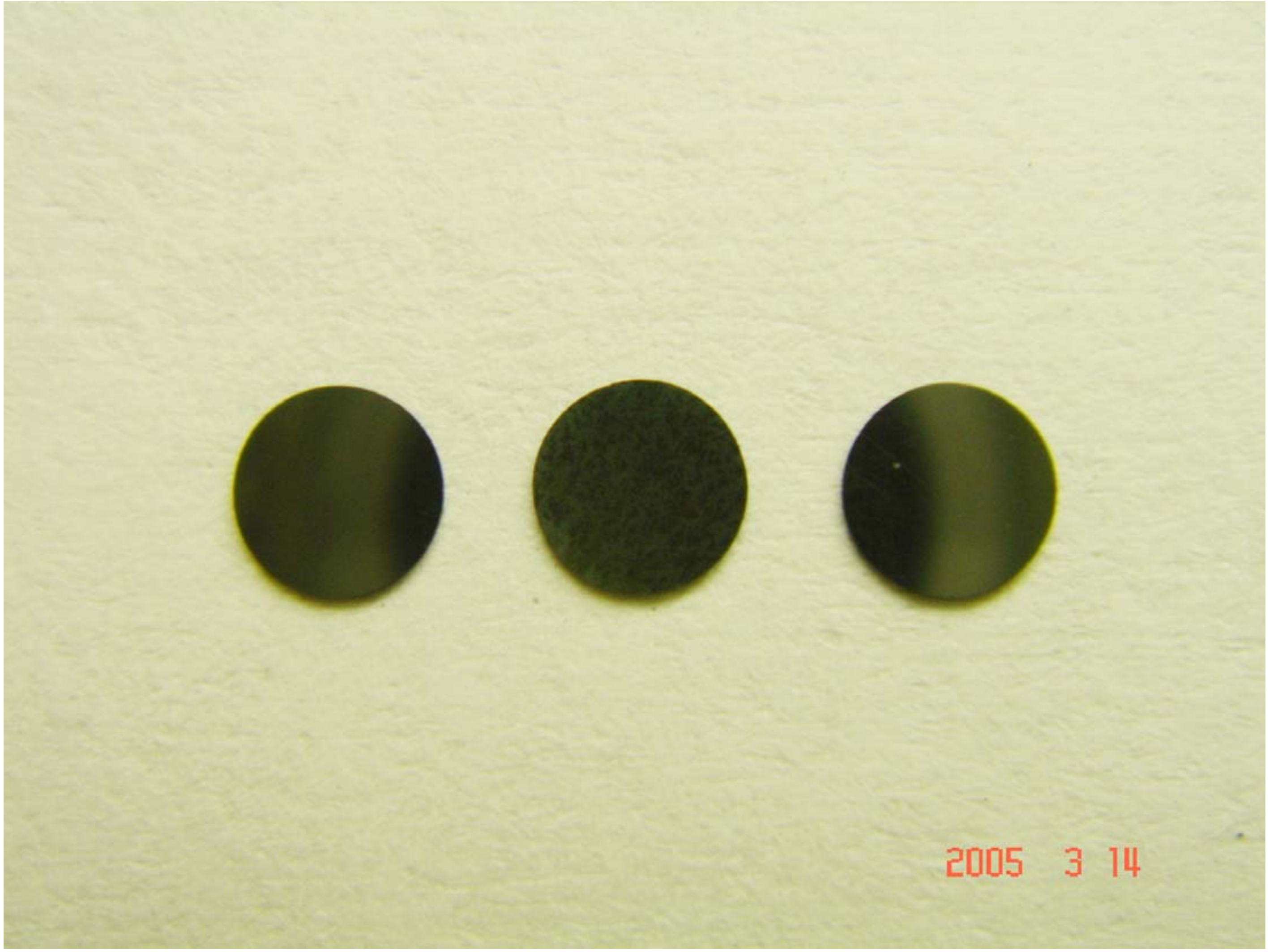
Photo#:	00054	Date:	3/14/05	Equip.:	DSC-T1
Note:	CD31 - 34 (left to right), side 1/2				

Photo#:	00020	Date:	3/14/05	Equip.:	DSC-T1
Note:	HC31 - 34 (left to right), side 1/2				



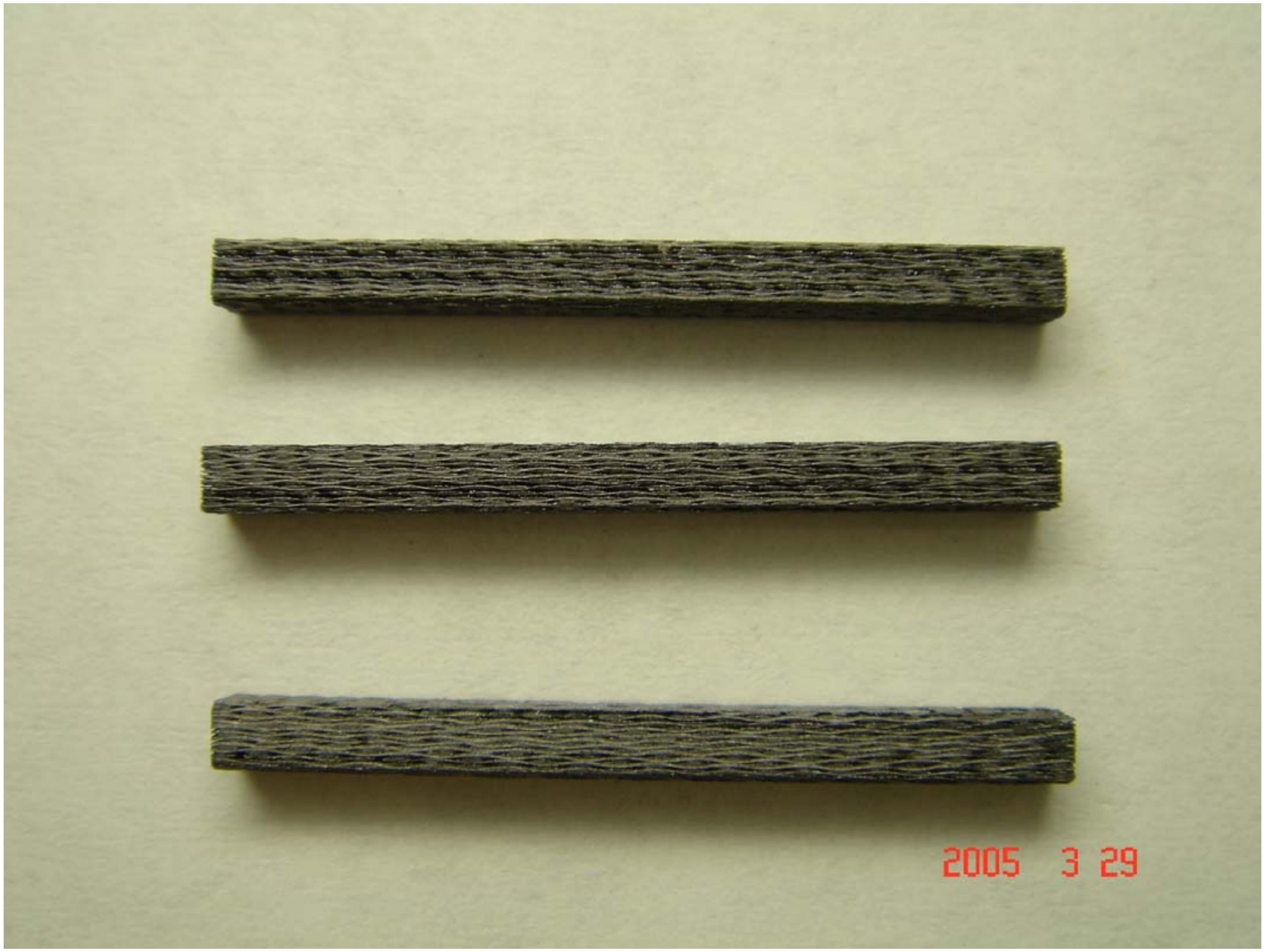
Photo#:	**00021**	Date:	3/14/05	Equip.:	DSC-T1
Note:	HC31 - 34 (left to right), side 2/2				

Photo#:	00056	Date:	3/14/05	Equip.:	DSC-T1
Note:	LP41-60 (3 out of 20 TEM discs), side 1/1				



Photo#:	**00060**	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR01-03 (top to bottom), side 1/4				

Photo#:	00061	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR01-03 (top to bottom), side 2/4				

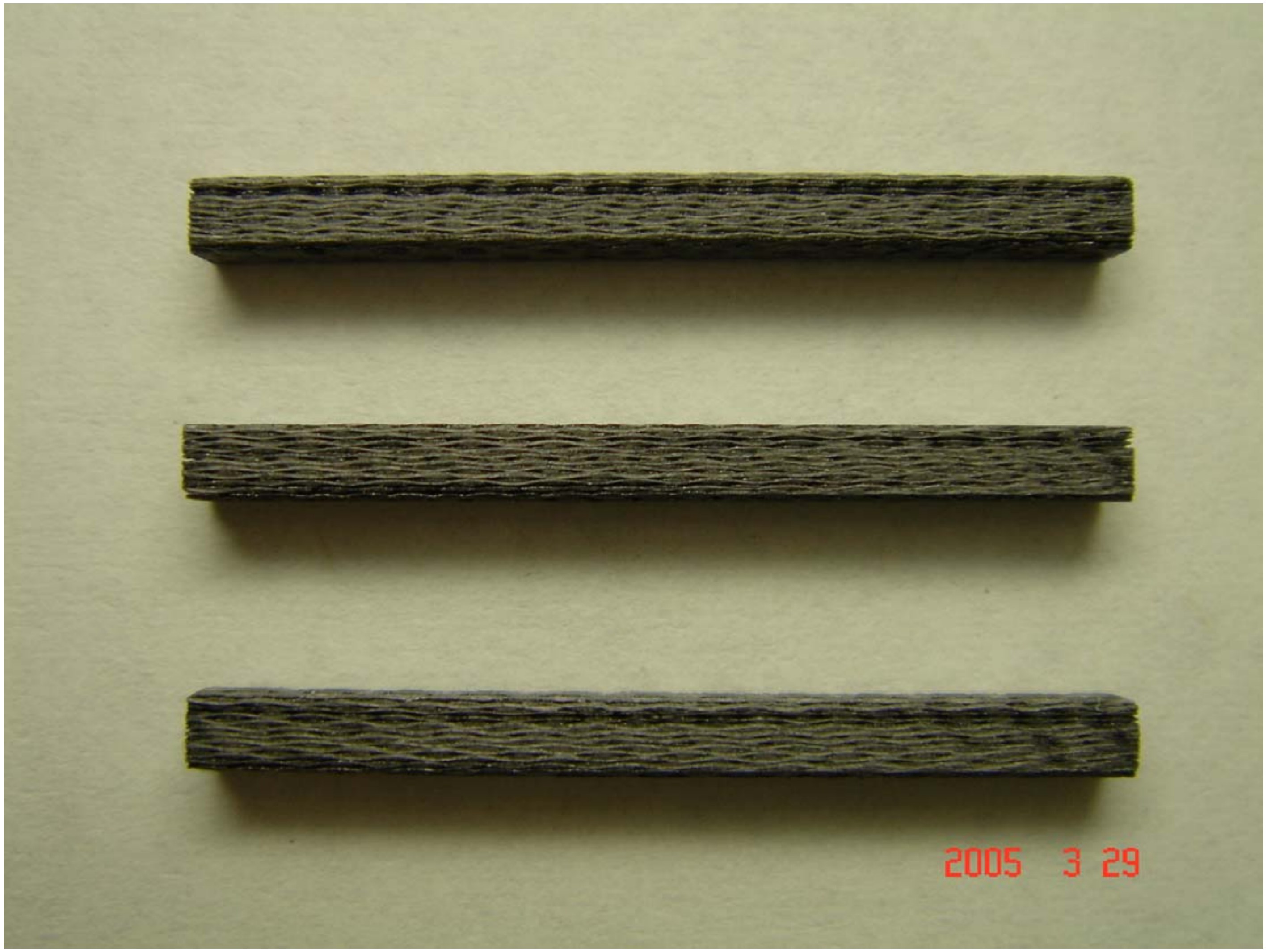


Photo#:	00062	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR01-03 (top to bottom), side 3/4				

Photo#:	00063	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR01-03 (top to bottom), side 4/4				

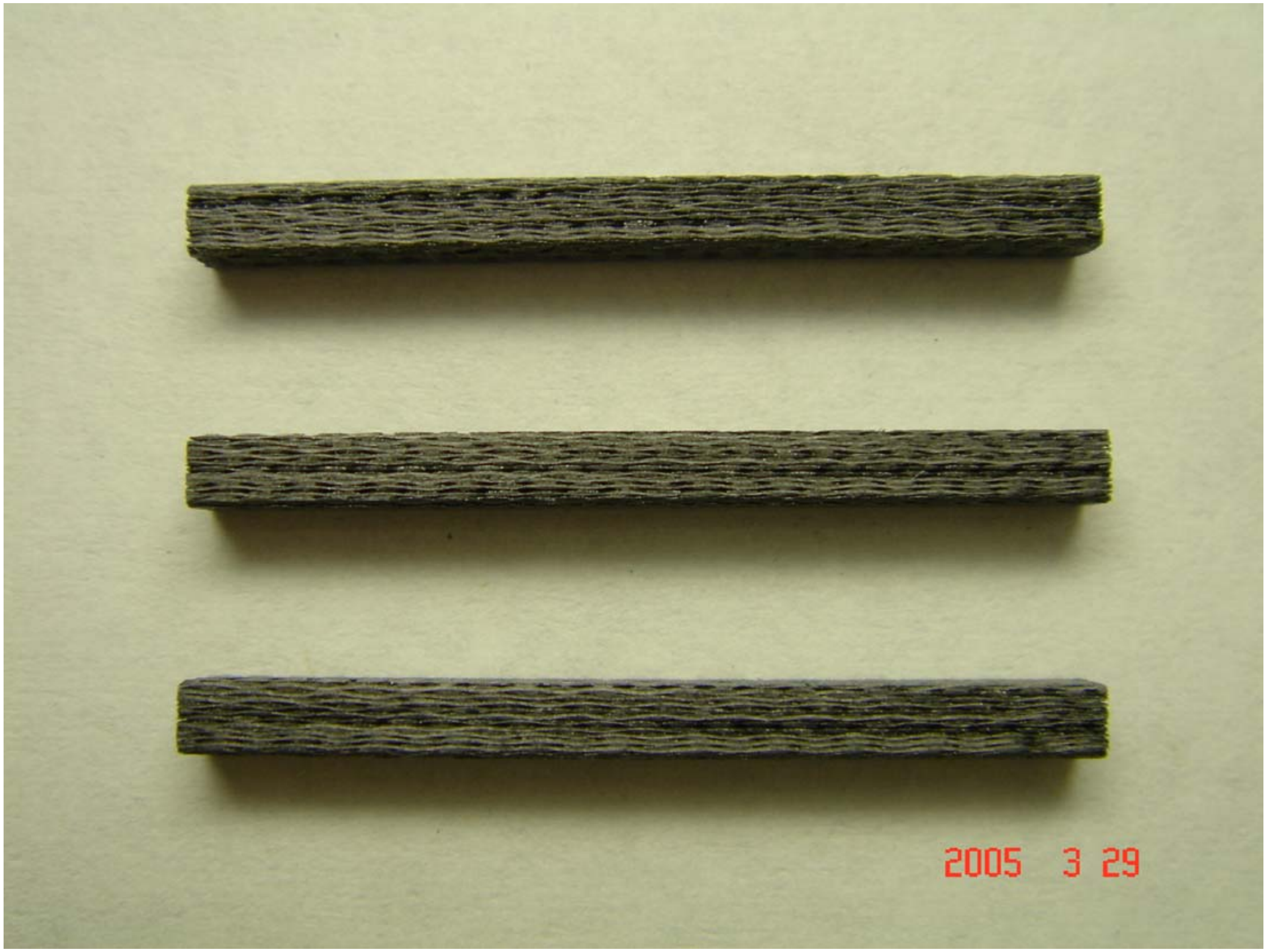
Photo#:	**00064**	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR04-06 (top to bottom), side 1/4				

Photo#:	00065	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR04-06 (top to bottom), side 2/4				



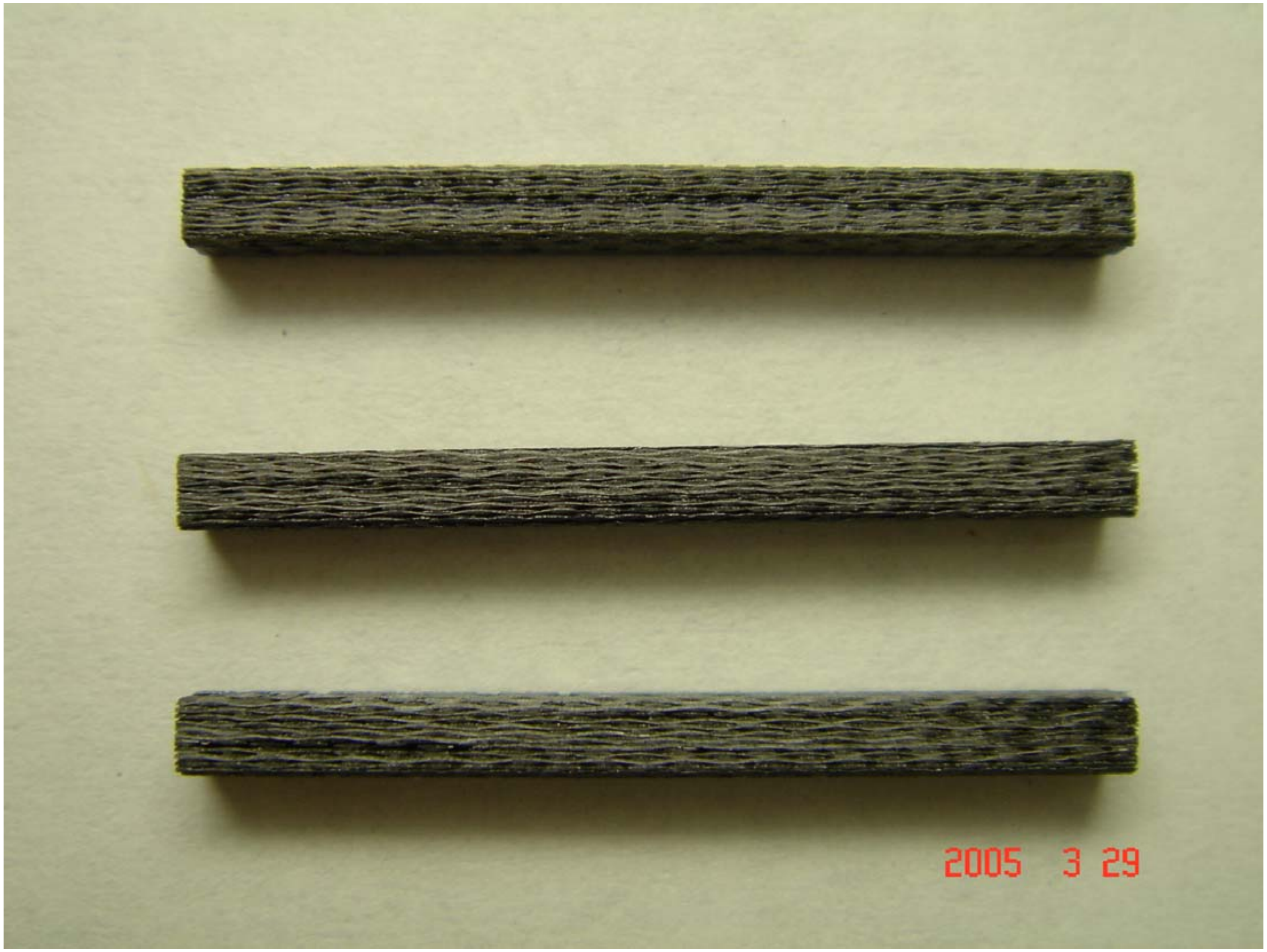
Photo#:	00066	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR04-06 (top to bottom), side 3/4				

Photo#:	**00067**	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR04-06 (top to bottom), side 4/4				



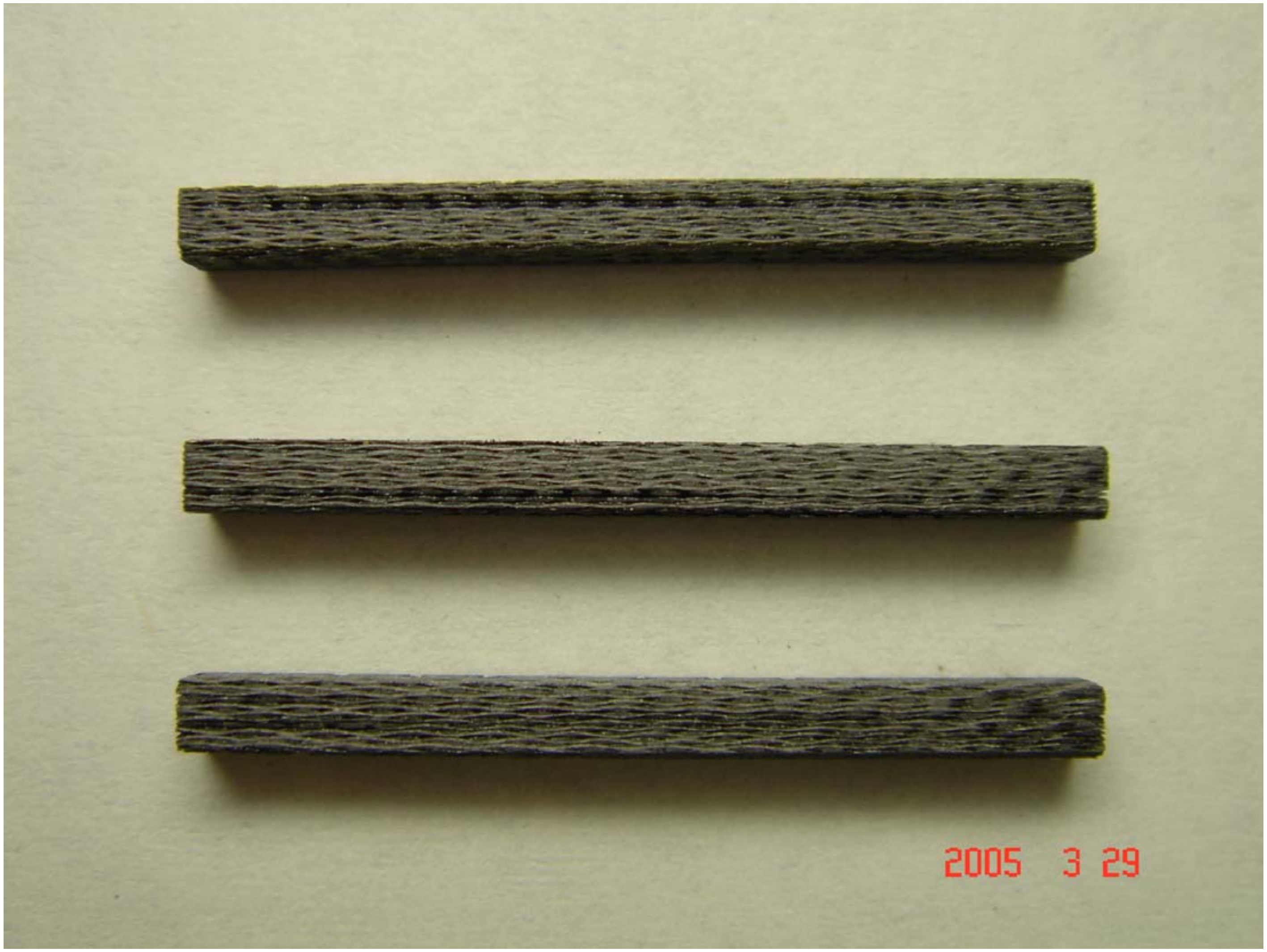
Photo#:	00068	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR07-09 (top to bottom), side 1/4				

Photo#:	00069	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR07-09 (top to bottom), side 2/4				



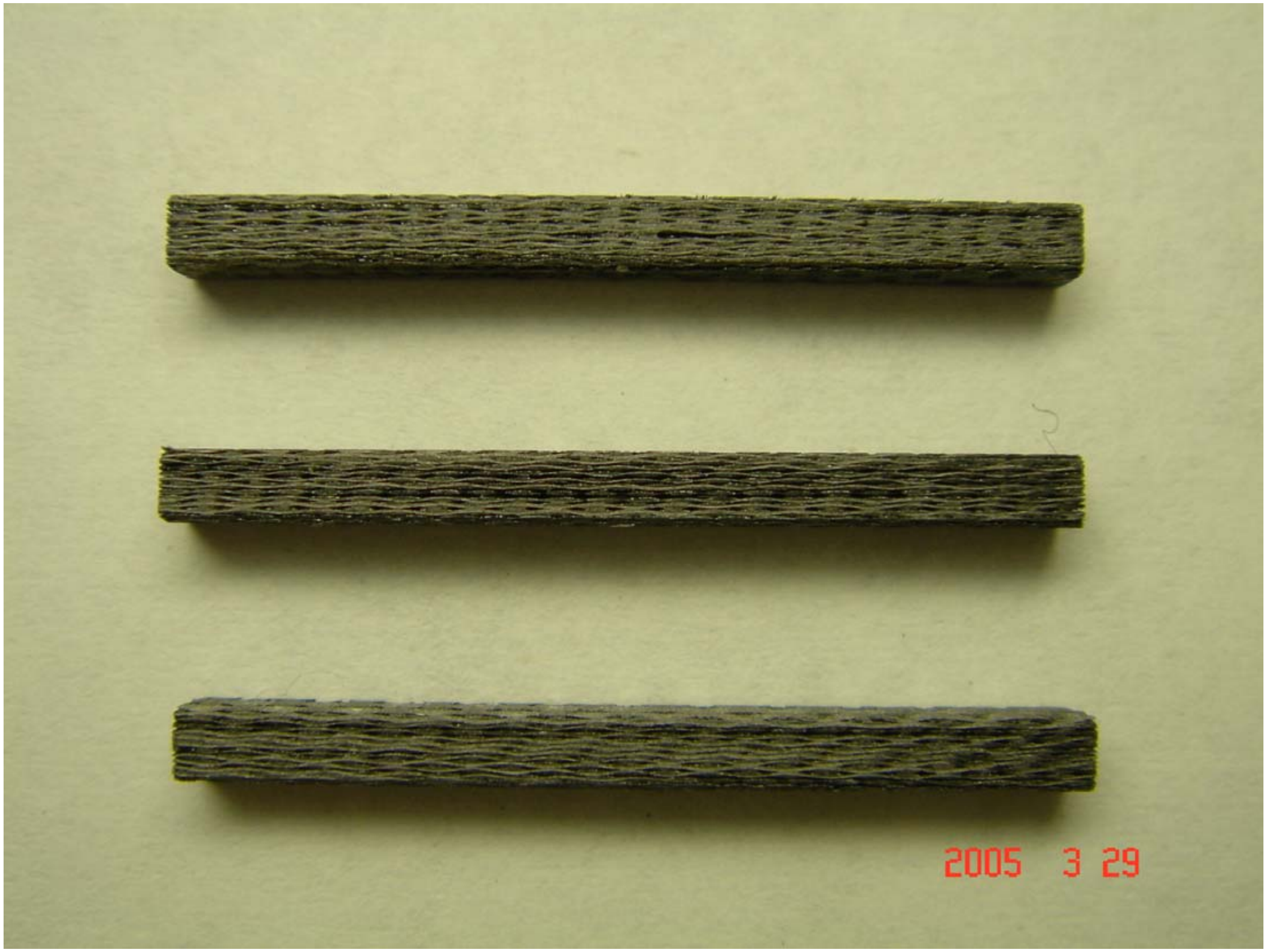
Photo#:	00070	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR07-09 (top to bottom), side 3/4				

Photo#:	00071	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR07-09 (top to bottom), side 4/4				



Photo#:	00072	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR10-12 (top to bottom), side 1/4				

Photo#:	00073	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR10-12 (top to bottom), side 2/4				

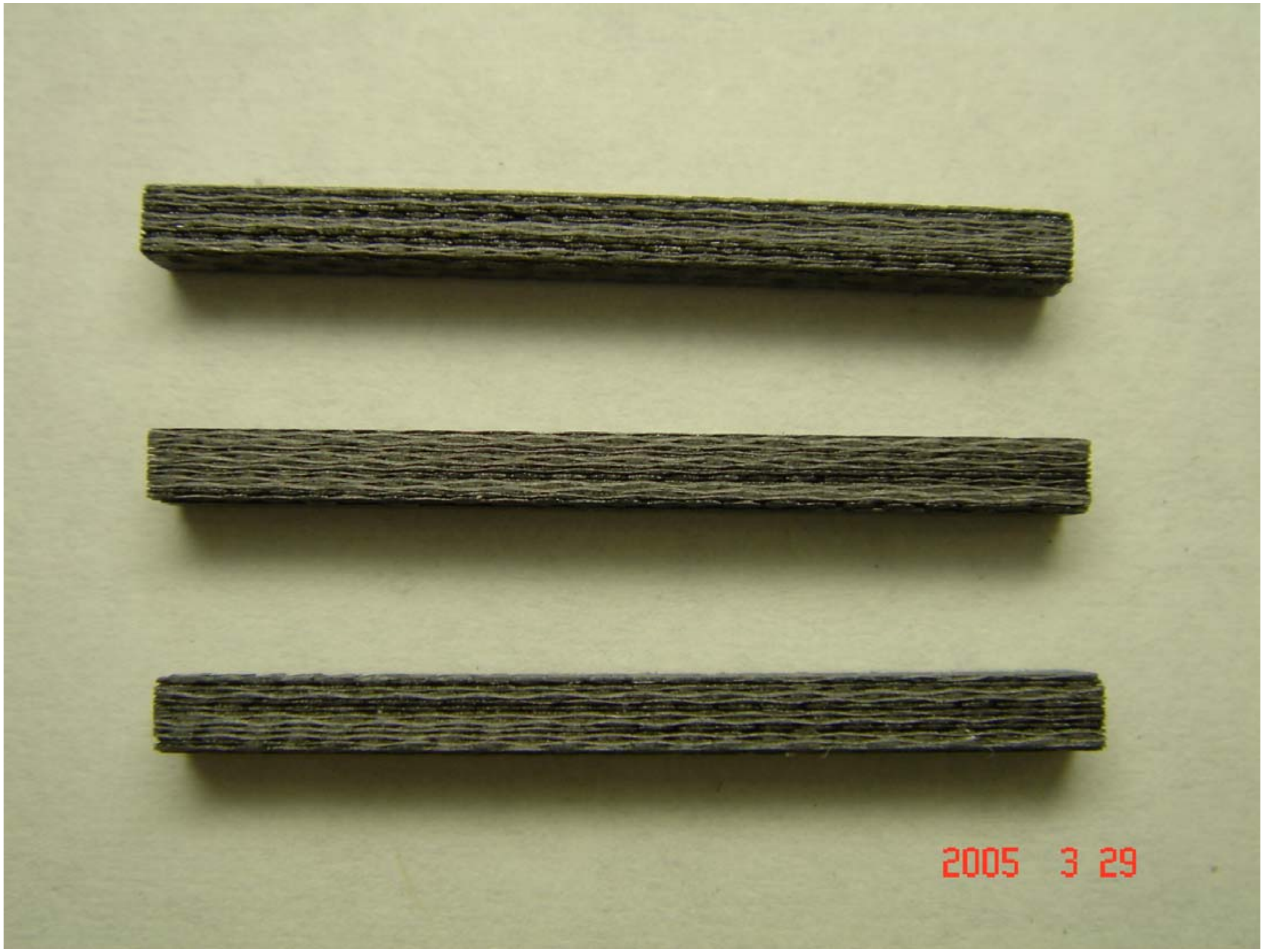


Photo#:	00074	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR10-12 (top to bottom), side 3/4				

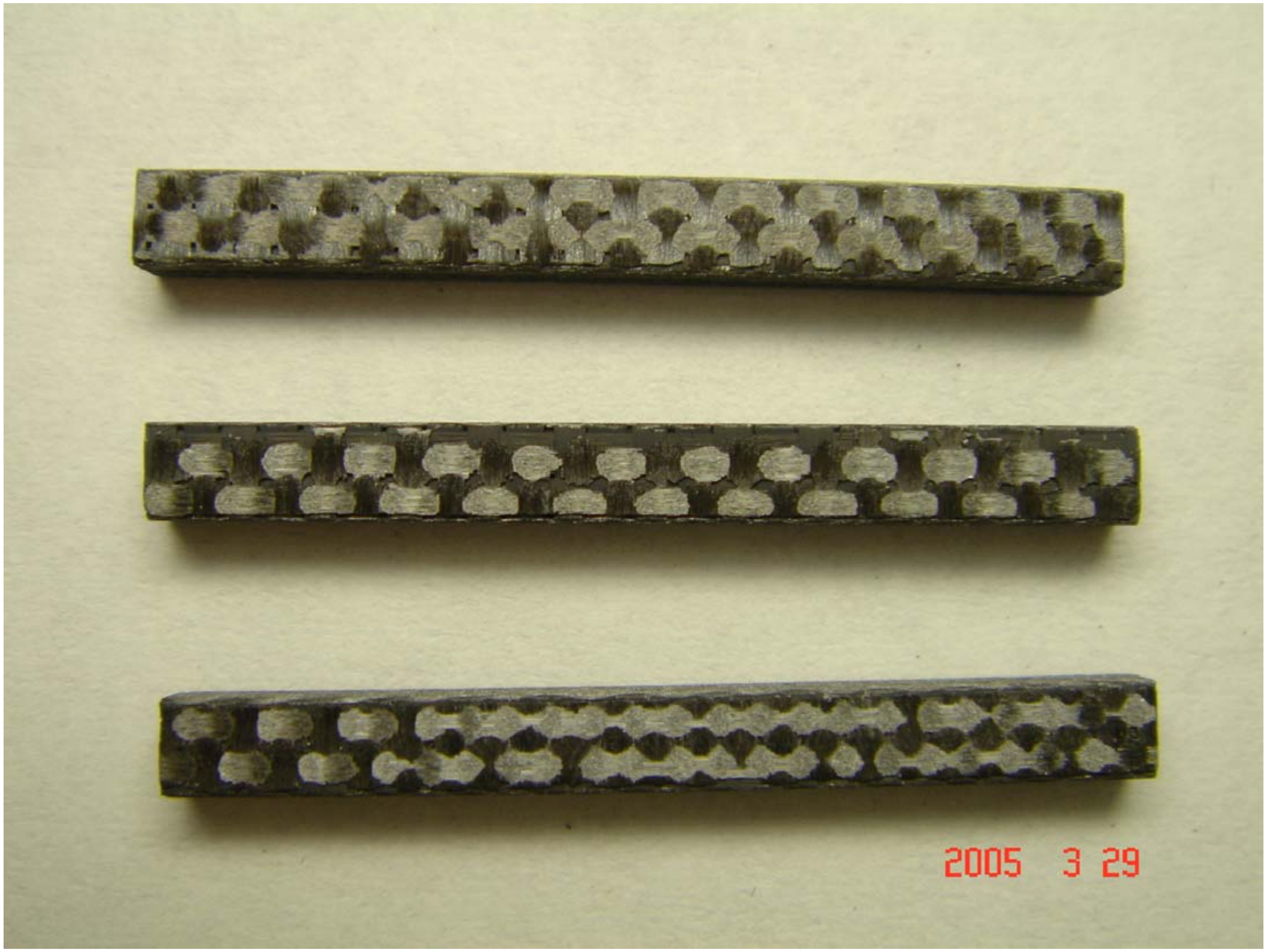
Photo#:	**00075**	Date:	3/29/05	Equip.:	DSC-T1
Note:	SR10-12 (top to bottom), side 4/4				

Photo#:	**00081**	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST01 - 03 (top to bottom), side 1/4				

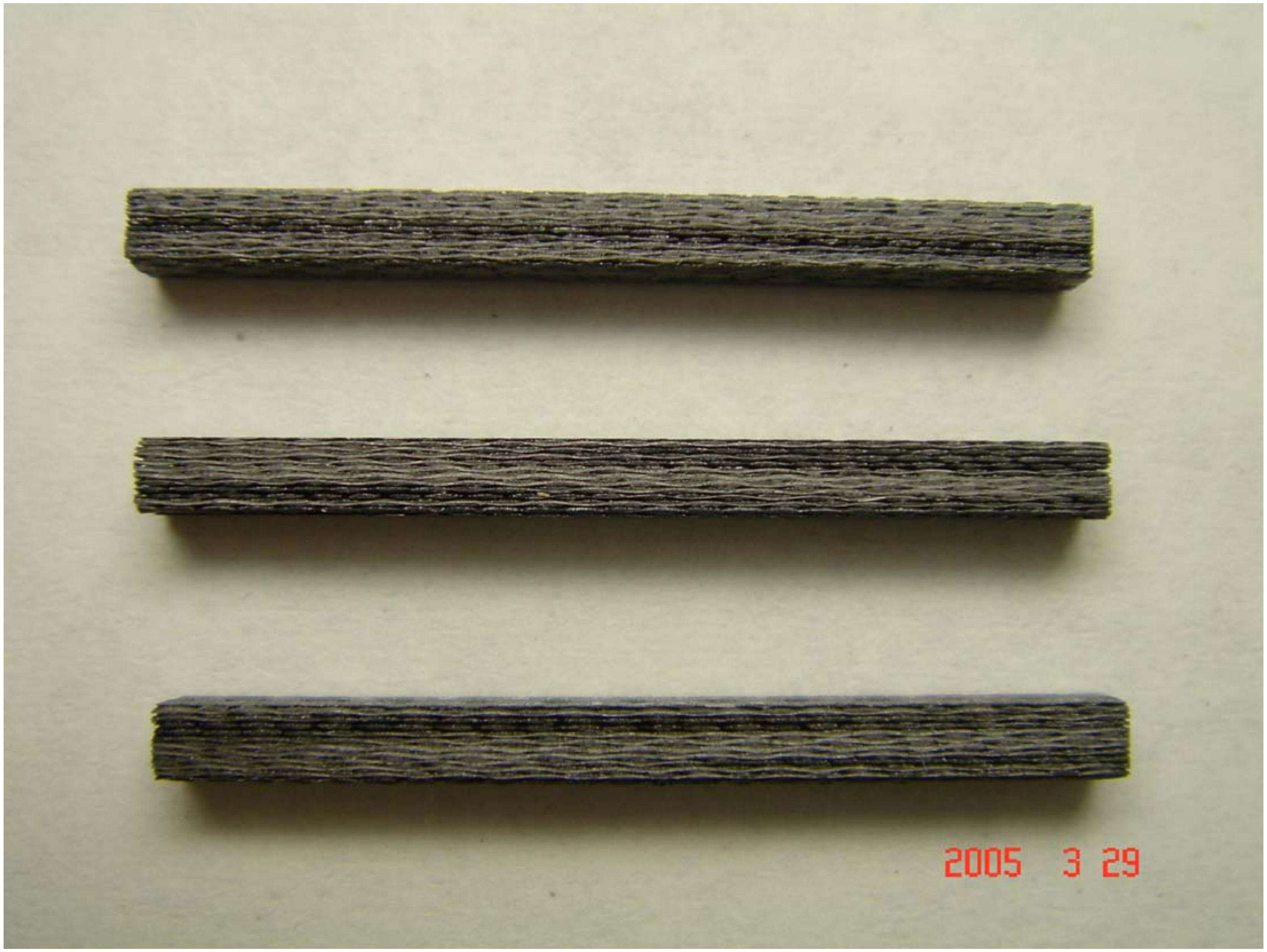
Photo#:	00082	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST01 - 03 (top to bottom), side 2/4				



Photo#:	00083	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST01 - 03 (top to bottom), side 3/4				



Photo#:	00084	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST01 - 03 (top to bottom), side 4/4				

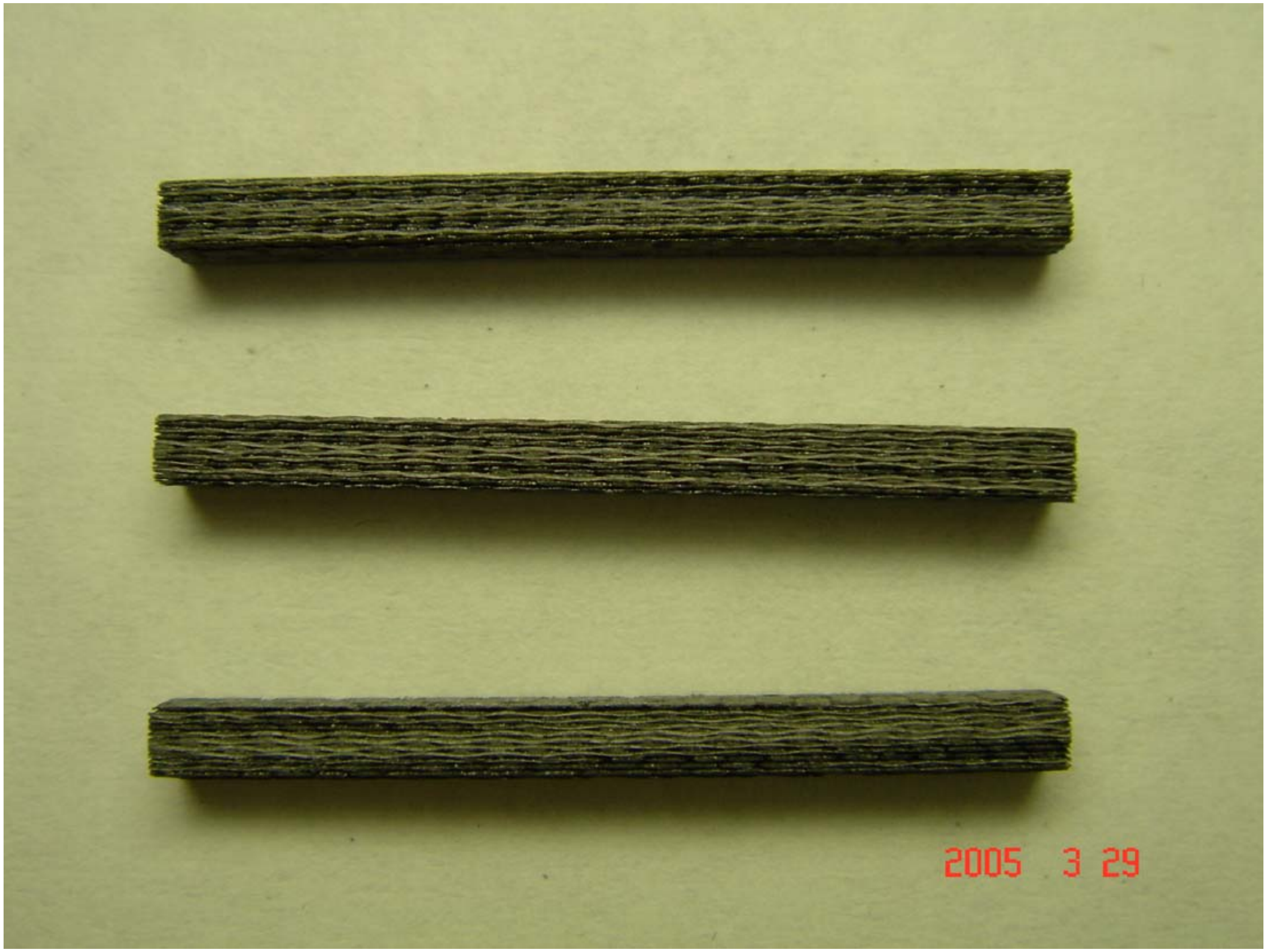


Photo#:	00085	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST04 - 06 (top to bottom), side 1/4				

Photo#:	00086	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST04 - 06 (top to bottom), side 2/4				

Photo#:	00087	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST04 - 06 (top to bottom), side 3/4				

Photo#:	00088	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST04 - 06 (top to bottom), side 4/4				

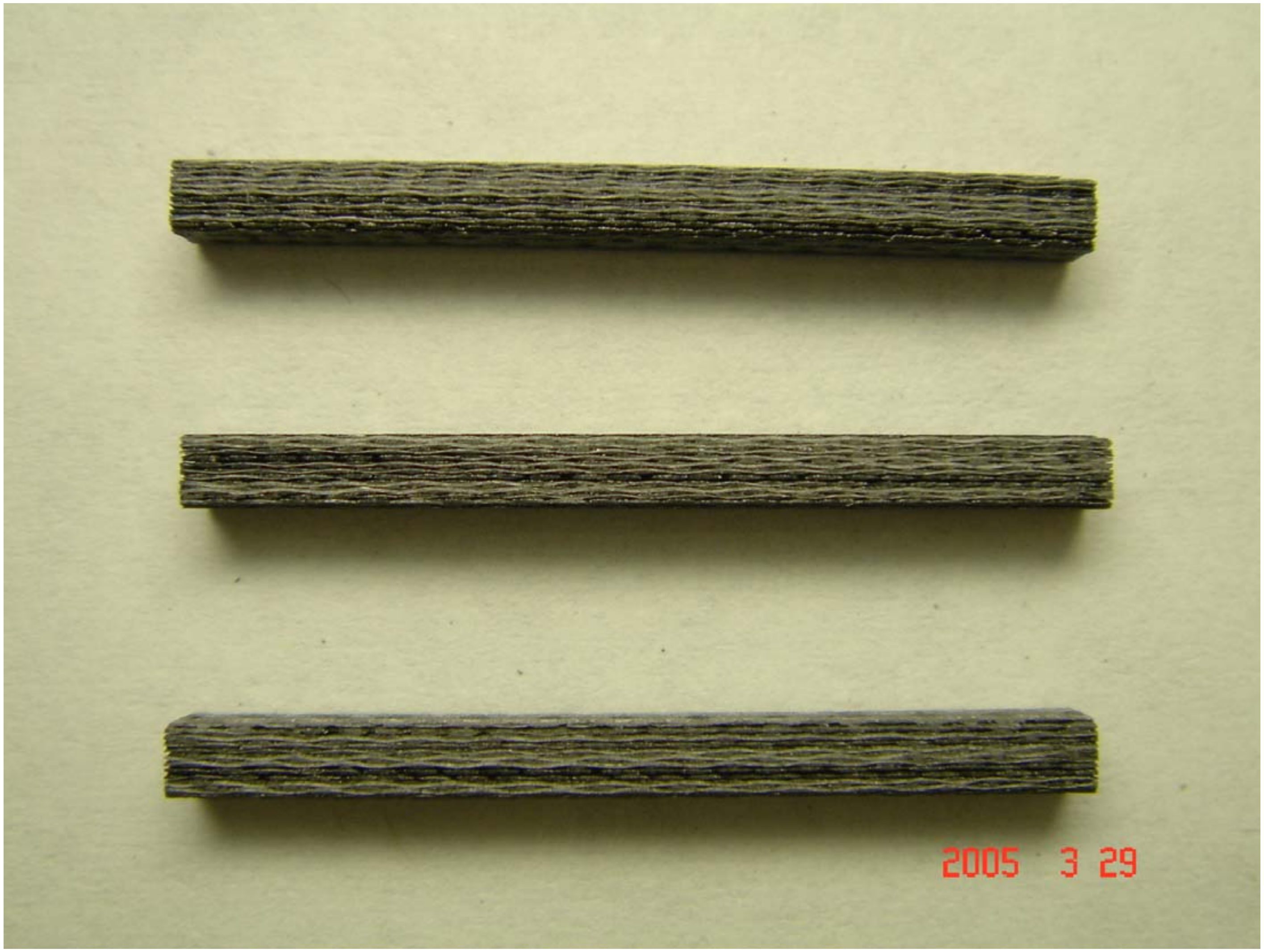


Photo#:	**00089**	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST07- 09 (top to bottom), side 1/4				

Photo#:	**00090**	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST07- 09 (top to bottom), side 2/4				

Photo#:	00091	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST07- 09 (top to bottom), side 3/4				

Photo#:	00092	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST07- 09 (top to bottom), side 4/4				

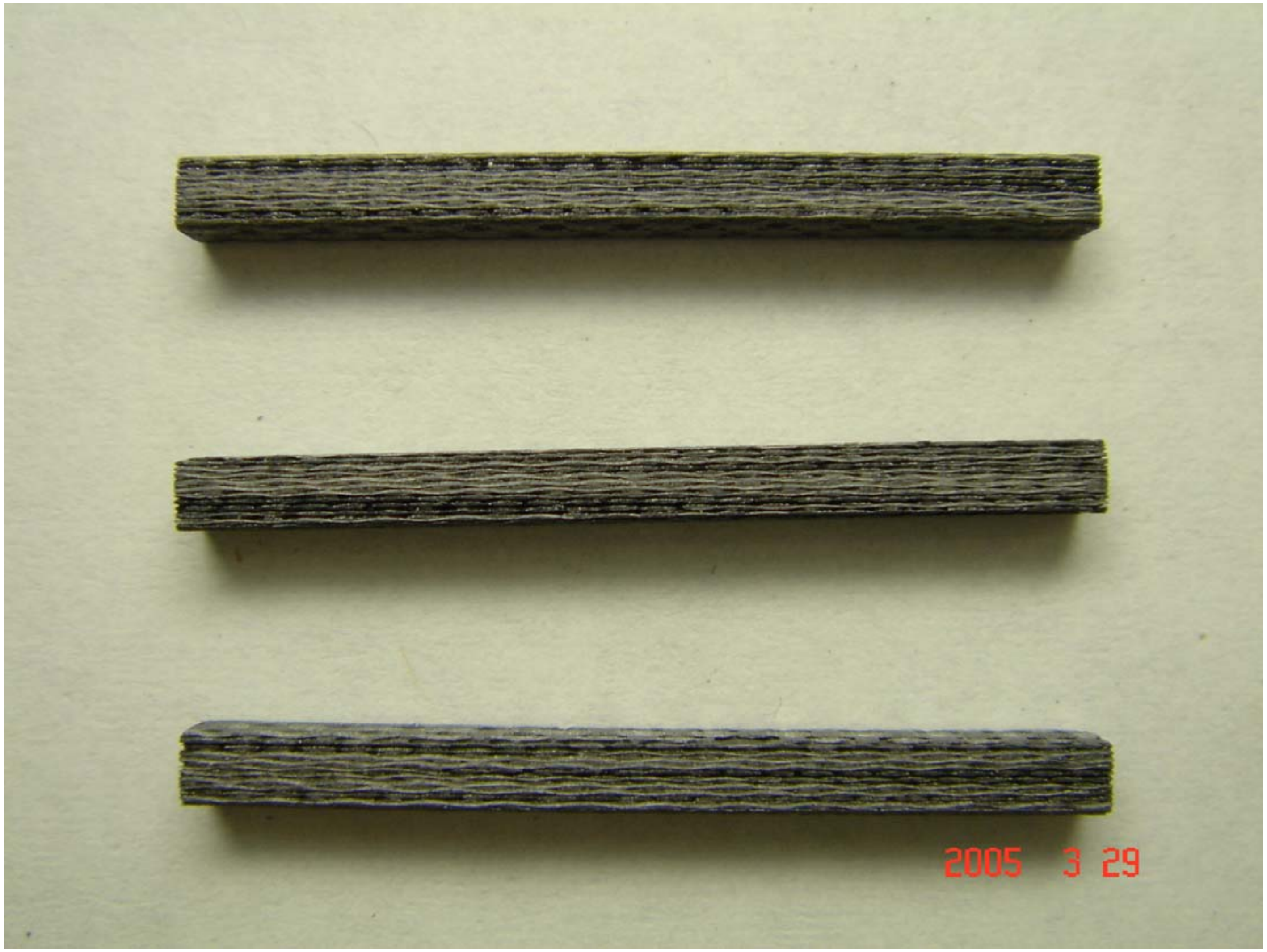


Photo#:	00093	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST10- 12 (top to bottom), side 1/4				

Photo#:	00094	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST10- 12 (top to bottom), side 2/4				

Photo#:	00095	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST10- 12 (top to bottom), side 3/4				

Photo#:	00096	Date:	3/29/05	Equip.:	DSC-T1
Note:	ST10- 12 (top to bottom), side 4/4				



Photo#:	00023	Date:	3/14/05	Equip.:	DSC-T1
Note:	ST21-22 (left to right), side 1/3				

Photo#:	00024	Date:	3/14/05	Equip.:	DSC-T1
Note:	ST21-22 (left to right), side 2/3				

Photo#:	**00025**	Date:	3/14/05	Equip.:	DSC-T1
Note:	ST21-22 (left to right), side 3/3				

Photo#:	00005	Date:	3/14/05	Equip.:	DSC-T1
Note:	TR31- 34 (left to right), side 1/2				

Photo#:	00006	Date:	3/14/05	Equip.:	DSC-T1
Note:	TR31- 34 (left to right), side 2/2				

Photo#:	**00008**	Date:	3/14/05	Equip.:	DSC-T1
Note:	TT31- 34 (left to right), side 1/2				

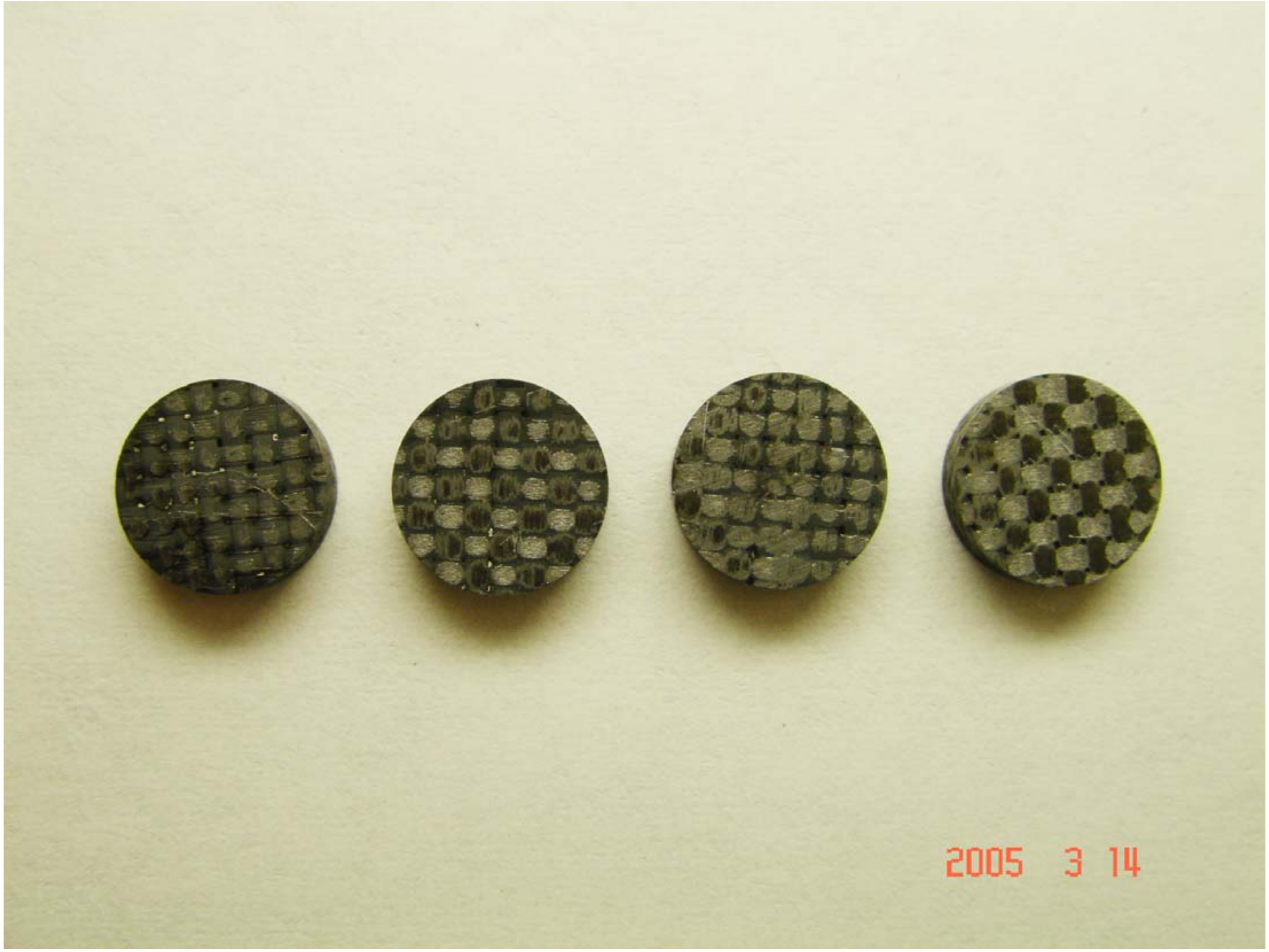
Photo#:	00009	Date:	3/14/05	Equip.:	DSC-T1
Note:	TT31- 34 (left to right), side 2/2				

Photo#:	00011	Date:	3/14/05	Equip.:	DSC-T1
Note:	TF31- 34 (left to right), side 1/2				

Photo#:	**00012**	Date:	3/14/05	Equip.:	DSC-T1
Note:	TF31- 34 (left to right), side 2/2				

Photo#:	**00014**	Date:	3/14/05	Equip.:	DSC-T1
Note:	SR31- 34 (left to right), side 1/2				

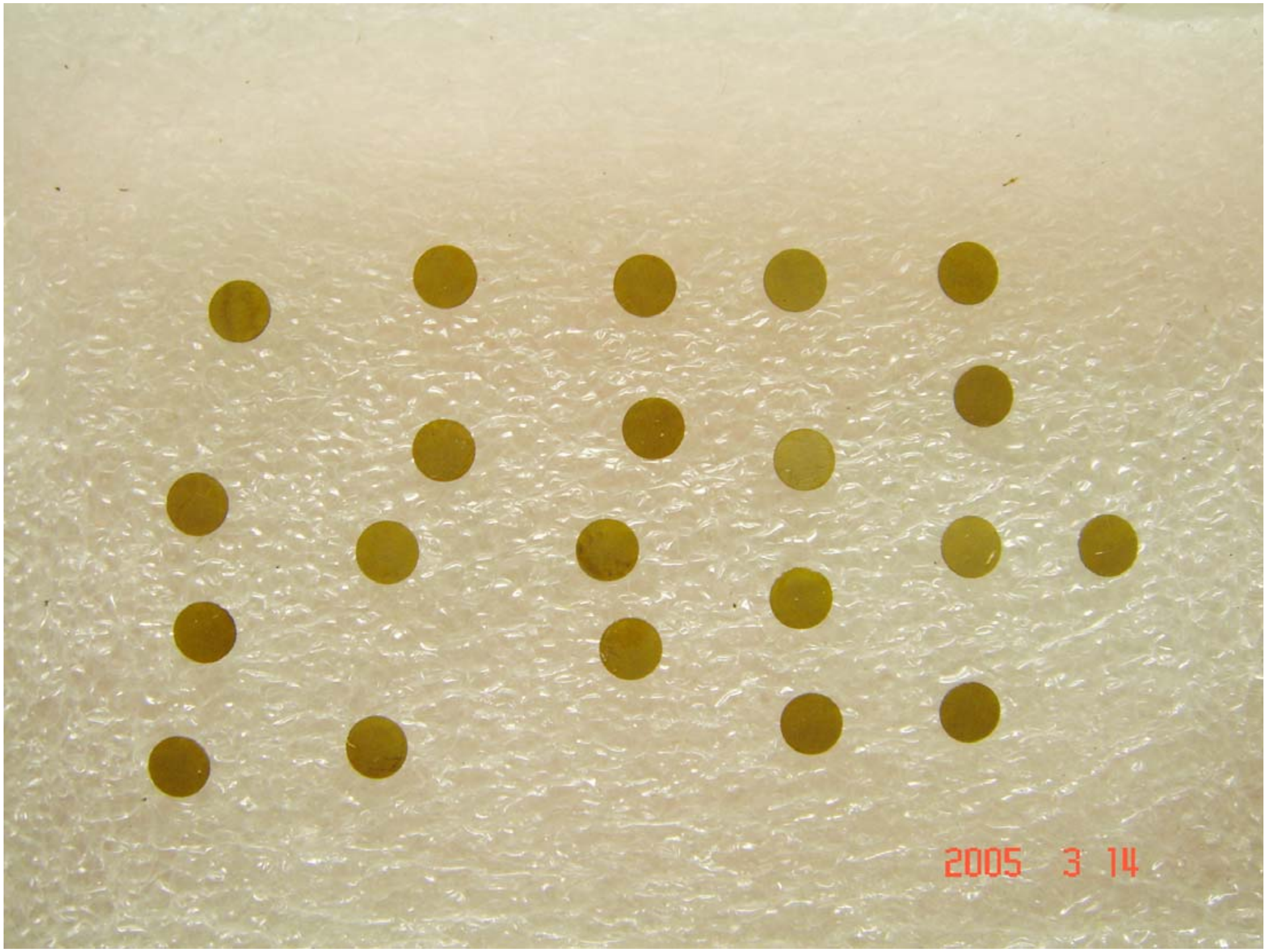
Photo#:	**00015**	Date:	3/14/05	Equip.:	DSC-T1
Note:	SR31- 34 (left to right), side 2/2				



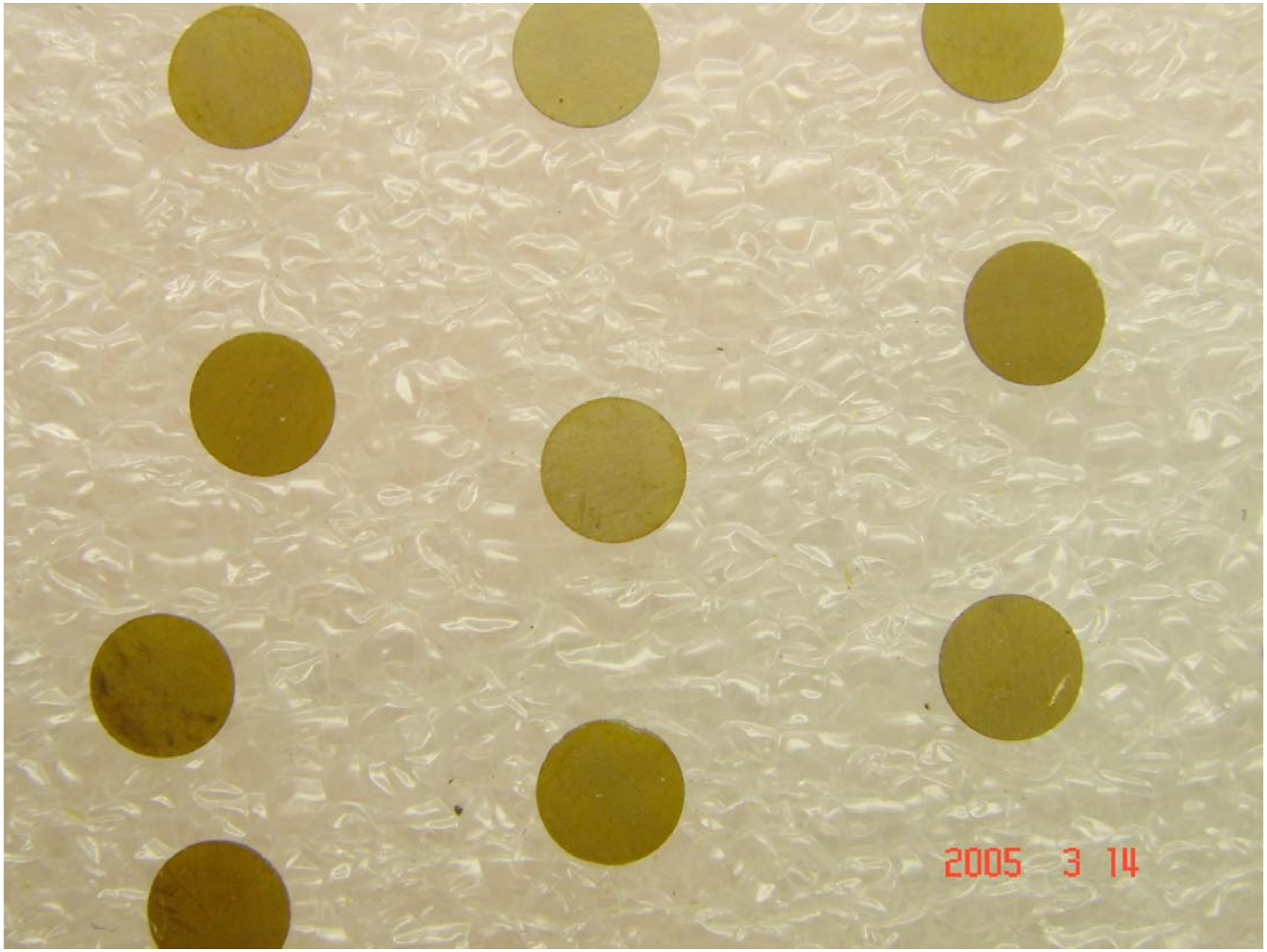
Photo#:	00017	Date:	3/14/05	Equip.:	DSC-T1
Note:	ST31- 34 (left to right), side 1/2				

Photo#:	00018	Date:	3/14/05	Equip.:	DSC-T1
Note:	ST31- 34 (left to right), side 2/2				

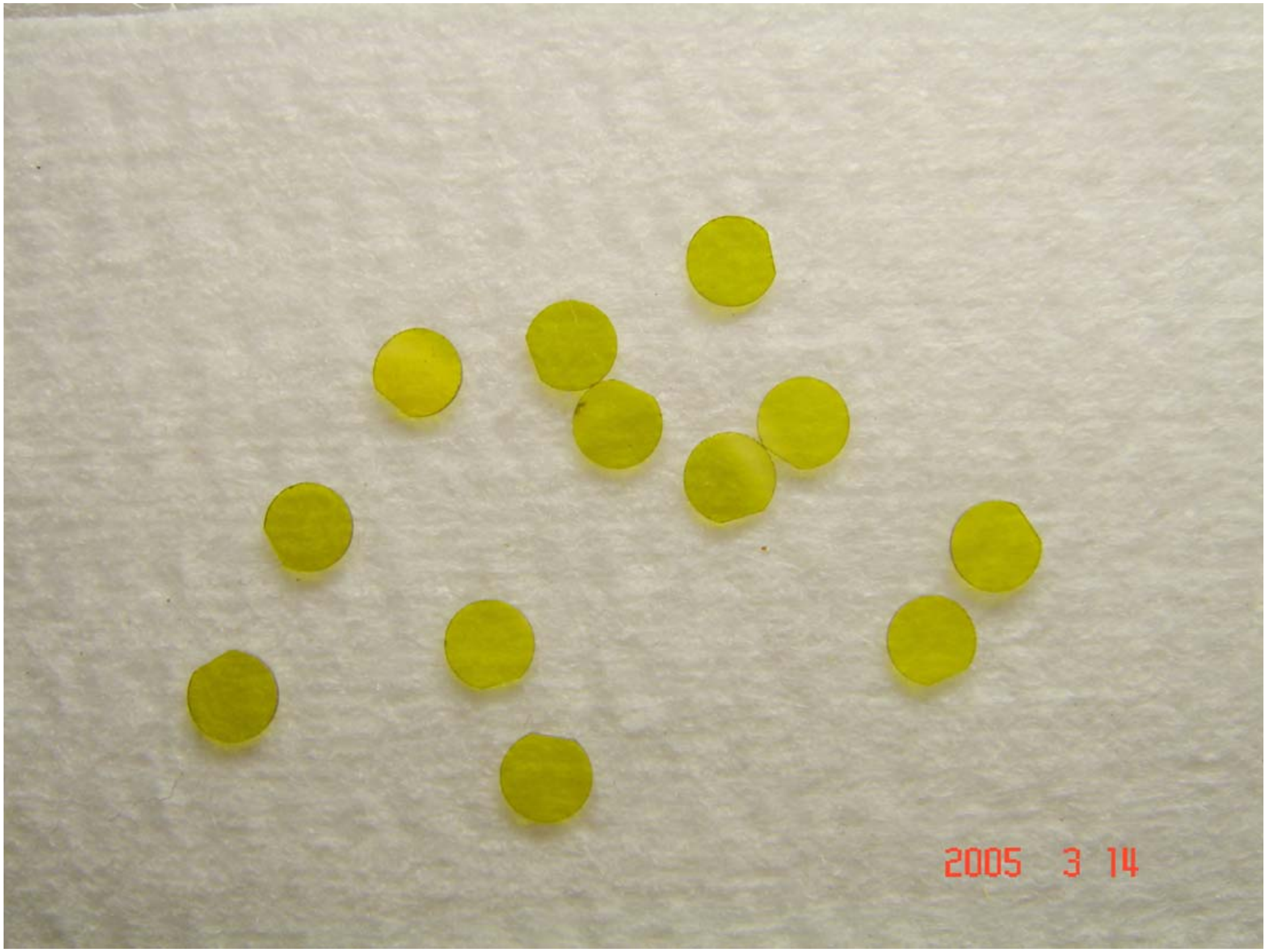
Photo#:	00027	Date:	3/14/05	Equip.:	DSC-T1
Note:	CD41- 60 (individual specimen not assigned ID), photo 1/2				



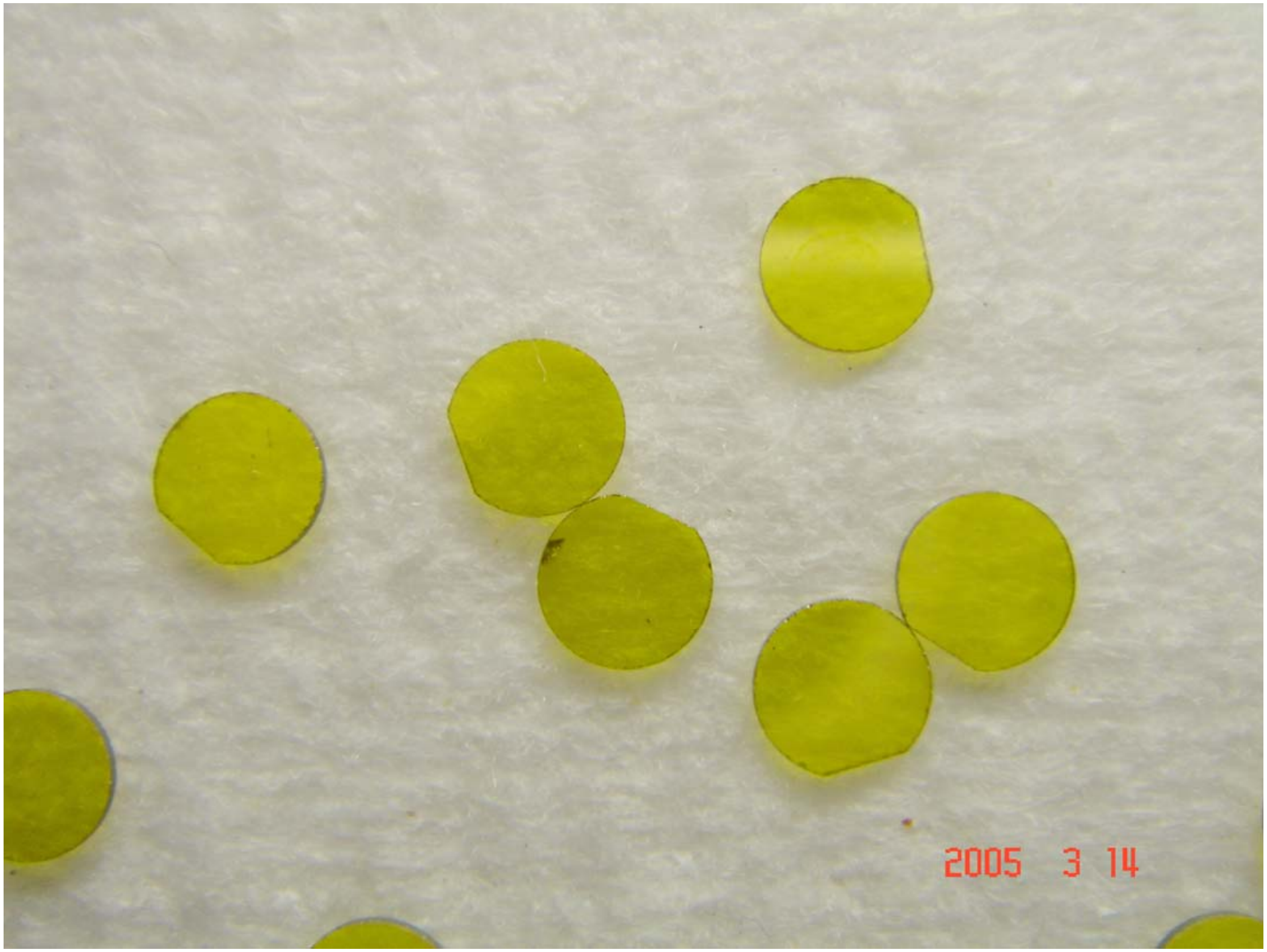
Photo#:	00028	Date:	3/14/05	Equip.:	DSC-T1
Note:	CD41- 60 (individual specimen not assigned ID), photo 2/2				



Photo#:	00030	Date:	3/14/05	Equip.:	DSC-T1
Note:	SX41- 50 (individual specimen not assigned ID), photo 1/2				



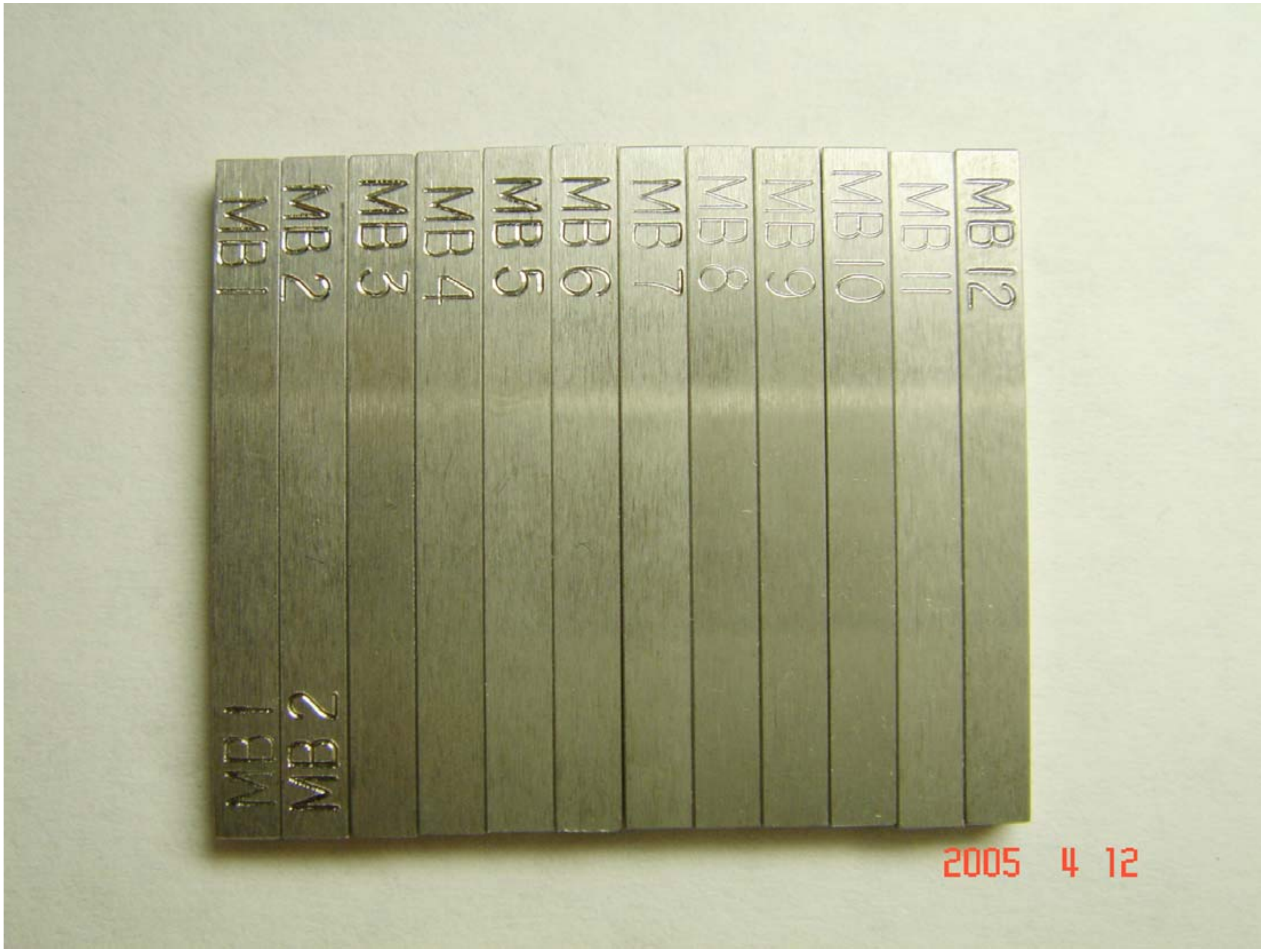
Photo#:	**00031**	Date:	3/14/05	Equip.:	DSC-T1
Note:	SX41- 50 (individual specimen not assigned ID), photo 2/2				



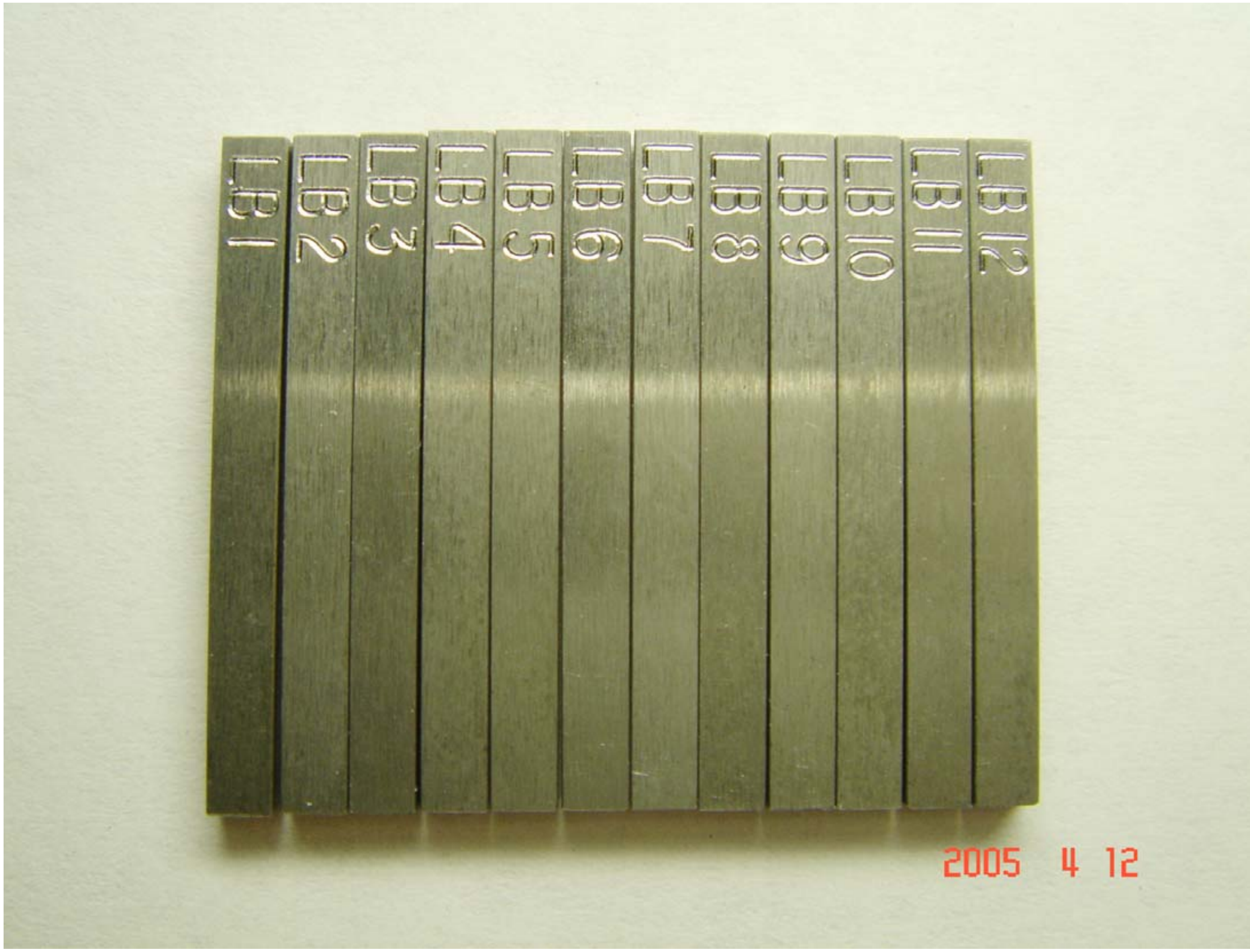
Photo#:	**00107**	Date:	4/12/05	Equip.:	DSC-T1
Note:	L01-32 (see engraved ID), photo 1/1				

Photo#:	00108	Date:	4/12/05	Equip.:	DSC-T1
Note:	M01-32 (see engraved ID), photo 1/1				

Photo#:	00109	Date:	4/12/05	Equip.:	DSC-T1
Note:	MB1-12 (see engraved ID), photo 1/1				



Photo#:	00110	Date:	4/12/05	Equip.:	DSC-T1
Note:	LB1-12 (see engraved ID), photo 1/1				



Photo#:	**00111**	Date:	4/12/05	Equip.:	DSC-T1
Note:	LC1-3 (see engraved ID), photo 1/1				

Photo#:	00112	Date:	4/12/05	Equip.:	DSC-T1
Note:	MA1-12 (see engraved ID), photo 1/1				

Photo#:	**00113**	Date:	4/12/05	Equip.:	DSC-T1
Note:	LA1-12 (see engraved ID), photo 1/1