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Carbide-Carbon Materials for Multipurpose Applications

1st IFAST Annual Meeting

4th May 2022

F. Carra (CERN)

On behalf of IFAST WP4.4

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WP4.4 – Objectives and Participants

- Large scale Carbide-Carbon Materials for multipurpose applications (M1 – M48)
  - **Promote the use of carbide-carbon materials (CCM)** in future particle physics facilities and open up the market to commercial applications
  - Thermal conductivity 2-3 times higher than Cu! Stronger, low density

- How?

3x larger volume per sintering cycle

+

1.5x lower sintering temperature material

→

2x Cost Reduction

Higher efficiency

- Who?

Deliverables and Budget

Milestone/Deliverable Number	Title	Lead beneficiary	Type	Dissemination level	Due Date (in months)
MS14	Evaluation of a CCM alternative to Molybdenum-Graphite	CERN	Report	Public	16
D4.4	Production of large-size CCM plates	CERN	Demonstrator	Public	24

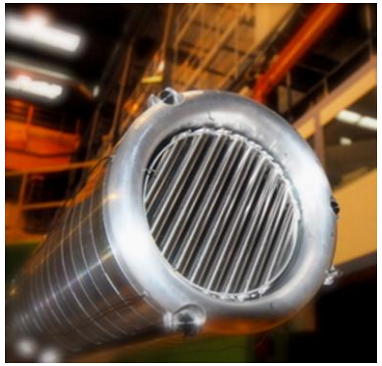
D4.4 description

- Produce two large CCM plates (cross section >400 cm^2) in a single sintering cycle

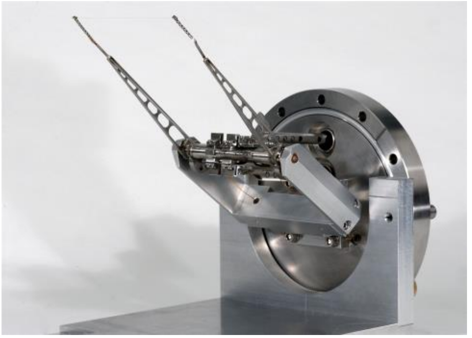
Beneficiary short name	Person-months	Monthly personnel cost	Personnel costs	Travel	Equipment and consumables	Other direct costs	Sub-contracting	Material direct costs	Total direct costs	Total indirect costs	Total costs (direct + indirect)	EC requested funding
CERN	3.0	8,000.00	24,000.00	16,000.00	20,000.00	10,000.00		46,000.00	70,000.00	17,500.00	87,500.00	35,000.00
Nanoker	10.0	3,500.00	35,000.00	3,000.00	95,000.00			98,000.00	133,000.00	33,250.00	166,250.00	85,000.00
Total	**13.0**		**59,000.00**	**19,000.00**	**115,000.00**	**10,000.00**	**0.00**	**144,000.00**	**203,000.00**	**50,750.00**	**253,750.00**	**120,000.00**

Motivation

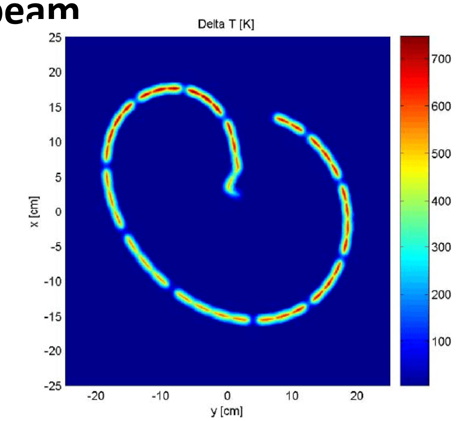
- **Increasing worldwide request for thermal management materials** (high thermal diffusivity and specific heat, low density)
- **Cost still high**: CCM are limited to high-end applications (nuclear energy, particle physics, aerospace, …)
- Decrease of energy consumption, improvement of production cycle **efficiency and sustainability** are also a must
- In particle physics: very interesting for **beam-intercepting devices and beam instrumentation, beam windows, etc.**



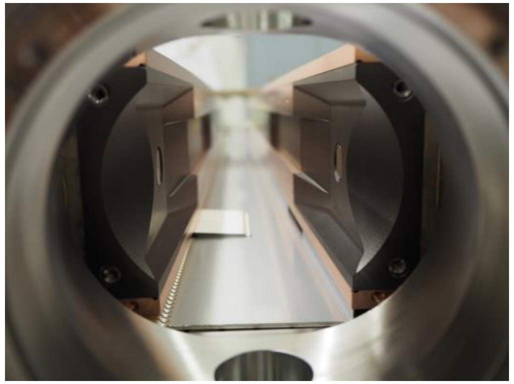
Targets



Beam wire scanners



Dumps



Collimators

Expected figures for the development of the thermal management market in the next years, source: https://www.marketsandmarkets.com/Market-Reports/thermal-management-market-155049228.html

CCM Production Cycle

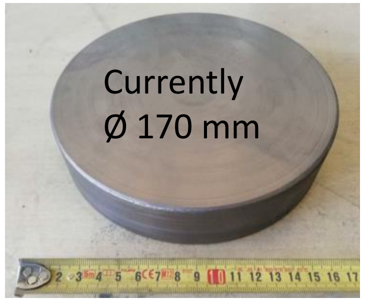
Selection and sieving of the powders

Preparation of the desired composition

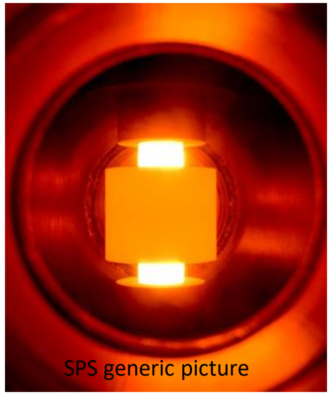
Powder	Vol. %
Graphite	93.9
Mo	5.5
Ti	0.6

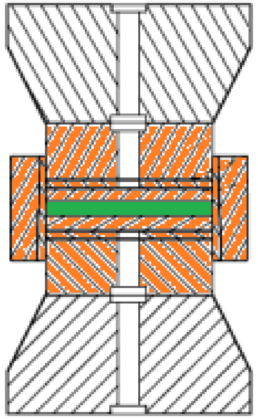
Mixing

Green body preparation



Spark Plasma Sintering (SPS) >25 MPa, >2600 °C

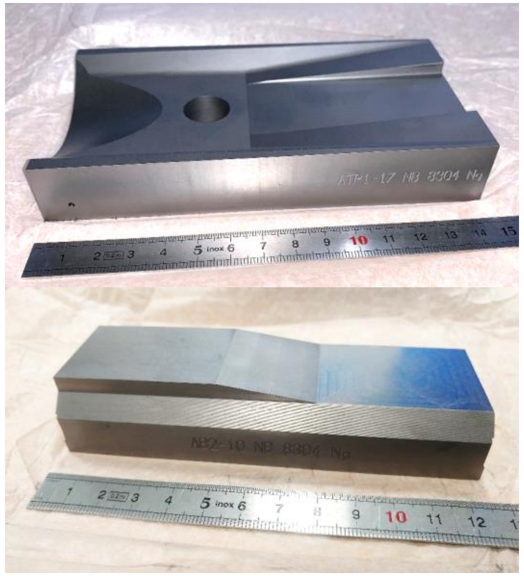

SPS generic picture



Sintered CCM
Single-use mould elements (graphite)

Stress relieving thermal treatment 0 MPa, >2400 °C

Machining of the pieces



Year 1 activities – Technical Specification

- Definition of the **minimum thermophysical properties** for a use in HEP beam-intercepting devices and in thermal-management applications

Property	Specification		
	‖*	⊥	Unit
Density at 20ºC	2.40 – 2.60		$[g/cm^3]$
Specific heat at 20ºC	> 0.6		[J/(g·K)]
Electrical conductivity at 20ºC	> 0.75		[MS/m]
Thermal Diffusivity 20ºC /at 300ºC	> 350/100	> 20/6	[mm^2/s]
Thermal conductivity at 20ºC /at 300ºC	> 500/280	> 35/20	[W/(m·K)]
Volumetric CTE 20-1000ºC	< 7		$[10^{-6}K^{-1}]$
Coefficient of thermal expansion 20-1000ºC	< 2.9	< 15	$[10^{-6}K^{-1}]$
Young's Modulus at 20ºC	35 < E < 75	5 < E < 8	[GPa]
Flexural strength at 20ºC	> 60	> 10	[MPa]
Flexural strain to rupture at 20ºC	> 2500	> 4000	[µm/m]
Dimensional stability*	< 0.05	< 0.25	%

**The dimensional stability shall be ensured after the following thermal cycle: heating of the specimen up to 1950ºC with a ramp of 5ºC/min. Cooling of the specimen down to room temperature with the same ramp.*

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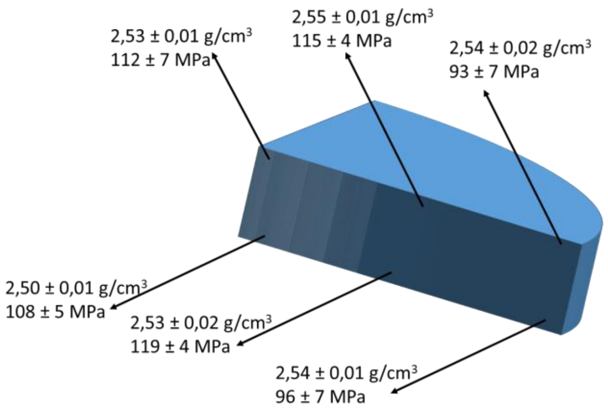
Year 1 – Increase of volume per cycle

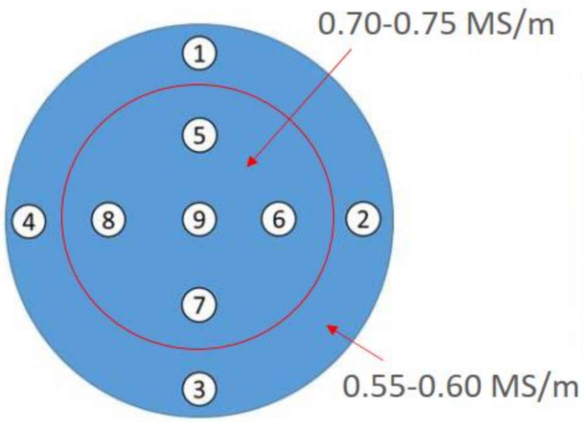
- **Molybdenum-Graphite** (sintered at 2640°C)

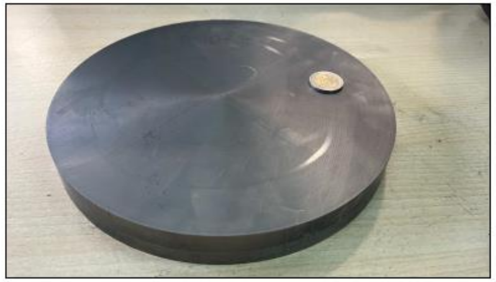
2 plates produced with 230 mm Diameter (2x bigger section than before IFAST)



Disk (230 mm diameter)	Density (g/cm^3)	Electrical Conductivity (Mean values on each side) (MS/m)
Plate #1 (p=26 MPa)	**2,53**	**0,6 – 0,63**
Plate #2 (p=40 MPa)	**2,60**	**0,65 – 0,68**
Specification	**2,3 ÷2,6**	**>0,8**

Lower electrical conductivity values than in the 170 mm diameter disks





Pre-compaction of the green powder:

Maximum Applied Force Uniaxial Hydraulic Press ~ 900 kN

- 170 mm Ø → 40 MPa → 2,00 g/cm^3
- 230 mm Ø → 21 MPa → 1,65 g/cm^3

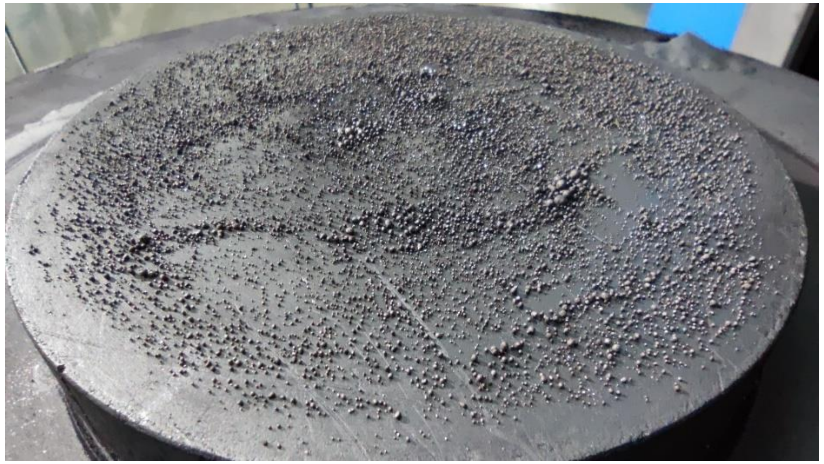
Next: increase the metal content, together with the higher sintering pressure

Year 1 – Decrease of sintering Temperature

- **Chromium-Graphite** (sintered at 2000°C – 1.3x lower T)
- Concept proposed by **Jorge Guardia** within ARIES WP14 & WP17, technically was not demonstrated yet (very poor mechanical properties)

3 plates produced with 170 mm Diameter

Disk (170 mm diameter)	Density (g/cm^3)	Electrical Conductivity (MS/m)
Plate #1	2,30	1,00 – 1,07
Plates #2 & #3	2,30	0.75/0.81
Specification	2,3 ÷2,6	>0,8



Reusable Mold and Parts → Important Cost Reduction

- **Plate #1 produced in a single plate per cycle**, very promising properties, decision for full characterization at CERN
- **Plates #2 and #3 double-plate per cycle**, losing a bit in conductivity → composition and cycle to be optimized

Year 1 – CrGr Characterization

- **Full thermomechanical characterization** done at CERN Mechanical La...
- **Very promising results**, some parameters to be improved duri... ...hanical strength increased by a factor of 5 wrt ARIES!

Milestone MS14 achieved!

Alternative to MoGr identified, report being finalized

	Sp...			...1	
Property				**F**	**Unit**
Density at 20ºC			2.32		[g/cm³]
Specific heat at 20ºC			0.687		[J/(g·K)]
Electrical conductivity ...			1.02		[MS/m]
Thermal Diffusivity ...		.../6	470/120	33/9	[mm^2/s]
Thermal conduct...		> 35/20	**750**/350	52/27	[W/(m·K)]
Volu...		...7	6.7		[$10^{-6}K^{-1}$]
Coeffici...	...9	< 15	4.0	12.0	[$10^{-6}K^{-1}$]
	...5 < E < 75	5 < E < 8	46	3	[GPa]
	> 60	> 10	58	8	[MPa]
Fr...	> 2500	> 4000	3280	4200	[µm/m]
	< 0.05	< 0.25	-0.05	0.45	%

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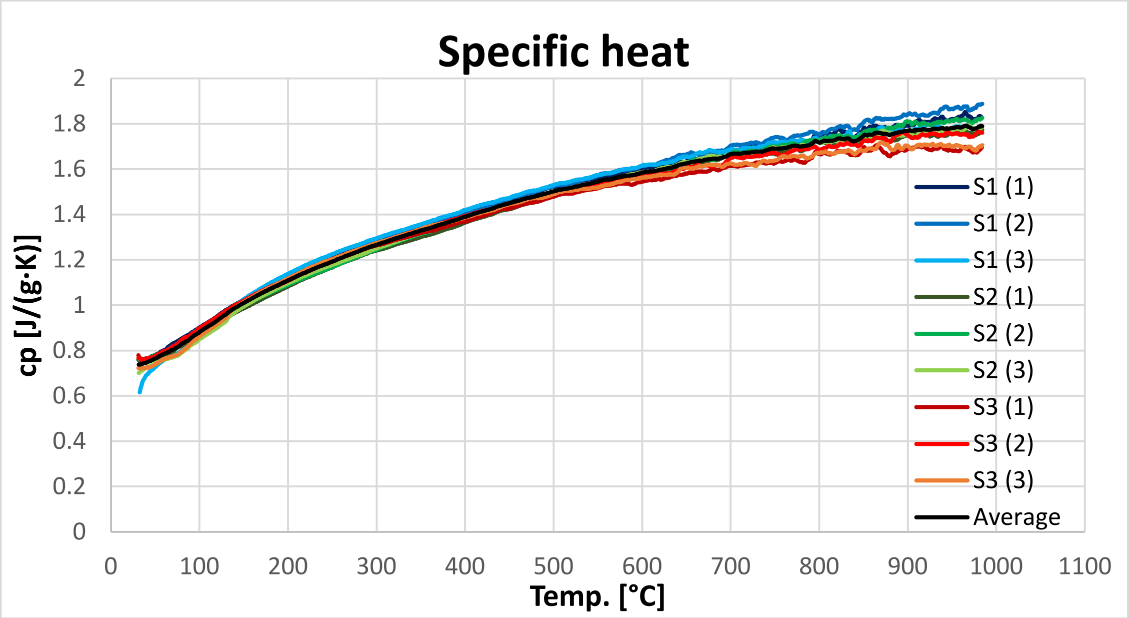
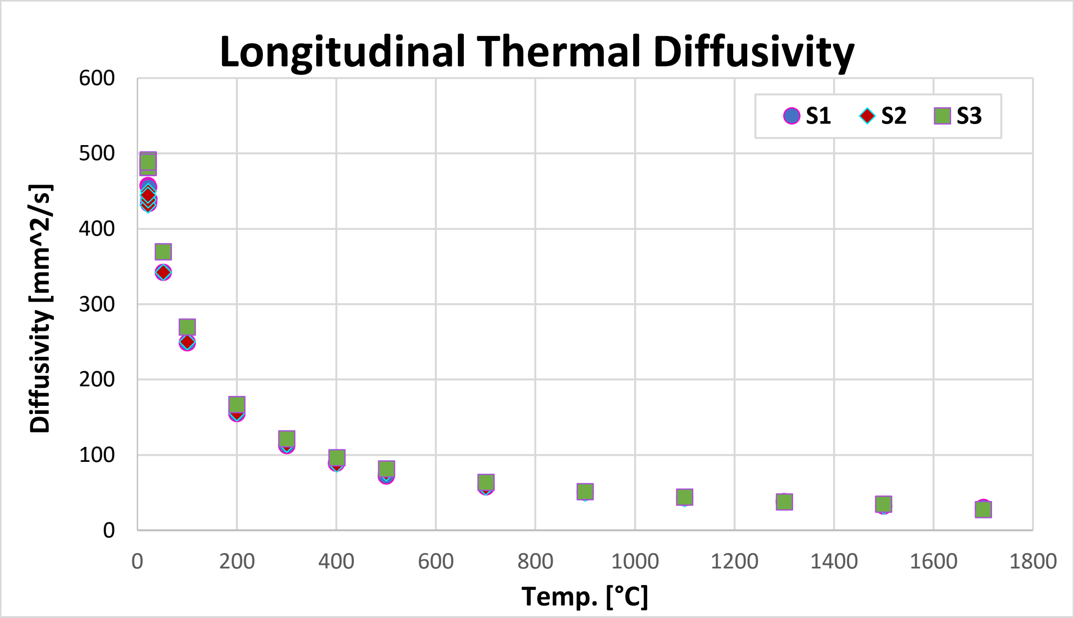
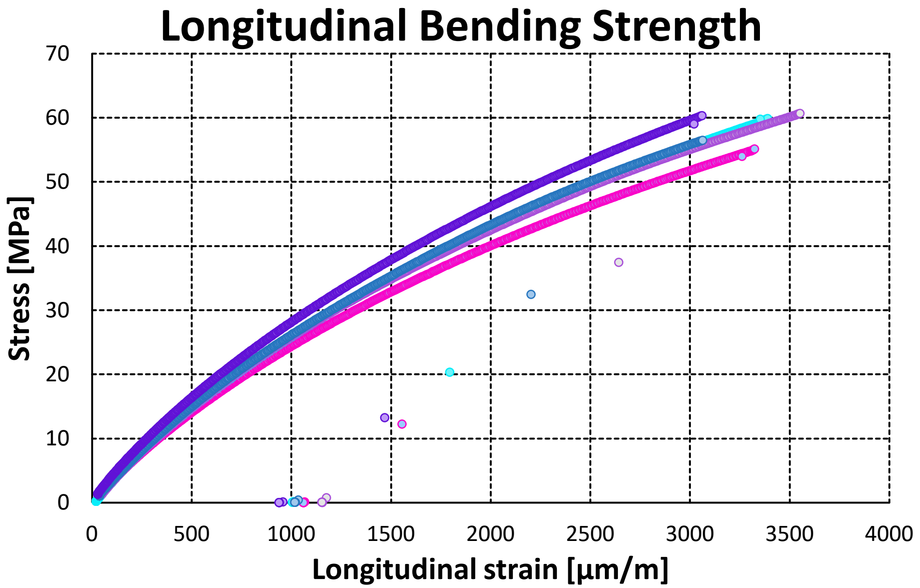
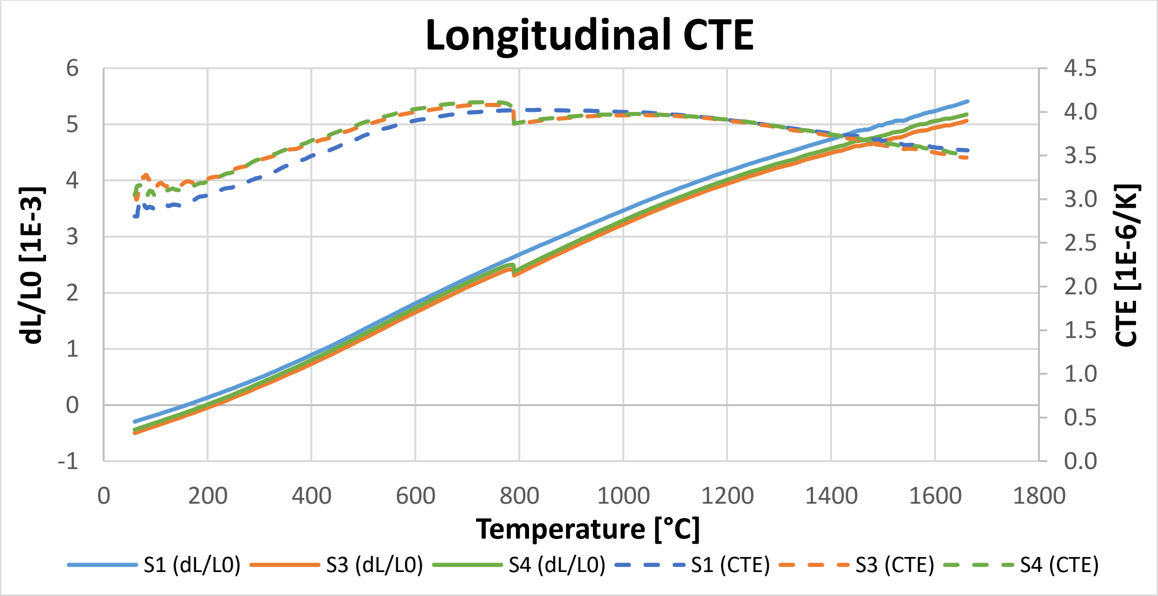
Year 1 – CrGr Characterization









Conclusions and Next Steps

- Carbide-Carbon Materials are of great interest because of their **exceptional thermal transport properties**
- WP4.4 aims at reducing the production costs and increasing the available component size, in order to **promote their use in industry and research**
- **Decrease of energy consumption, increase of production efficiency and sustainability** are also a must
- CERN and Nanoker working at an **upscaling of the blank size and at a reduction of the production temperature**
- **Positive results** have already been obtained in both directions in the first 12 months of the project
- More tests are foreseen in the coming weeks to optimize the thermophysical properties of the materials
- **Milestone MS14 achieved (M12, was due in M16), report being finalized**

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Thank you for your attention!

And thanks to the contribution of several people from WP4.4:

C. Accettura, C. Gutierrez, J. Guardia, S. Hoell, M. Losasso, S. Rivera, O. Sacristan

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