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(VVV-2022)
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Burning times of boron, aluminum diboride and aluminum dodecaboride microparticles

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Contents

- **Introduction** (metal fuels in rocket propellants, why B, AlB_2, and AlB_{12})
- **Aim of work:** $t_b(D)$
- **Experimental approach** (ingredients, set-up, treatment)
- **Results** (gaseous media characterization; burning times measurement)
- **Conclusions and future works**

Progress in the rocketry

⇕

Design of the propellant formulations

⇕

Increase of a specific impulse

⇕

Kondratyuk Yu. V. (1929)
Tsander F. A. (1932)

idea

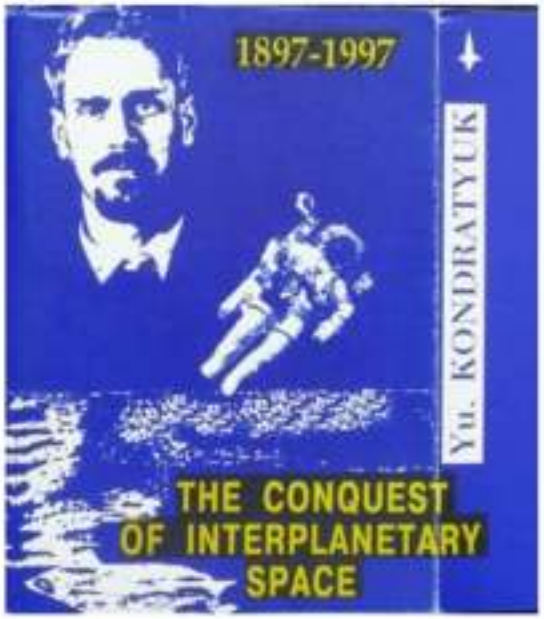
Metal fuels

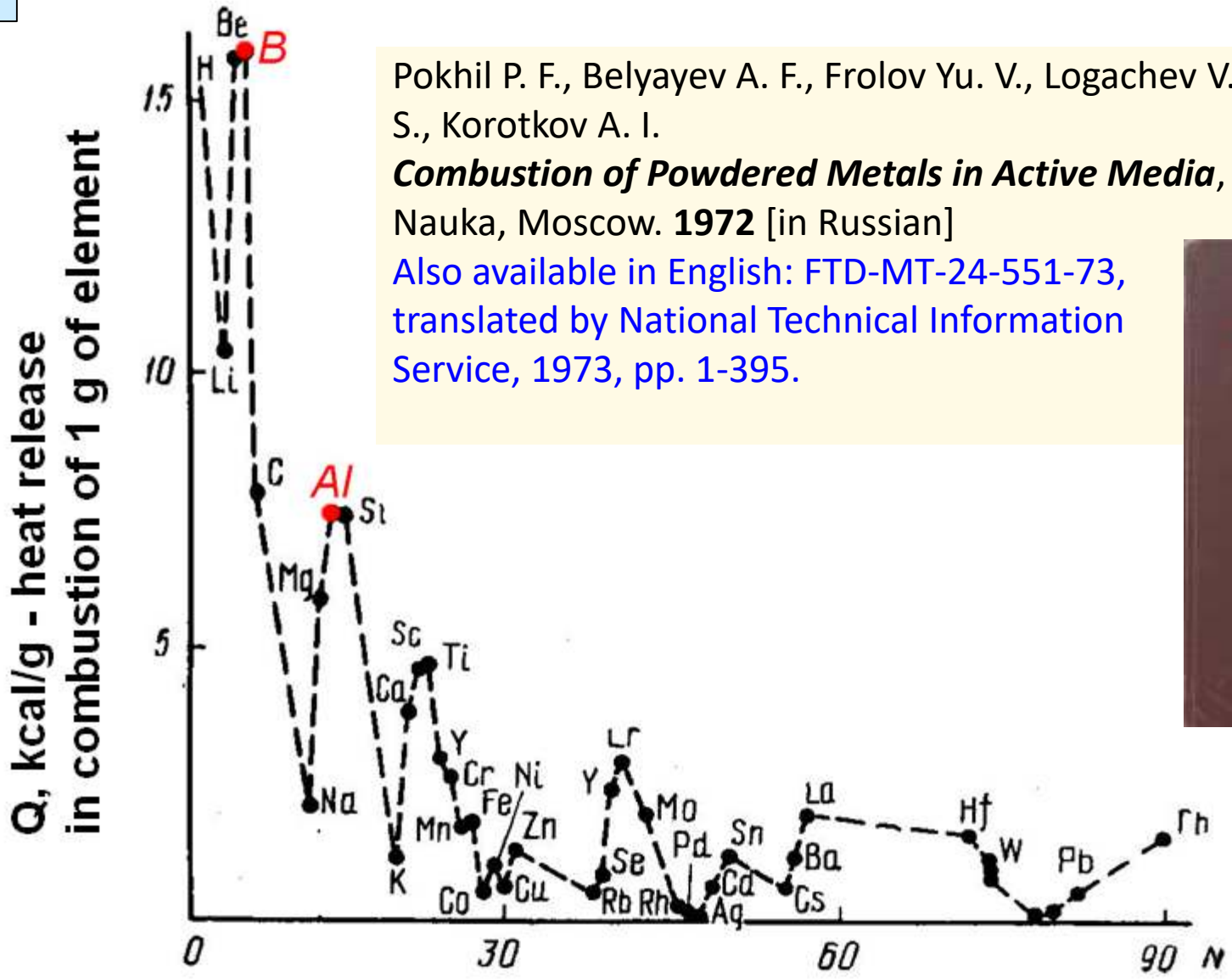
Li, Be, Mg,

Al, Ti, Zr, B

First edition
Novosibirsk, 1929

Jubilee edition in English
Novosibirsk, 1997





N - atomic number of a chemical element in periodic table

Pokhil P. F., Belyayev A. F., Frolov Yu. V., Logachev V. S., Korotkov A. I.
Combustion of Powdered Metals in Active Media, Nauka, Moscow. **1972** [in Russian]
Also available in English: FTD-MT-24-551-73, translated by National Technical Information Service, 1973, pp. 1-395.

Boron has disadvantages…

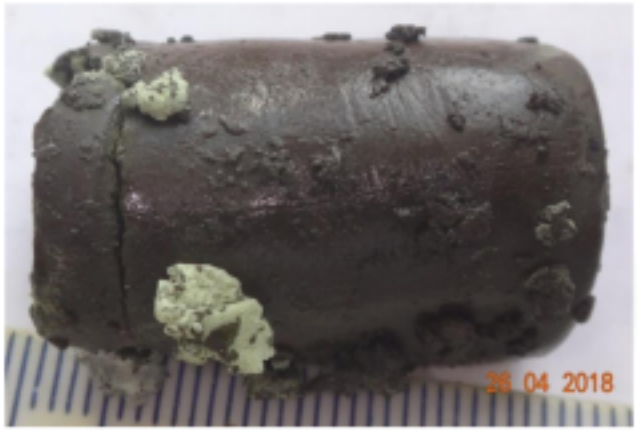
1. The amount of oxygen needed for **B** oxidation is about 3 times larger than that for **Al**

ram jet

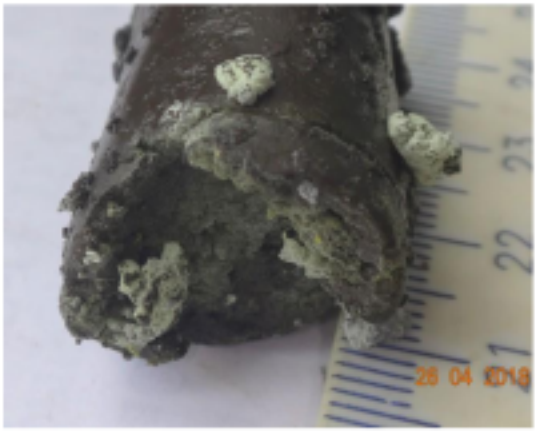
[***Rocket ram jet motors on solid and pastelike propellants*** // Sorokin V. A., Yanovsky L. S., Kozlov V. A., Surikov E. V. / Milyokhin Yu. M., Sorokin V. A. (Eds.) Moscow: Fizmatlit. 2010.] in Russian

Boron has disadvantages…

2. Problems of chemical stability and compatibility with other propellant components



use of



boron compounds

Boron has disadvantages…

3. It is difficult to burn up boron with a high conversion efficiency

“activate” boron combustion

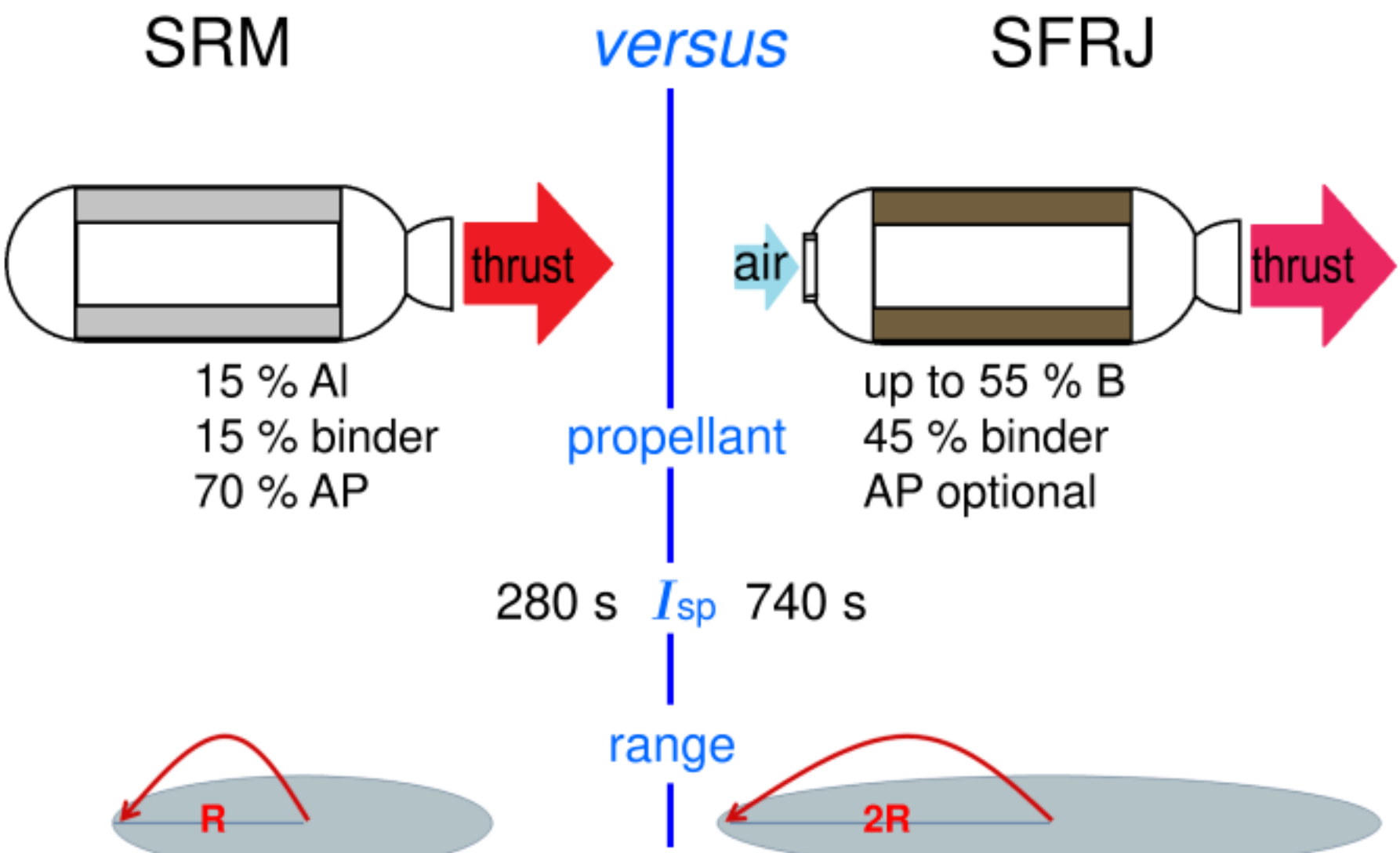
How to provide the compatibility?
How to activate boron combustion?

Solutions

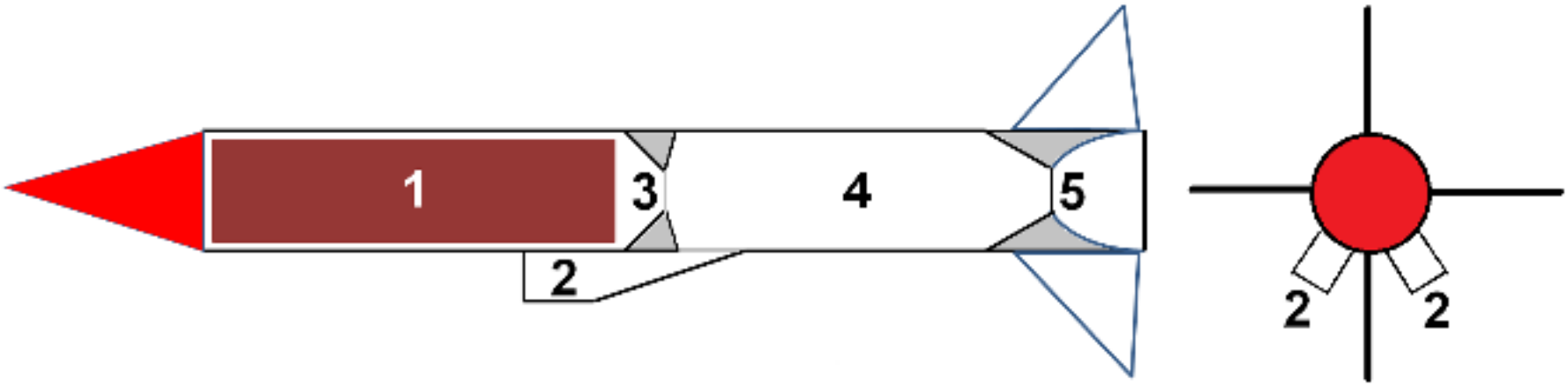
B	AlB_{12}	B_4C	MgB_2	AlB_2
1	0.83	0.78	0.47	0.44

- **boron compounds**
  (borides: **AlB_2**, AlB_{10}, **AlB_{12}**, MgB_2;
  carbide: B_4C)
- **boron alloys** (Al-B mechanical alloys)
- **mechanical activation**
- **functionalization of particle surface**
  (covering)
- **non-traditional oxidizers** ($KClO_4$)

Solid rocket motor *vs* Solid fuel ramjet



Gas-generator scheme of SFRJ



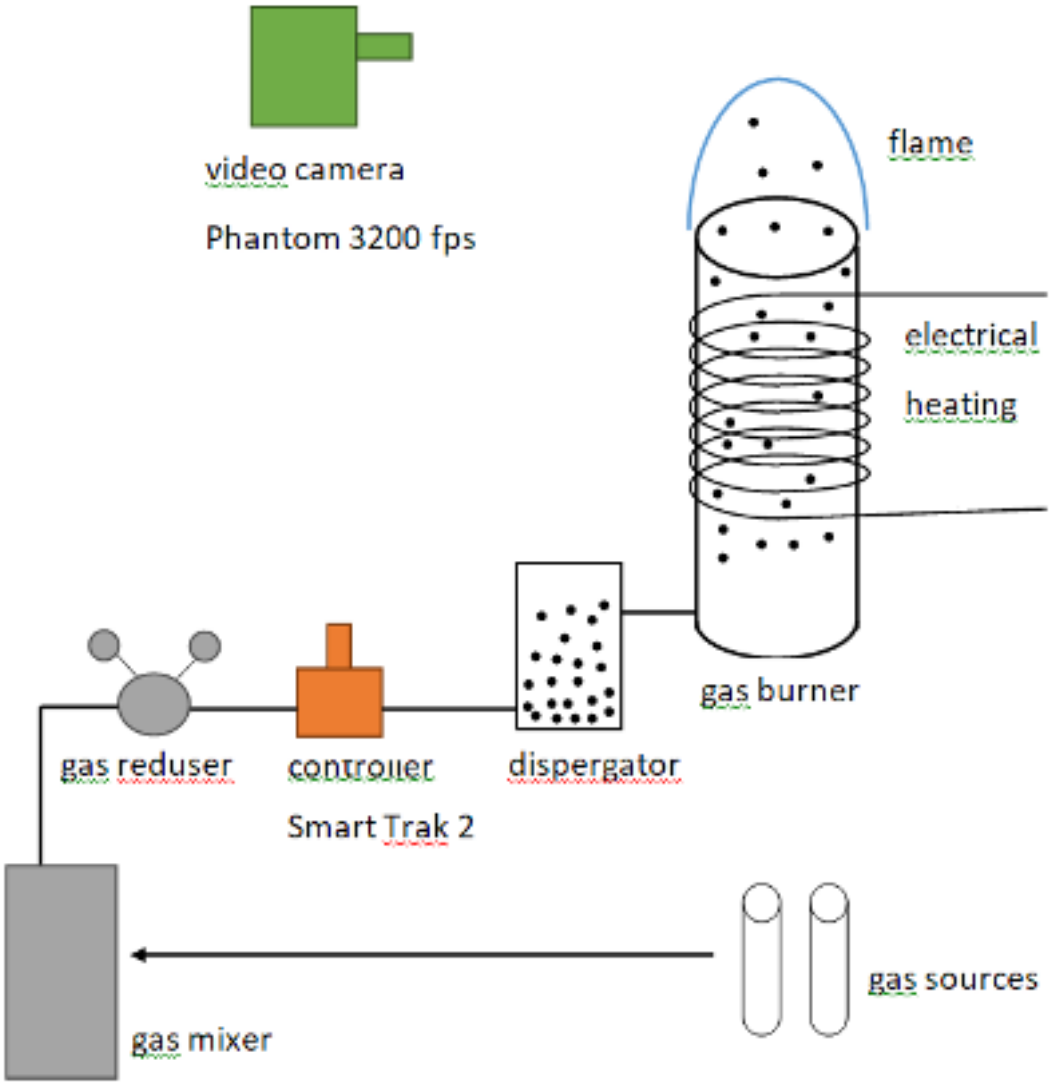
1 – gas generator propellant grain
2 – air inlet
3 – gas generator's nozzle
4 – afterburning chamber
5 – afterburning chamber's nozzle

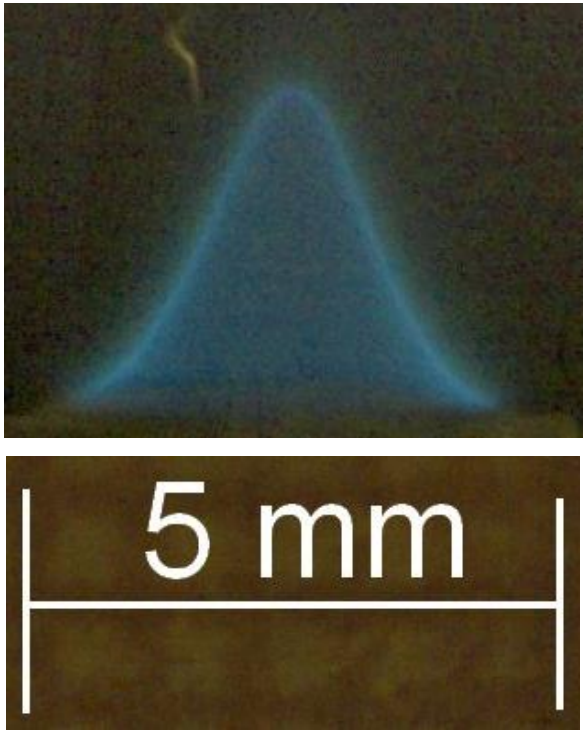
Conclusion on Introduction:

One need to know the burning time t_b for metal fuel particles

$$t_b(D) - ?$$

Experimental set-up





Experimental conditions

Set-up features

- ❒ **No inert gas carrier stream**
- ❒ **Preheated gas mixture (610 K)**
- ❒ **Elevated oxygen concentration**

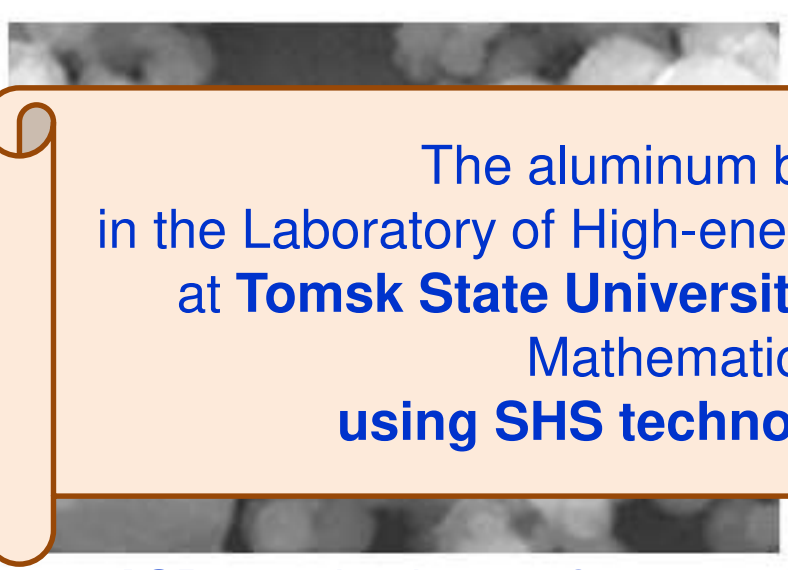
Gas flame parameters

(calculated with PREMIX \ CHEMKIN-II)

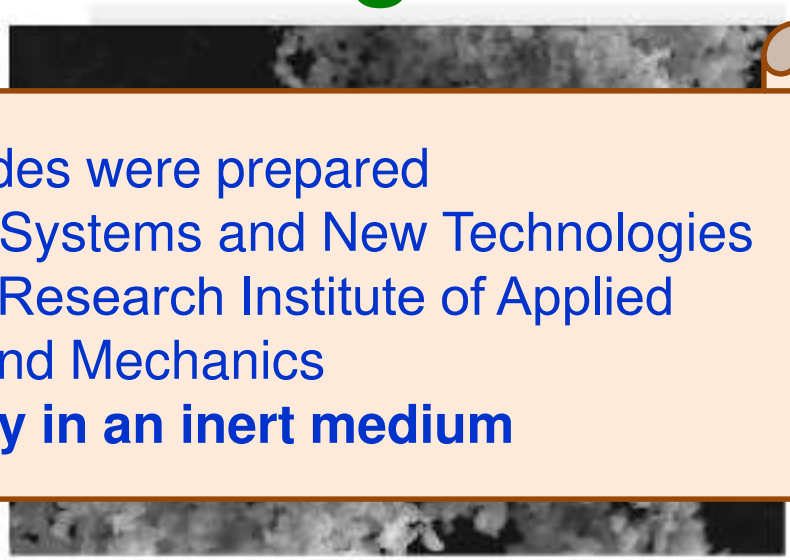
Initial gas mixture, %			Gas flow rate liter/min	T_0, K	T_f, K	Product composition, %			
C_2H_6	O_2	N_2				O_2	H_2O	CO_2	N_2
6.4	36.4	59.6	1.3	610	2065	21.47	11.57	7.8	58

Materials: SEM images

The aluminum borides were prepared
in the Laboratory of High-energy Systems and New Technologies
at **Tomsk State University**'s Research Institute of Applied Mathematics and Mechanics
using SHS technology in an inert medium

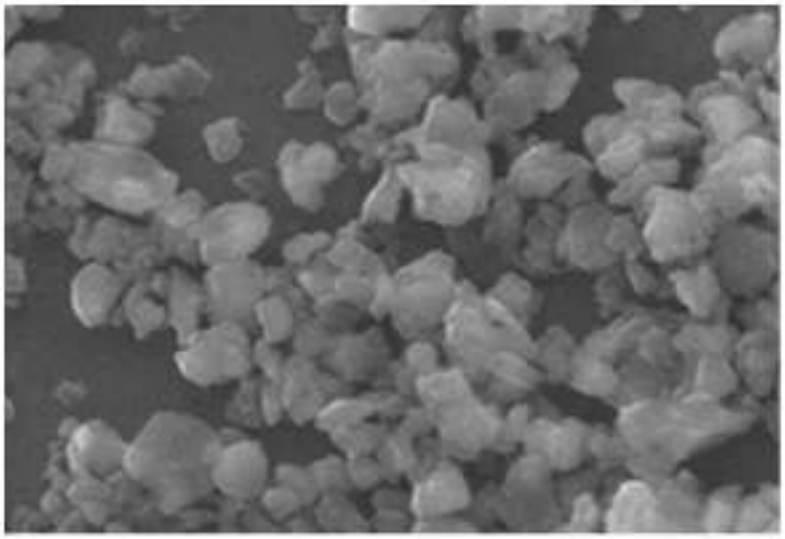


ASD-4 ≡ aluminum АСД-4

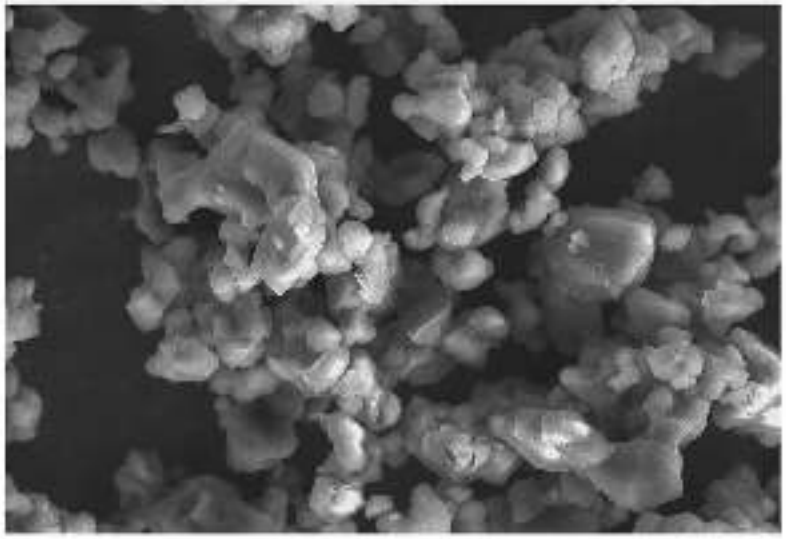


Bamor ≡ amorphous boron B-99A

5μm



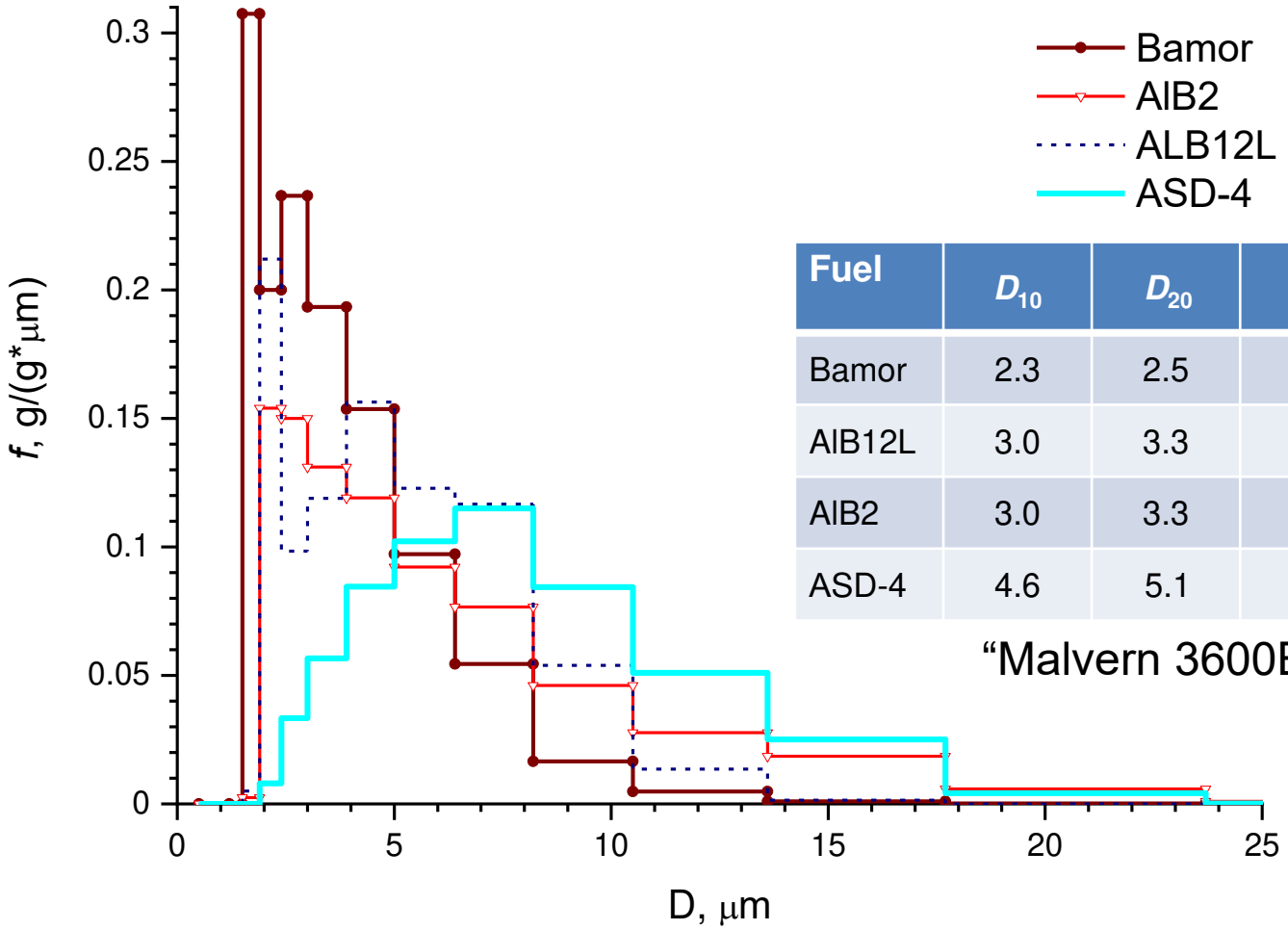
AlB2 ≡ aluminum diboride



AlB12L ≡ aluminum dodecaboride

Materials: particle size analysis

Bamor < AlB12L < AlB2 < ASD-4

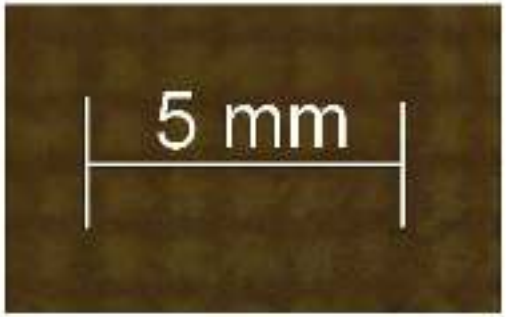


Fuel	D_{10}	D_{20}	D_{30}	D_{32}	D_{43}
Bamor	2.3	2.5	2.7	3.30	4.3
AlB12L	3.0	3.3	3.7	4.6	5.8
AlB2	3.0	3.3	3.8	5.0	7.5
ASD-4	4.6	5.1	5.7	7.1	8.9

"Malvern 3600E" sizer, D_{mn} in [μm]

Normalized mass distribution functions and mean sizes D_{mn}

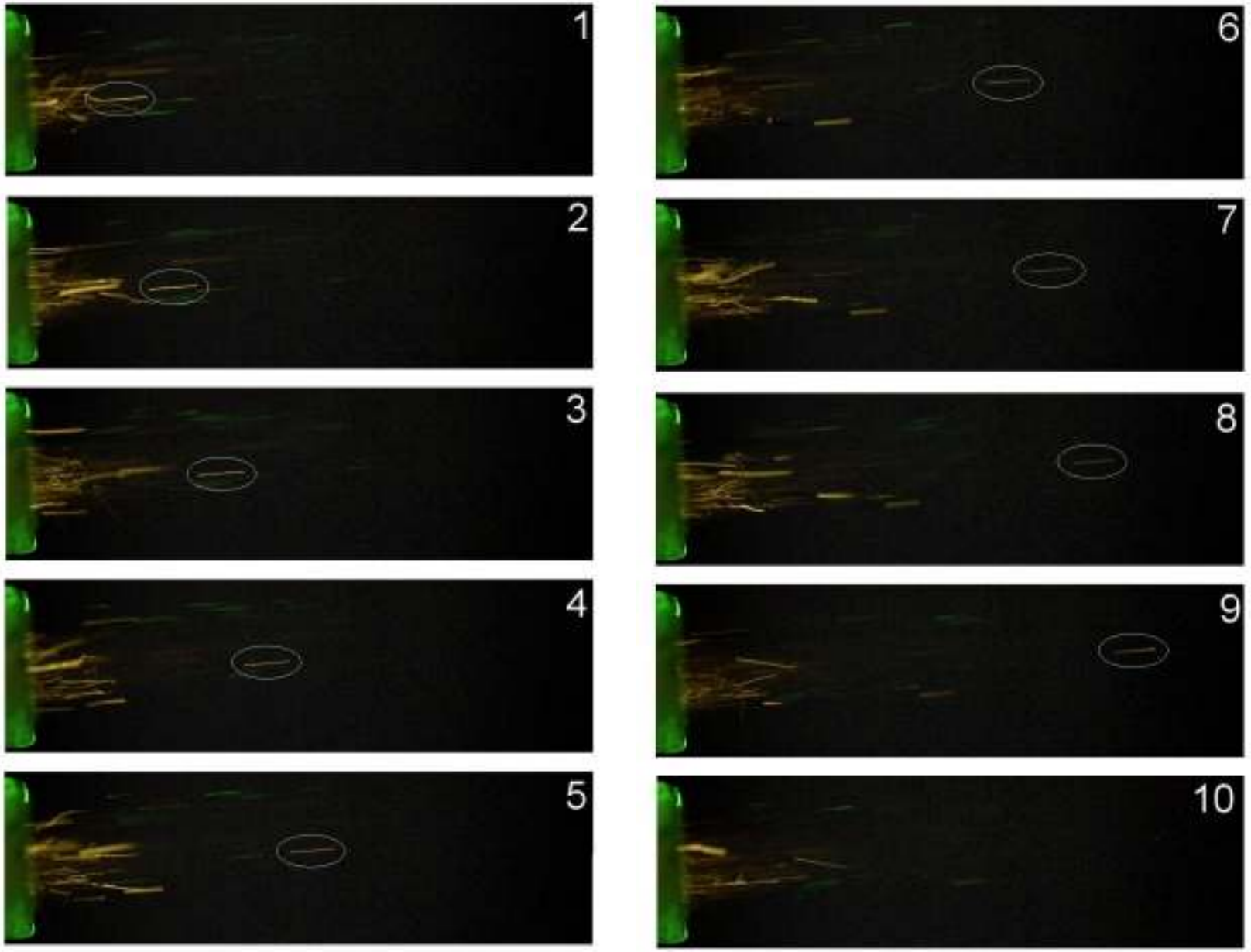
Treatment of video frames…



3200 fps

No $t_{ignition}$!

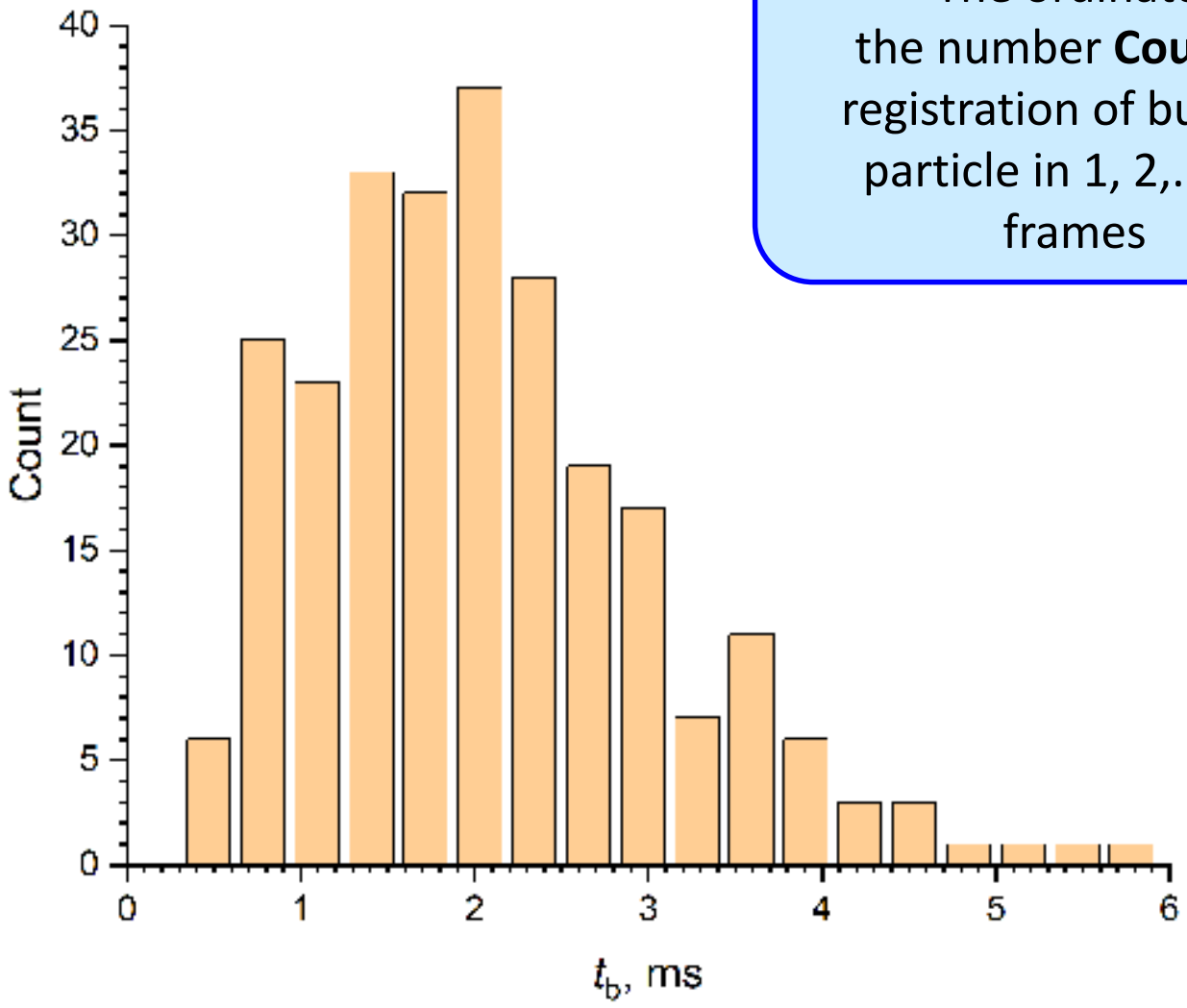
…treatment of video frames (continued)



Histogram for burning times t_b

(Data for Bamor)

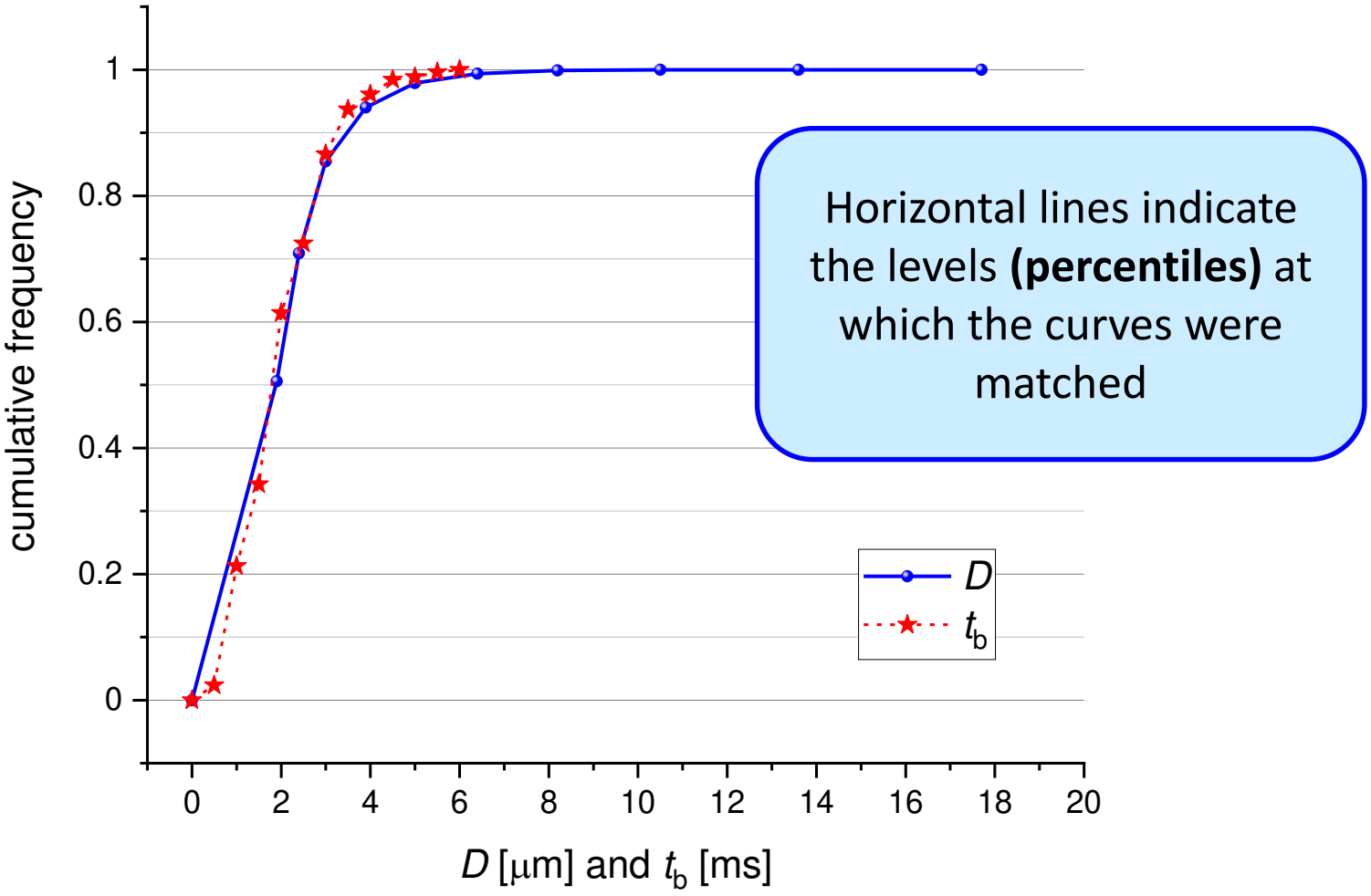
The ordinate:
the number **Count** of registration of burning particle in 1, 2,..., 18 frames



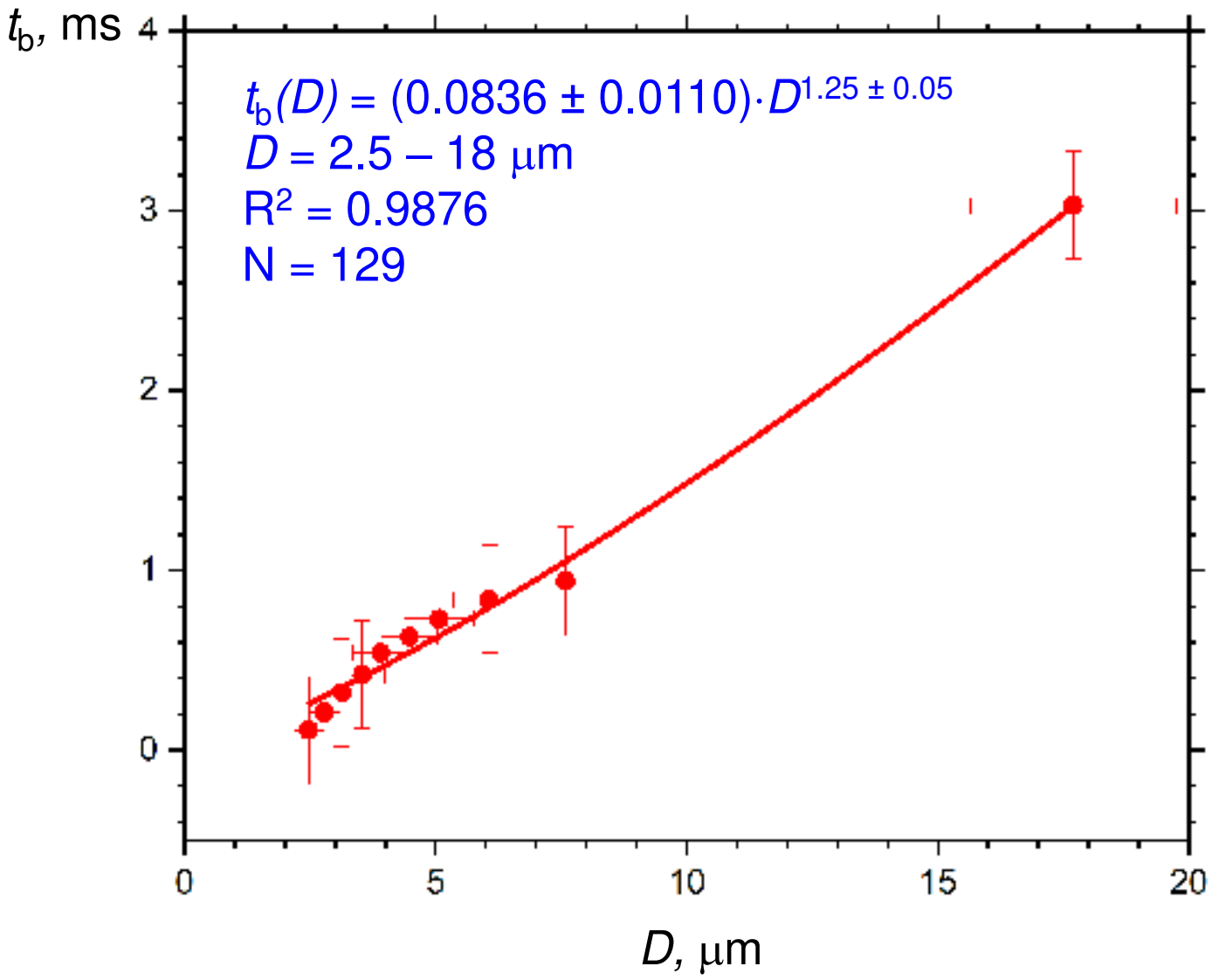
Cumulative distribution function

of particle's diameters D and burning times t_b

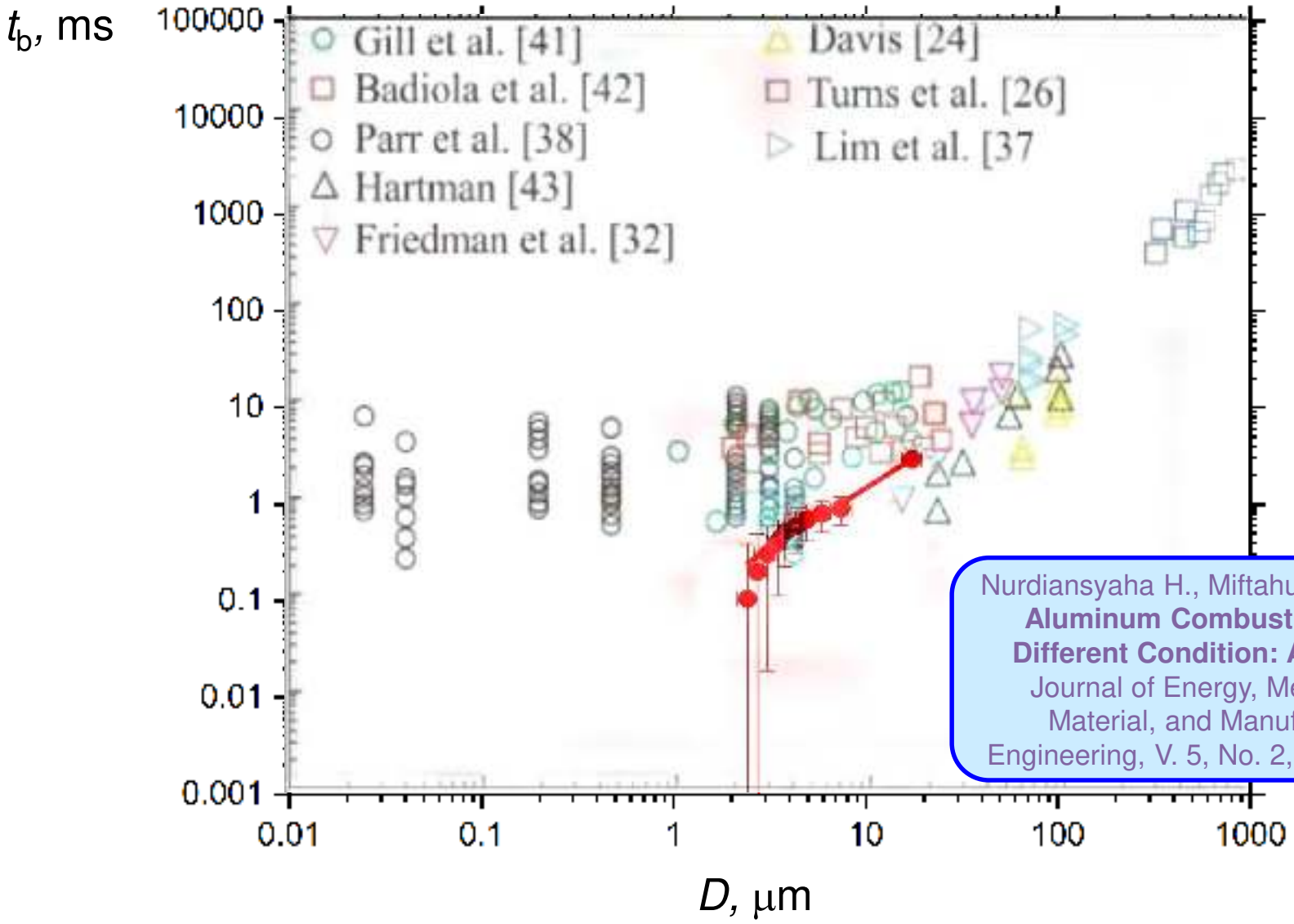
(Data for Bamor)



Results: aluminum ASD-4

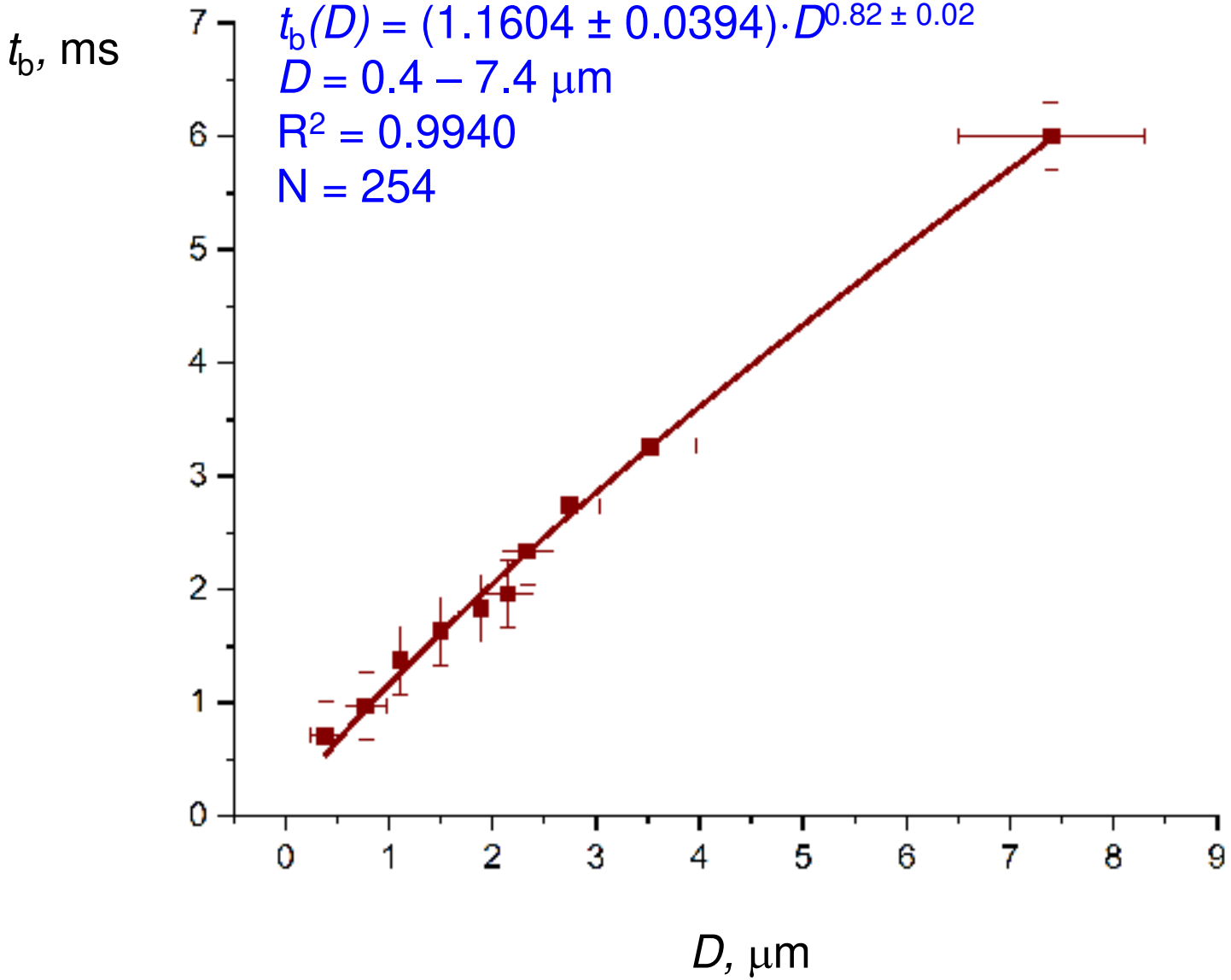


Aluminum - comparison

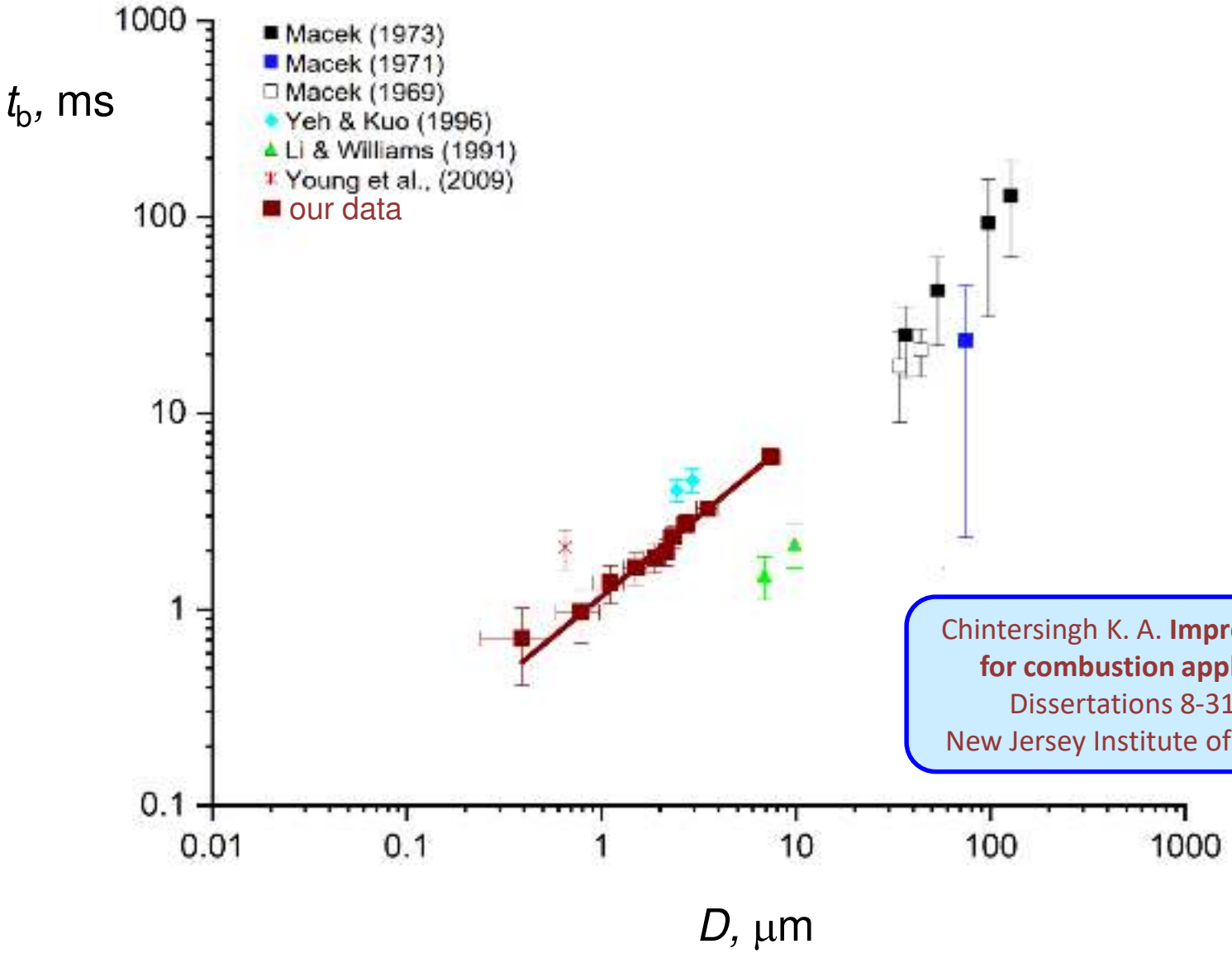


Nurdiansyaha H., Miftahul M., Ridha F. **Aluminum Combustion under Different Condition: A Review** // Journal of Energy, Mechanical, Material, and Manufacturing Engineering, V. 5, No. 2, 2020. p. 1-8.

Boron Bamor


t_b, ms
$t_b(D) = (1.1604 \pm 0.0394) \cdot D^{0.82 \pm 0.02}$
D = 0.4 – 7.4 μm
R^2 = 0.9940
N = 254
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
D, μm

Boron - comparison



Chintersingh K. A. **Improving boron for combustion applications.** Dissertations 8-31-2019. New Jersey Institute of Technology

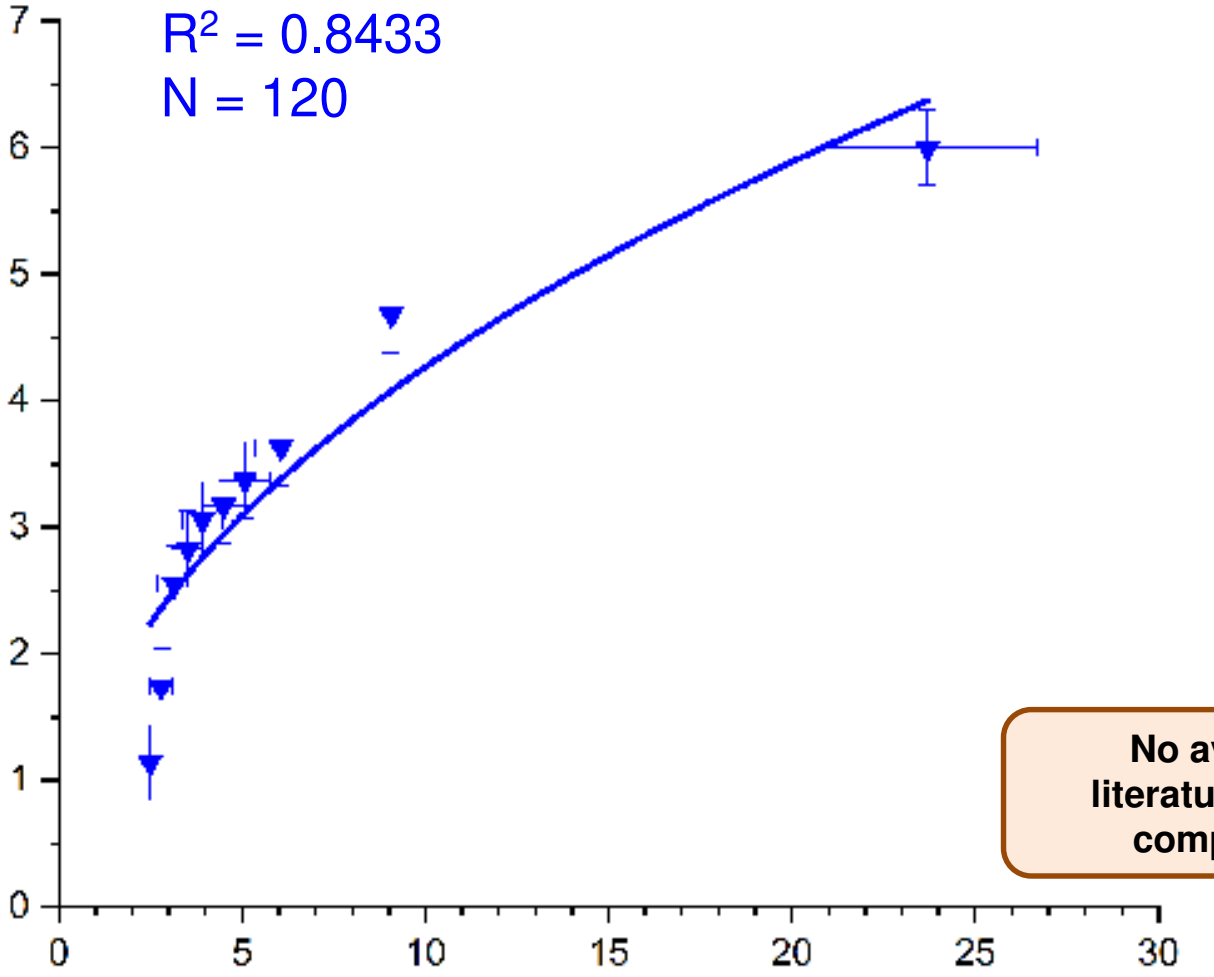
Aluminum diboride AlB2

$t_b(D) = (1.4635 \pm 0.2031) \cdot D^{0.46 \pm 0.06}$

D = 2.5 – 23.7 mm

R^2 = 0.8433

N = 120



No available literature data for comparison

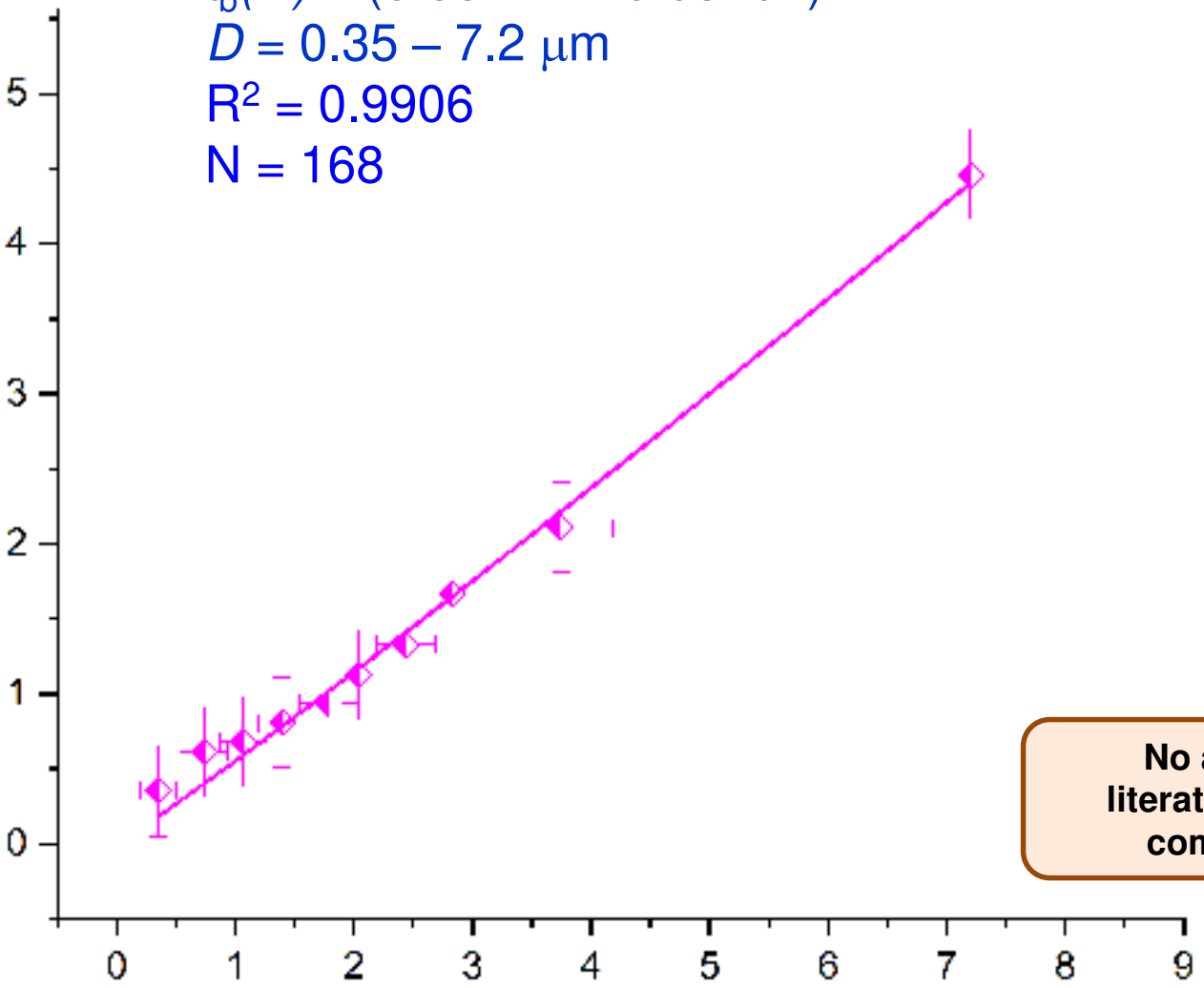
Aluminum dodecaboride AlB12L

$t_b(D) = (0.55141 \pm 0.03402) \cdot D^{1.05 \pm 0.04}$

$D = 0.35 – 7.2$ μm

$R^2 = 0.9906$

N = 168



No available literature data for comparison

Conclusions and future works

- **The burning times have been determined for Al, B, AlB_2 and AlB_{12} microparticles in the practically interesting conditions**

- **The experimental technique developed will be used for studying the other perspective fuels** (MgB_2, B_4C, $AlMgB_{14}$, etc.)

Acknowledgments

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№ 075-15-2020-781

Thank you for your attention !