Visualization and Analysis of Impact Damage in Sapphire

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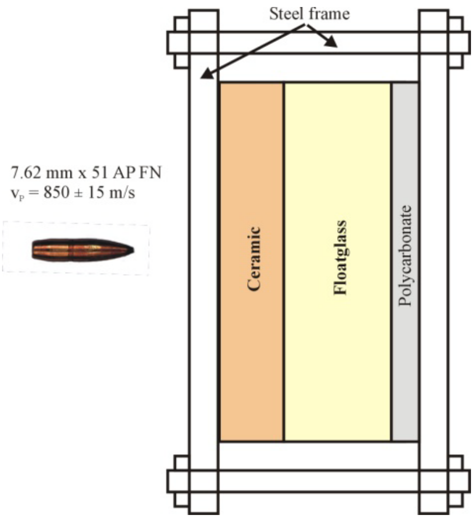
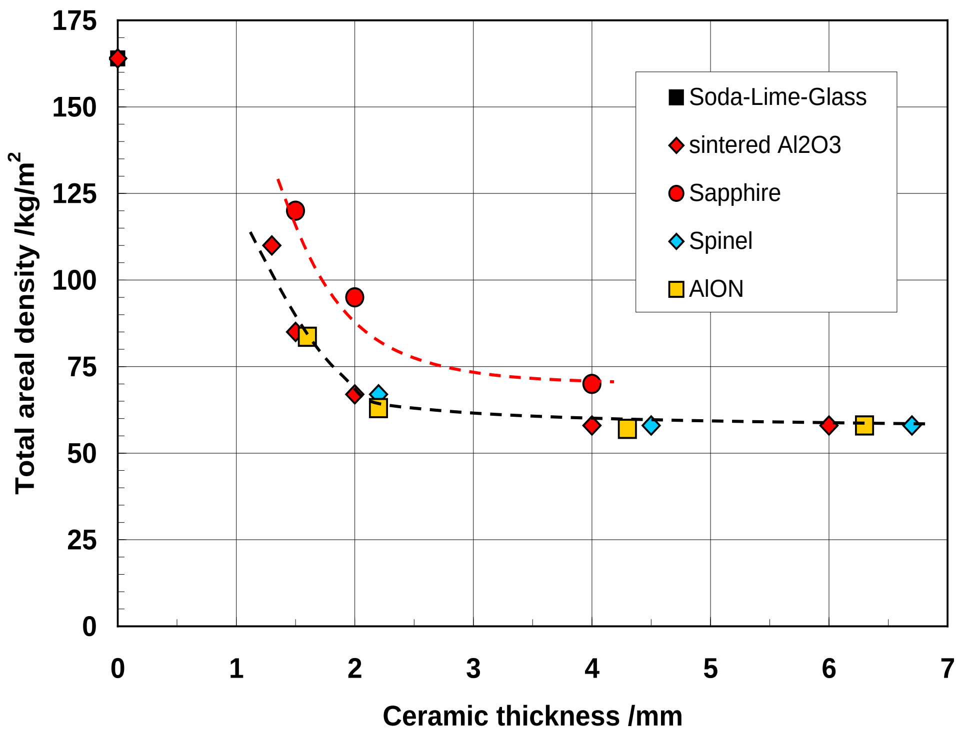
Introduction

- Significant weight reductions when transparent ceramic is used as strike face on a glass-polymer laminate

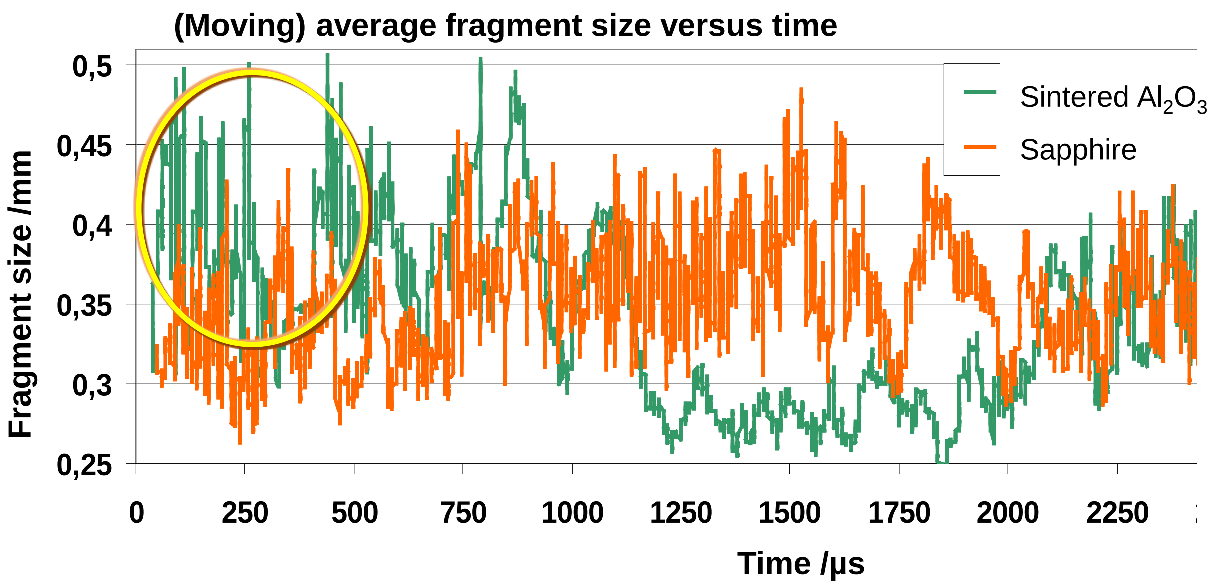




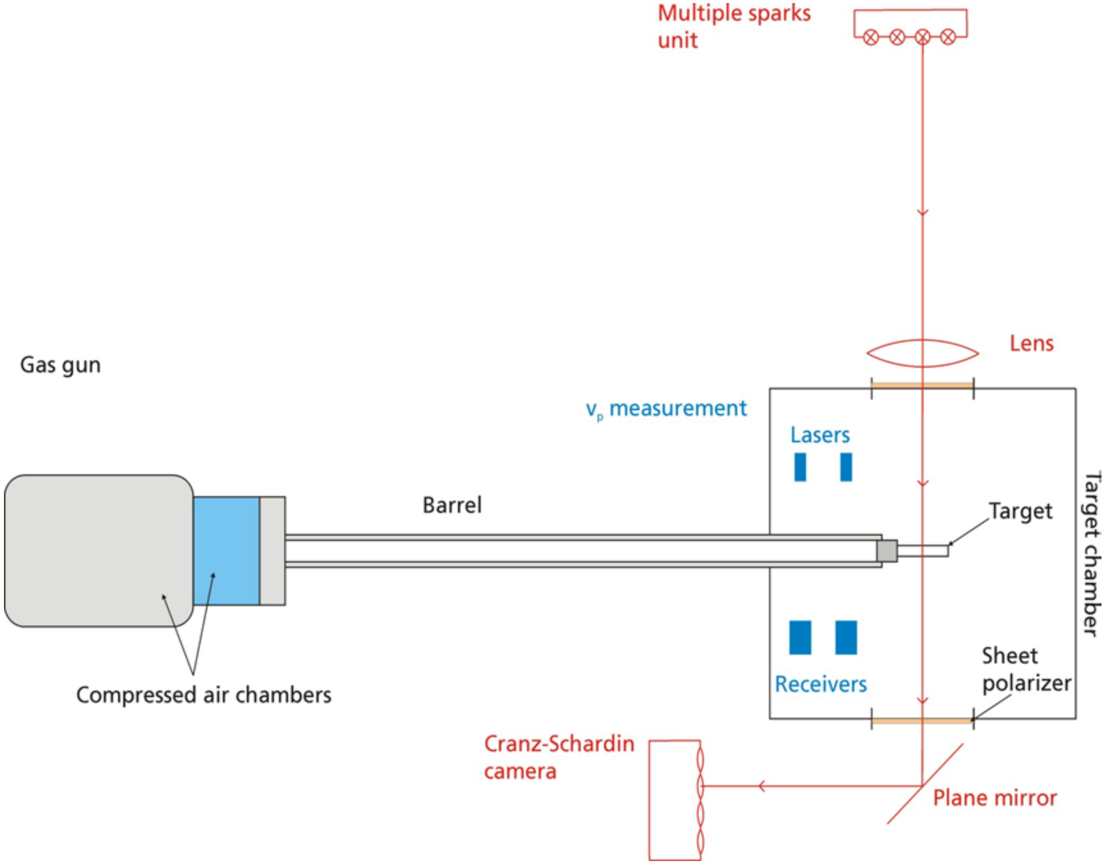
Fraunhofer EMI

Introduction

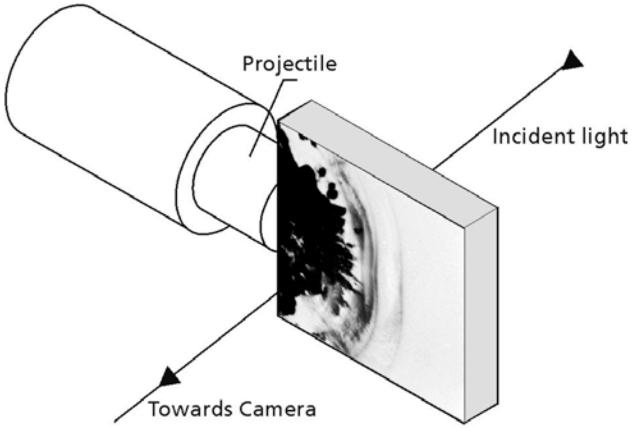
- High ballistic resistance is related to projectile deformation and erosion
- Ability to deform and erode the projectile depends on damage and failure mechanisms in target material
- Fragmentation of ceramic and glass layers plays a key role



Edge-On Impact Test Configuration

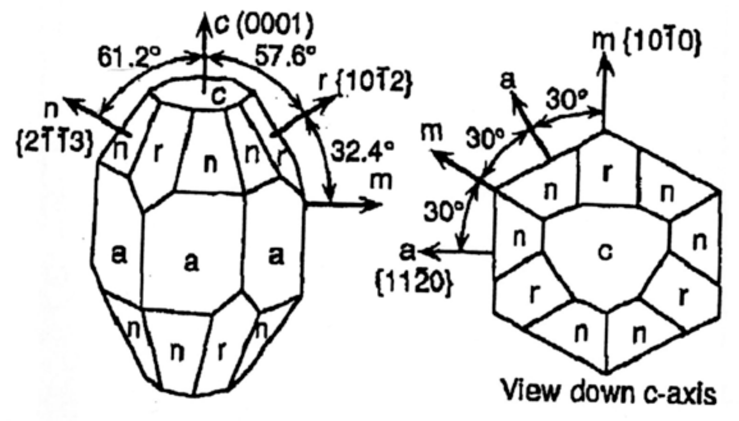


Close-up view of test sample set-up



Test Matrix

Sapphire crystal geometry and nomenclature



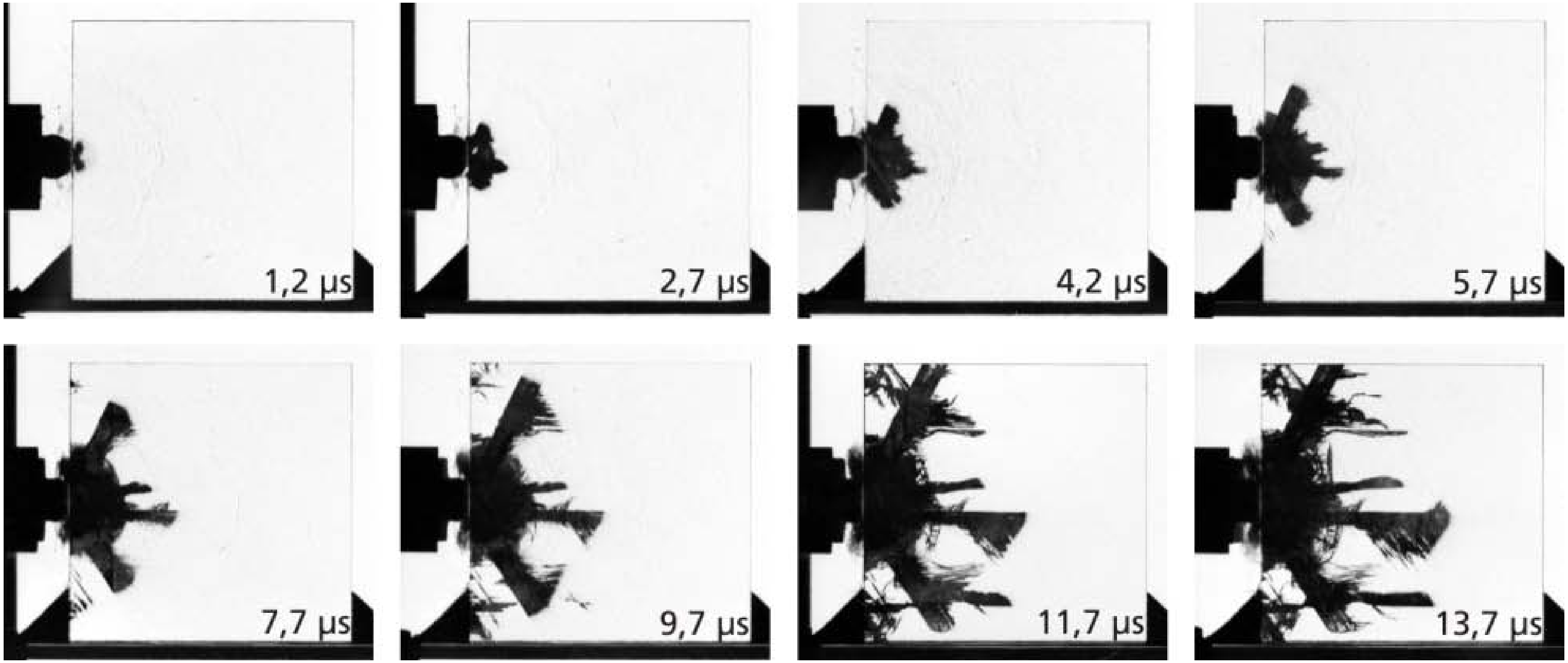
Schmidt and Harris, 1998; J. Am. Ceram. Soc. 81(4)

Config.	Impact Direction	Large Surface	Projectile	EMI Test #
1	a-axis (parallel)	c-plane	sphere	17074
			cylinder	17071
2	a-axis (parallel)	r-plane	sphere	17075
			cylinder	17069
3	c-axis (parallel)	a-plane	sphere	17076
			cylinder	17070
4	c-axis (perpendicular)	a-plane	sphere	17077
5		Edge surface r-plane	sphere	17359

Fraunhofer EMI

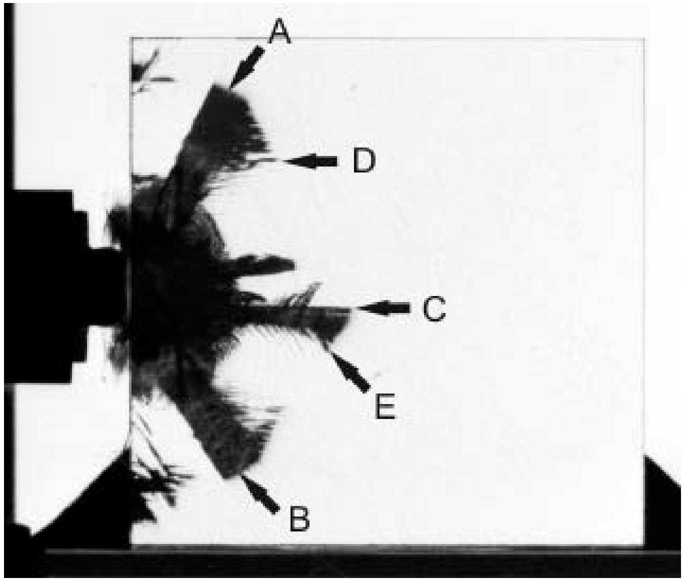
Sphere Impact

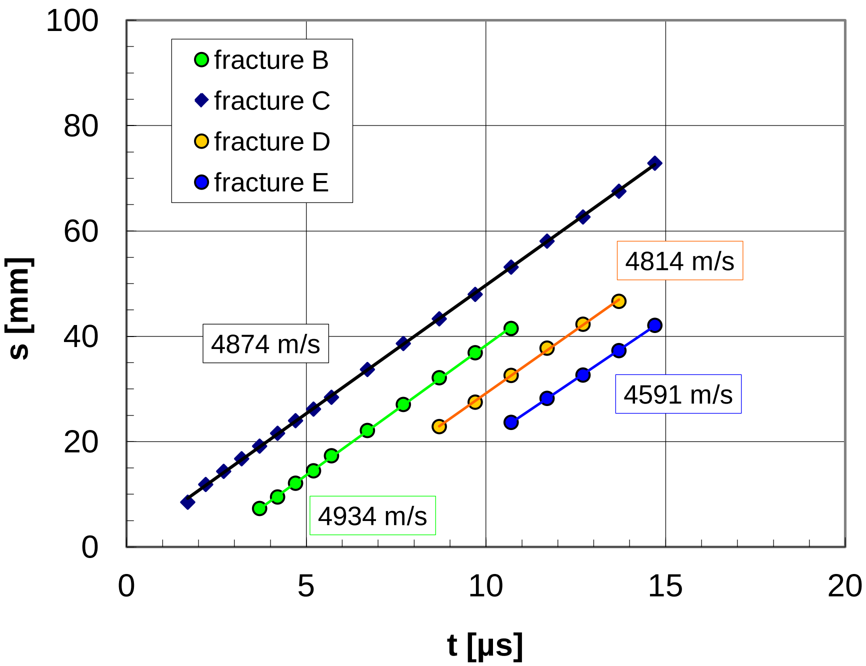
Impact velocity: 453 m/s



Path-time history of fracture propagation

Sphere impact parallel to a-axis; large surface c-plane

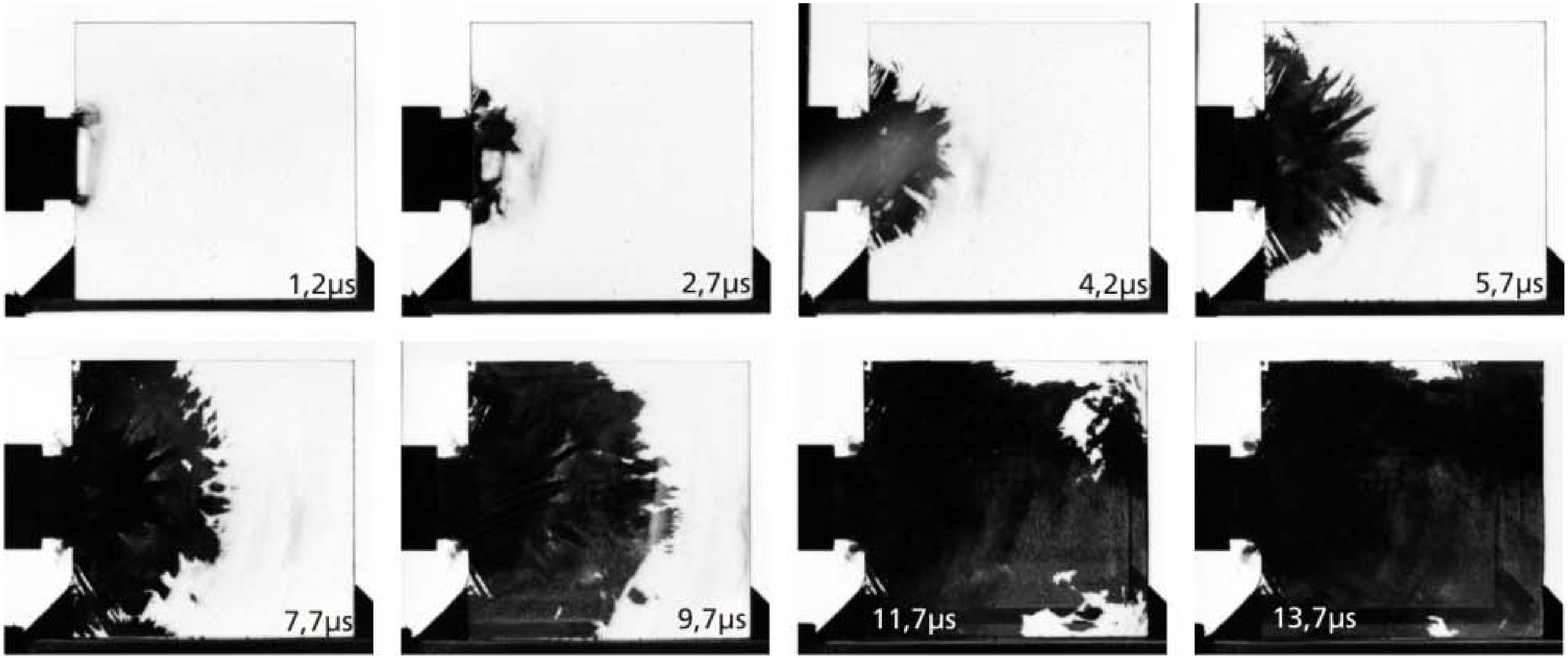




Fraunhofer EMI

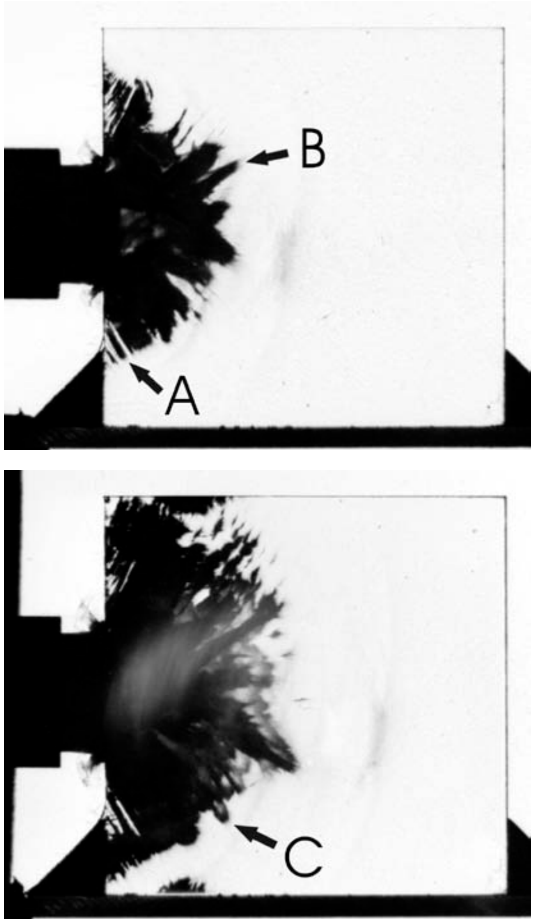
Cylinder Impact

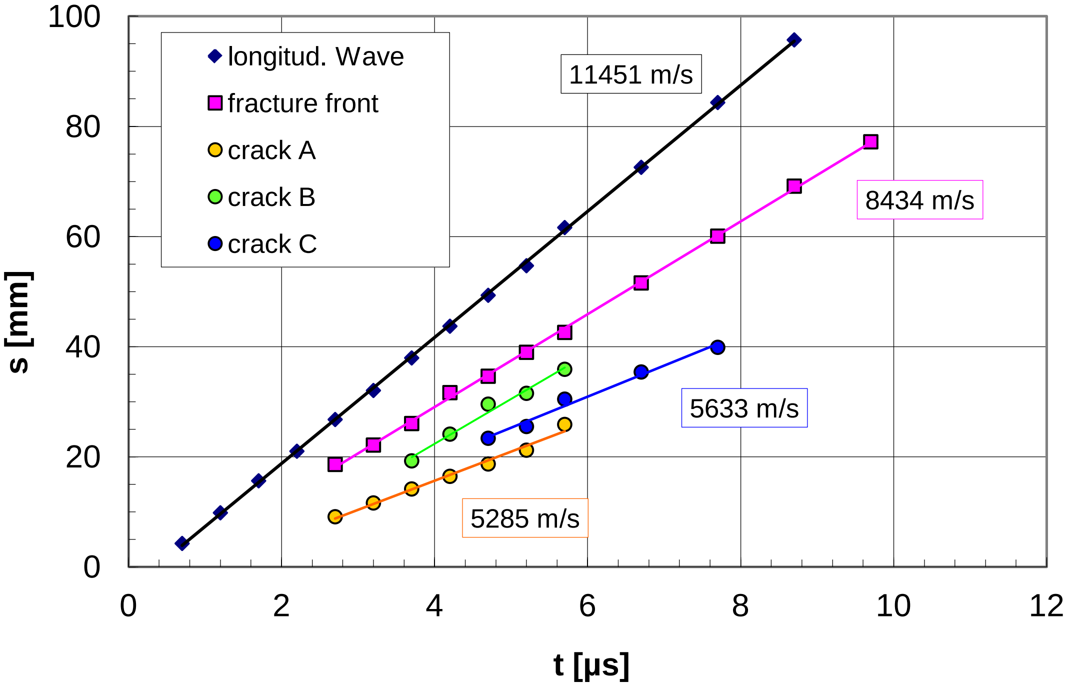
parallel to a-axis; large surface c-plane; v_P = 393 m/s



Path-time histories of fracture and wave propagation

Cylinder impact parallel to a-axis; large surface c-plane





Fraunhofer EMI

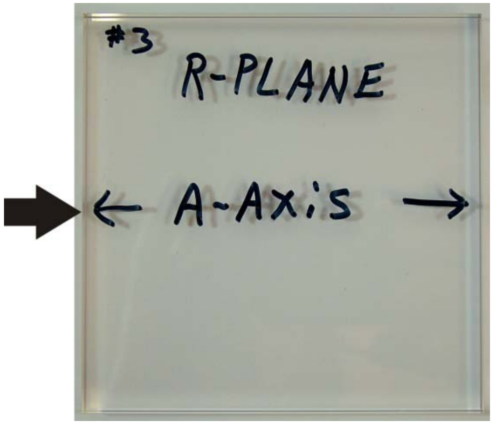
Comparison of Damage and Cleavage Controlled Crack Propagation

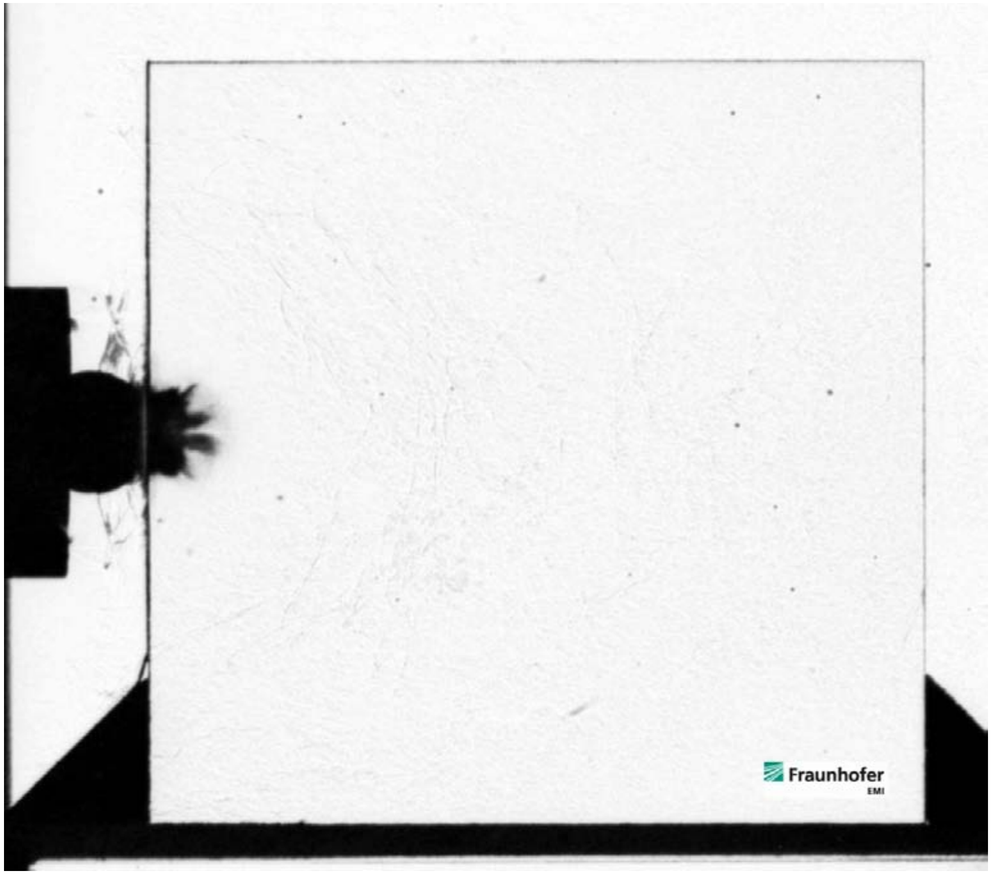
Sphere impact

Parallel to a-axis

Large surface r-plane

v_S = 457 m/s

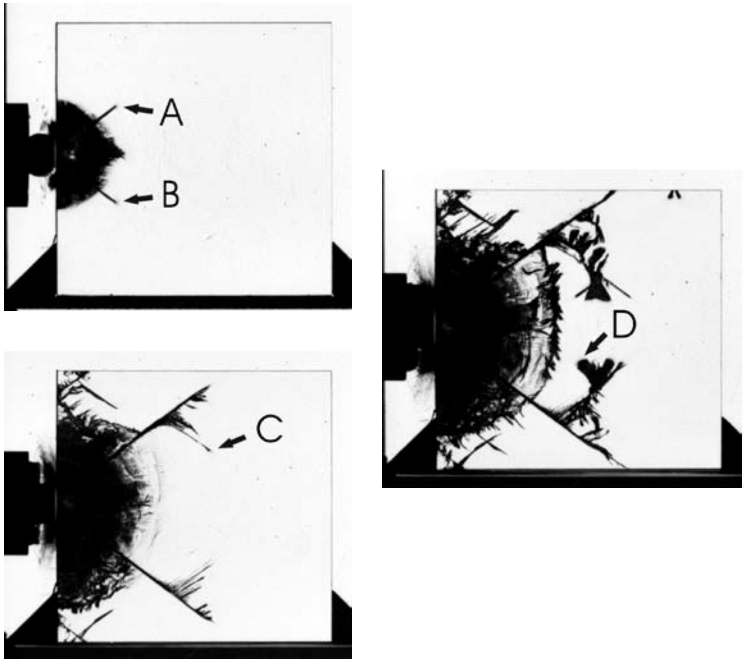


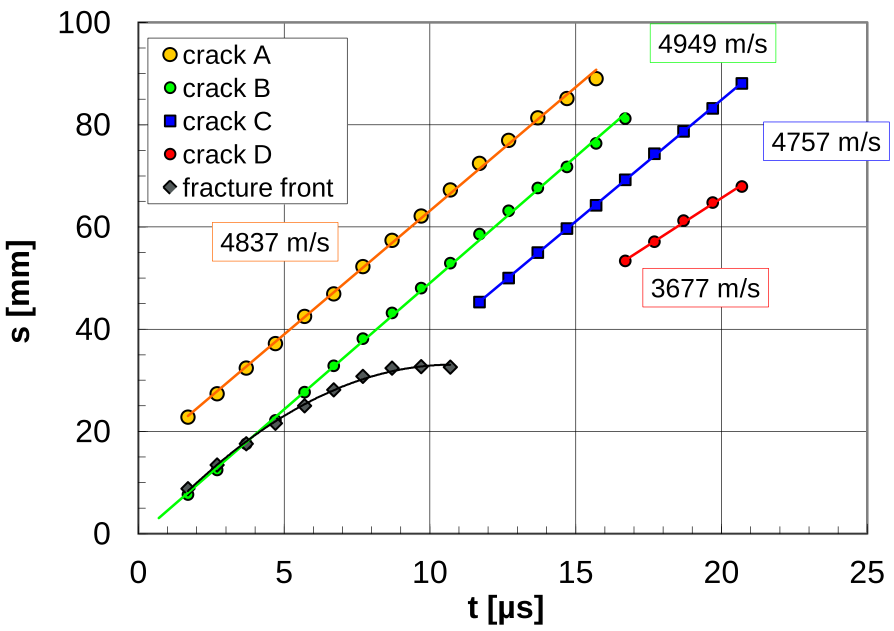


Comparison of Damage and Cleavage Controlled Crack Propagation

Sphere Impact, v_S = 450 m/s

Parallel to a-axis; Large surface r-plane

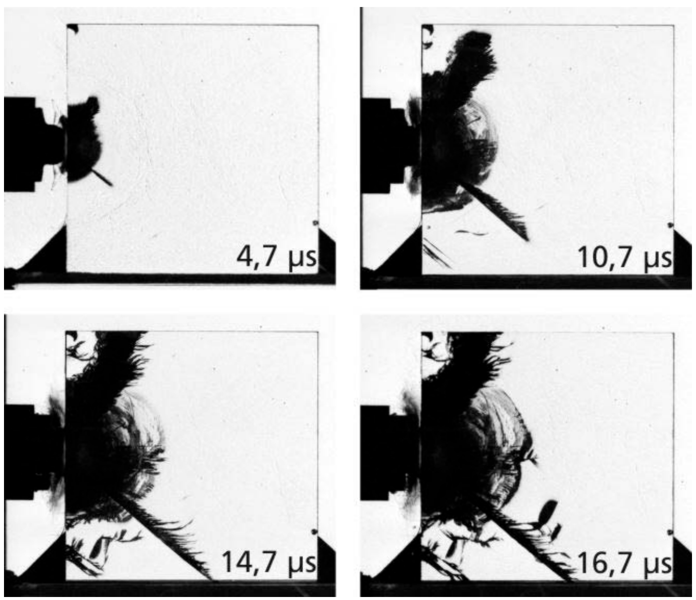


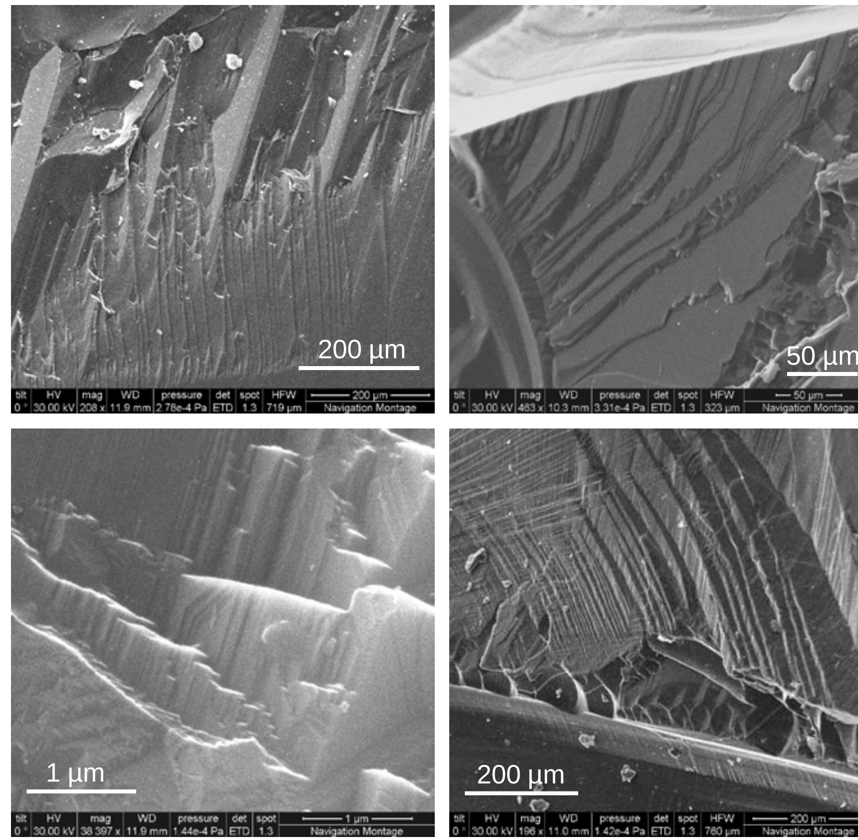


Evidence of cleavage controlled crack propagation

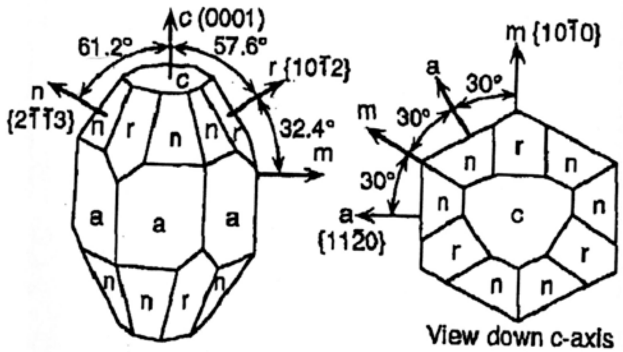
Sphere impact, v_S = 450 m/s

Parallel to c-axis; Large surface a-plane





Cleavage energies

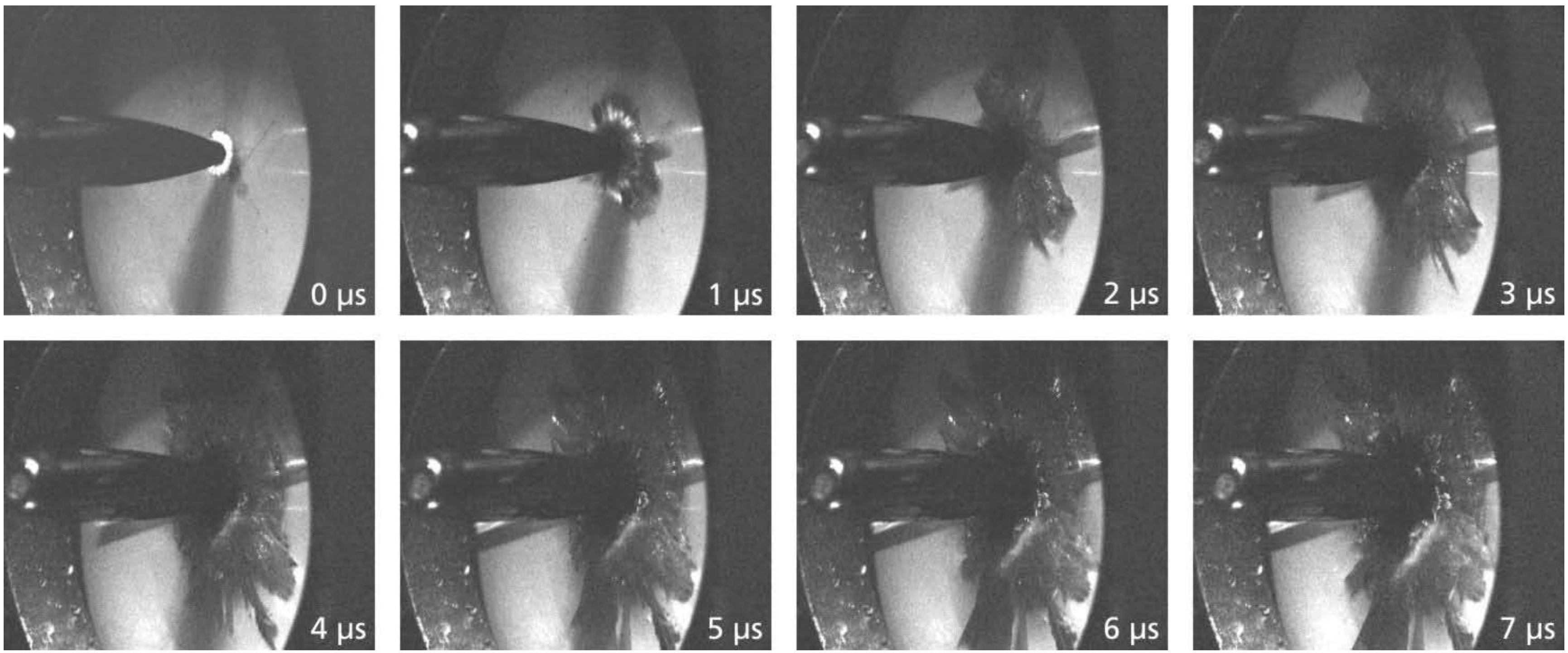


Cleavage plane			Theoret. Cleavage surface energy [J/m²]	Experimental cleavage energy [J/m²]	Fracture toughness K_{IC} $MPa{\cdot}m^{1/2}$
c-plane	(0001)	basal plane	~6.5	21.54	4.54
r-plane	(10$\bar{1}$1)	rhombohedral plane		6.45	2.38
m-plane	(10$\bar{1}$0)	prismatic plane		11.43	3.14

From R. Bradt: “Cleavage of Ceramic and Mineral Single Crystals“, George R. Irwin Symposium, 1997

Fracture propagation in sapphire under ballistic impact

$(11\bar{2}0)$



Conclusion

- Edge-on impact tests have been conducted in order to generate a set of baseline data for fracture and wave propagation in Sapphire of different crystal orientation.
- At impact of steel cylinders fracture patterns were observed, similar to those in polycrystalline materials.
- In case of impact of spherical steel projectiles, fracture mainly followed cleavage planes of the crystal.
- Crack velocities were determined:
  - Maximum average crack velocity: 5438 m/s
  - Minimum average crack velocity: 3700 m/s