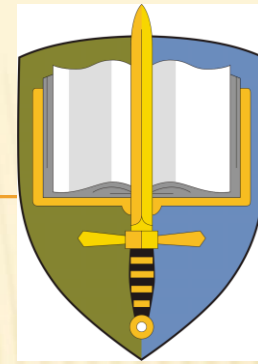


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# ANALYSIS OF DOUBLE BASE PROPELLANTS SERVICE LIFE RELATING TO MECHANICAL PROPERTIES IN EXTREME CLIMATIC CONDITIONS

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# INTRODUCTION

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Goals of this work were

- ❖ to investigate changes in double base (DB) propellants over ageing and
- ❖ to determine significance of nitrocellulose (NC) chain decomposition for evaluation of DB propellants service life.

Reasons for this research:

1. DB propellants are long term stored.
2. DB propellants are exposed to various temperature conditions when stored in field storages (e.g. in extreme climate zones).
3. Polymer NC is as a binder of DB is liable to relatively fast decomposition.
4. DB propellants markedly change its mechanical properties over operational temperature range.

# USED METHODS

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- ✘ Artificial ageing – simulation of time-temperature loading during storage.
- ✘ Size-exclusion chromatography (SEC) - determination of nitrocellulose polymer chain decomposition characteristics.
- ✘ Uniaxial compression and tensile tests - determination of changes of basic mechanical properties.
- ✘ Dynamic mechanical analyses – determination of transition temperatures and its shift.
- ✘ Reaction kinetics analyses – determination of predictive decomposition models.

# TESTED DB PROPELLANTS

- ❖ Type 1 – standard DB made by Explosia a.s. (Pardubice, CZE).
- ❖ Type 2 – with alternative less toxic auxiliary plasticizer.
- ❖ NC properties – 12% nitrogen, wood cellulose.
- ❖ Extruded grains – 30 mm in diameter, 300 mm long.

Propellant	Type 1	Type 2
Nitrocellulose	55.7 %	55.7 %
Nitroglycerine	28.3 %	26.0 %
Dinitrotoluene	8.5 %	
Alternative plasticizer		11.5 %
Ethyl centralite	2,9 %	2.9 %
Catalyzers	4,0 %	4.0 %

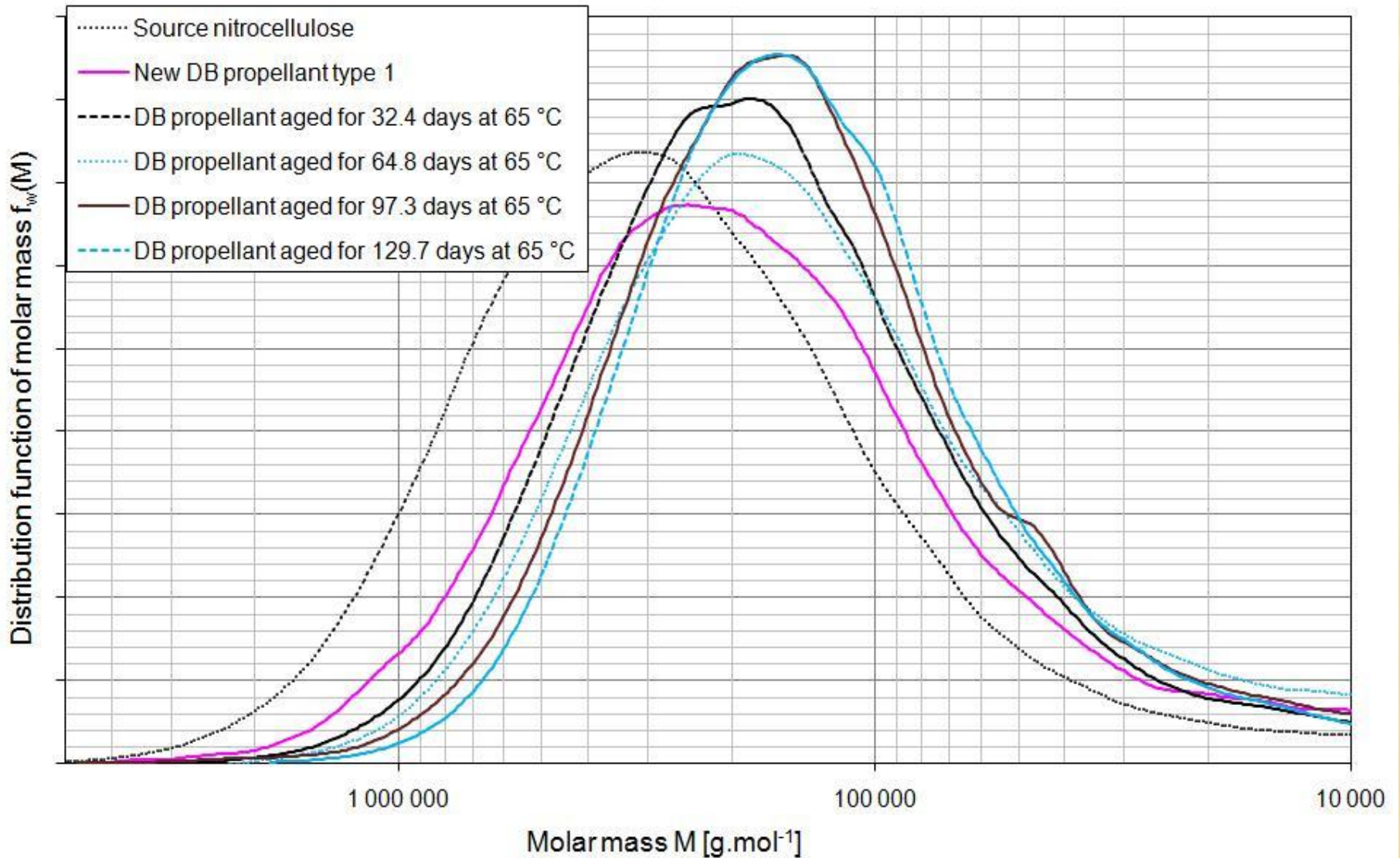


# ARTIFICIAL AGEING

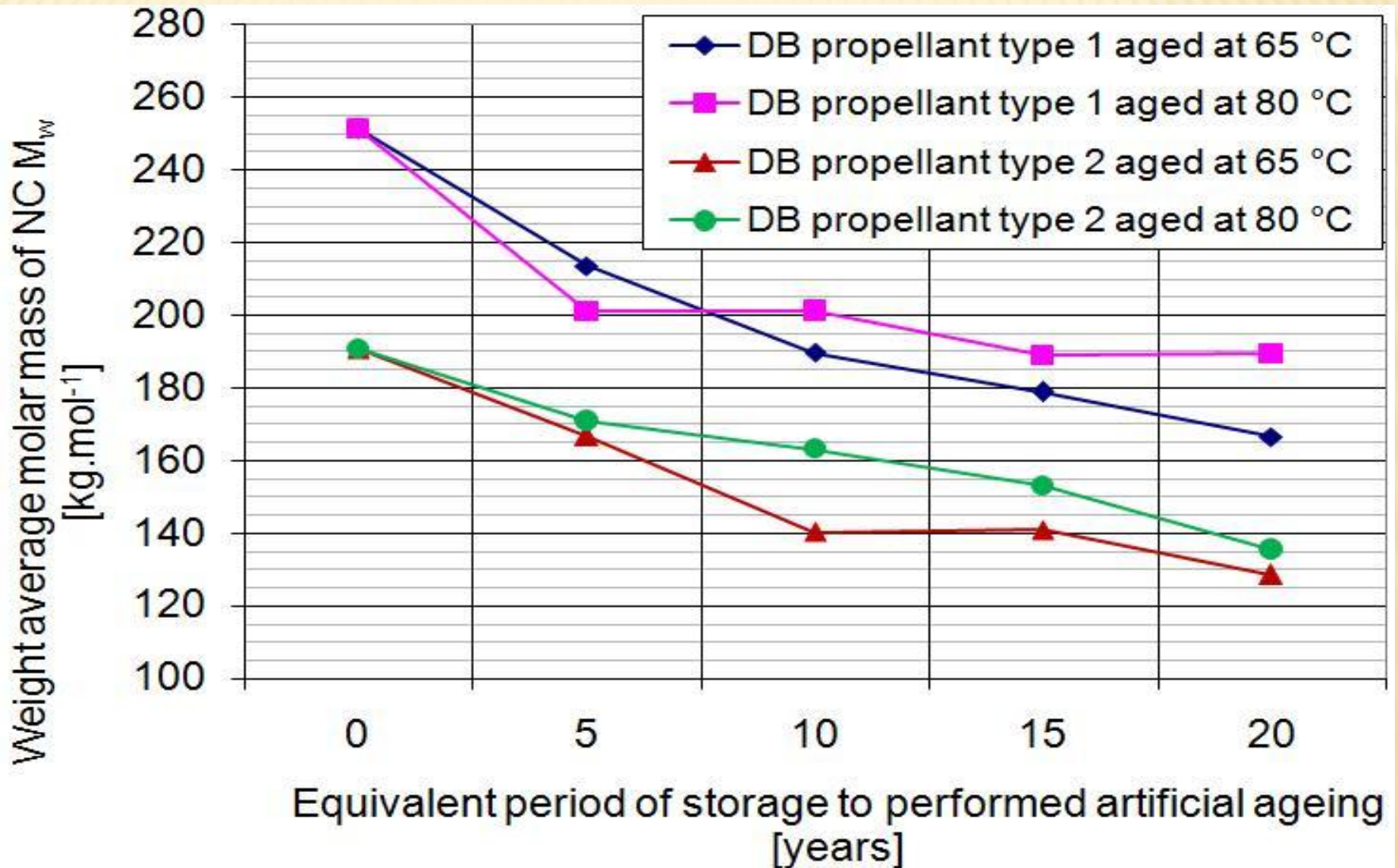
- ❖ Conditions set with respect to AOP-48.
- ❖ Ageing at two temperatures: 65 °C and 80 °C.
- ❖ Grains loaded in polymer coated aluminum bags.
- ❖ Ageing periods accordingly to Arrhenius equation (and known kinetic parameters of -NO<sub>2</sub> group decomposition):

Period of storage at 25 °C [years]	Corresponding period of artificial ageing at	
	65 °C [days]	80 °C [days]
5	32.4	5.3
10	64.9	10.6
15	97.3	15.9
20	129.7	21.2

# SEC CHROMATOGRAMS



# AVERAGE MOLAR MASS OF NITROCELLULOSE





# MODEL OF NITROCELLULOSE DECOMPOSITION

❖ Kinetic model of chain scission  
 (solve rate constant from molar masses) 
$$\frac{m}{M_n(t_i, T)} = \frac{m}{M_n(0)} + k_M(T)t_i$$

❖ Arrhenius equation  
 (solve activation energy from rate constant) 
$$\ln k_{Mi}(T_i) = \ln A - \frac{E_a}{RT_i}$$

Established kinetic parameters of decomposition in temperature range 65 °C to 80 °C:

		DB propellant type 1	DB propellant type 2
Activation energy $E_a$	[kJ.mol <sup>-1</sup> ]	85	105
Frequency factor $A$	[-]	1,84.10 <sup>3</sup>	3,28.10 <sup>6</sup>

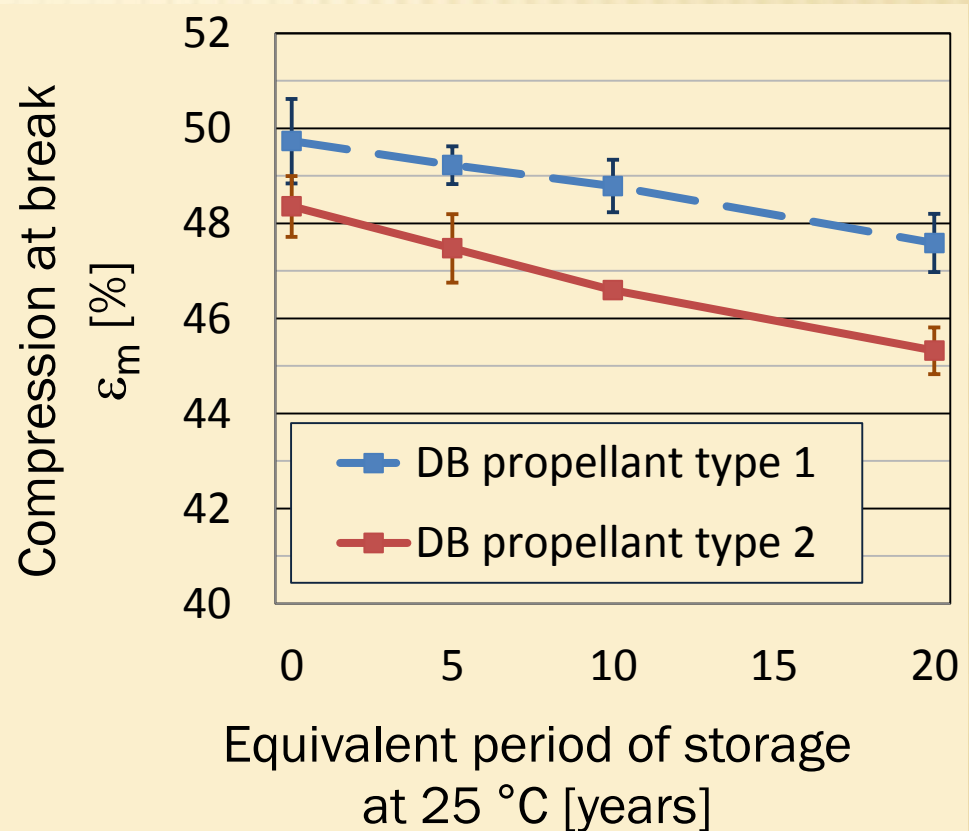


# CHANGES IN MECHANICAL CHARACTERISTICS

Uniaxial tensile and compression tests:

change of  $\varepsilon_m$  measured at 21 °C (aged for 129.7 days at 65 °C)

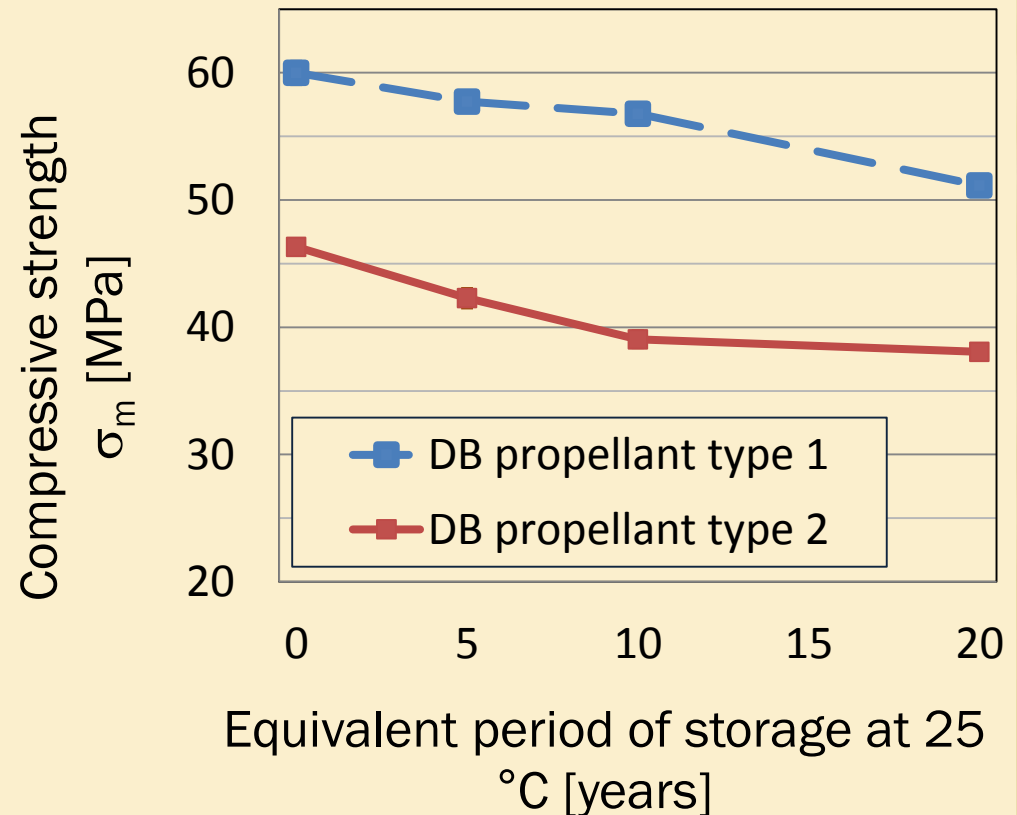
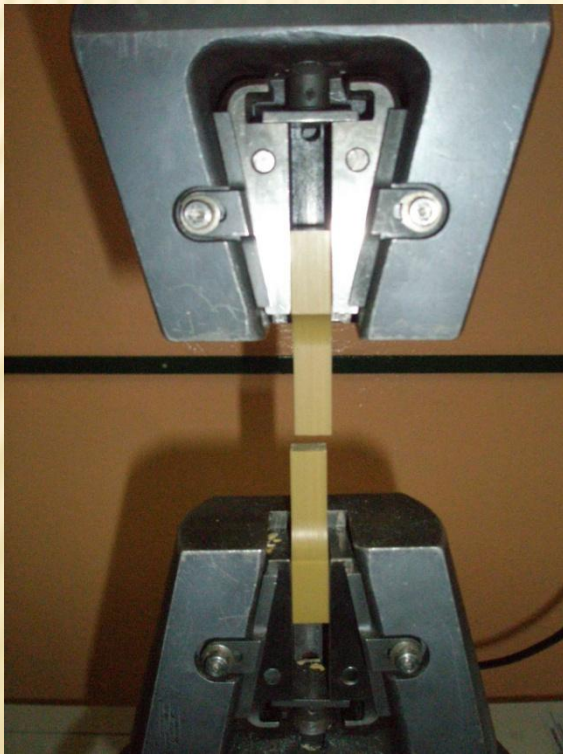
- ❖ in compression -4 % and -6 %,
- ❖ in tension -7 % and +13 %.



# CHANGES IN MECHANICAL CHARACTERISTICS

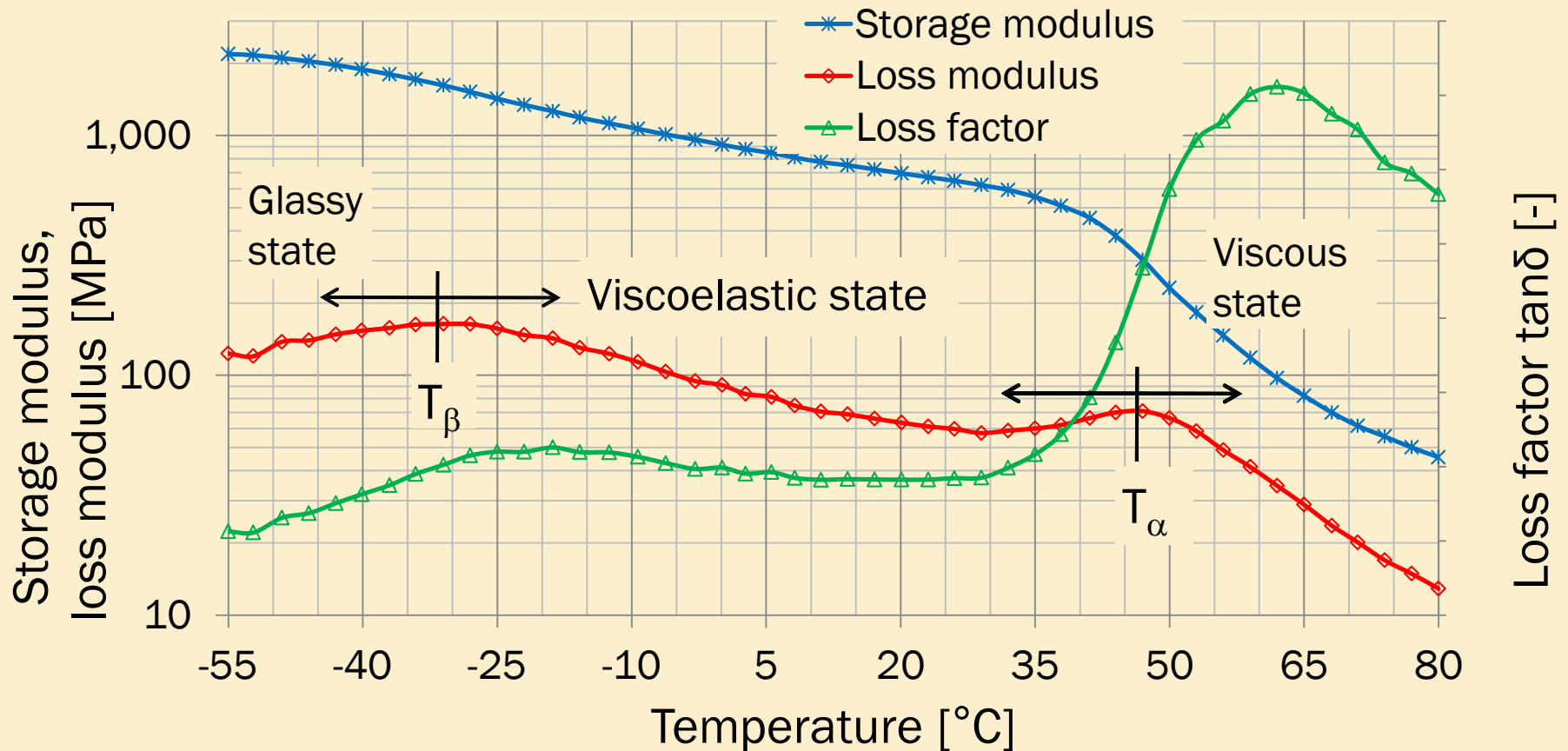
Decrease of  $\sigma_m$  measured at 21 °C (aged for 129.7 days at 65 °C)

- ❖ in compression by 15 % and 18 %,
- ❖ in tension by 16 % and 9 %.



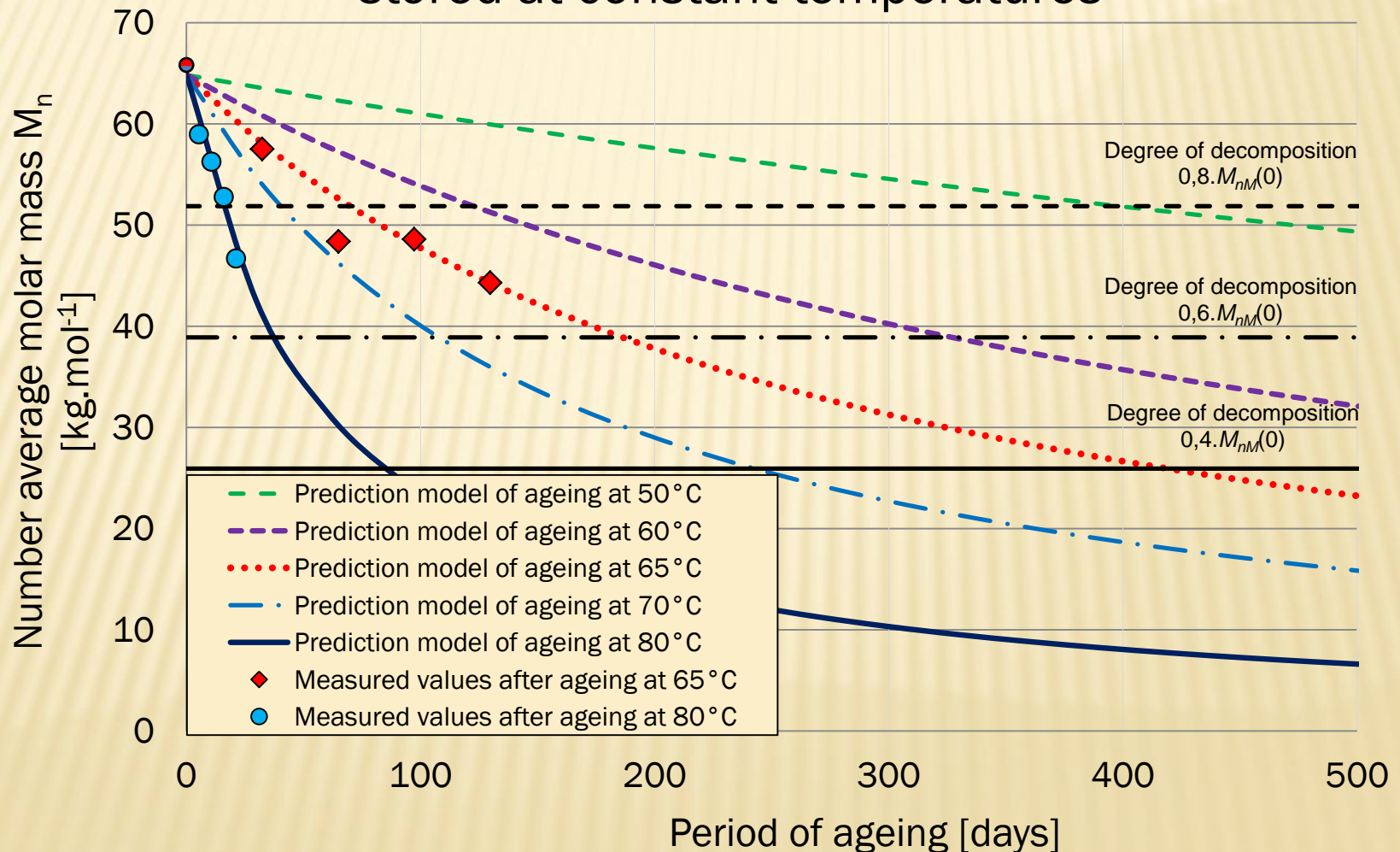
# DYNAMIC MECHANICAL ANALYSES

- ❖  $T_\alpha$  lowers during ageing 46 °C  $\rightarrow$  42 °C for both DB.
- ❖  $T_\beta$  does not show any trend -32 °C, -37 °C for DB type 1, 2.



# MODEL OF NITROCELLULOSE DECOMPOSITION

Predictive model of decomposition NC for DB type 2 stored at constant temperatures

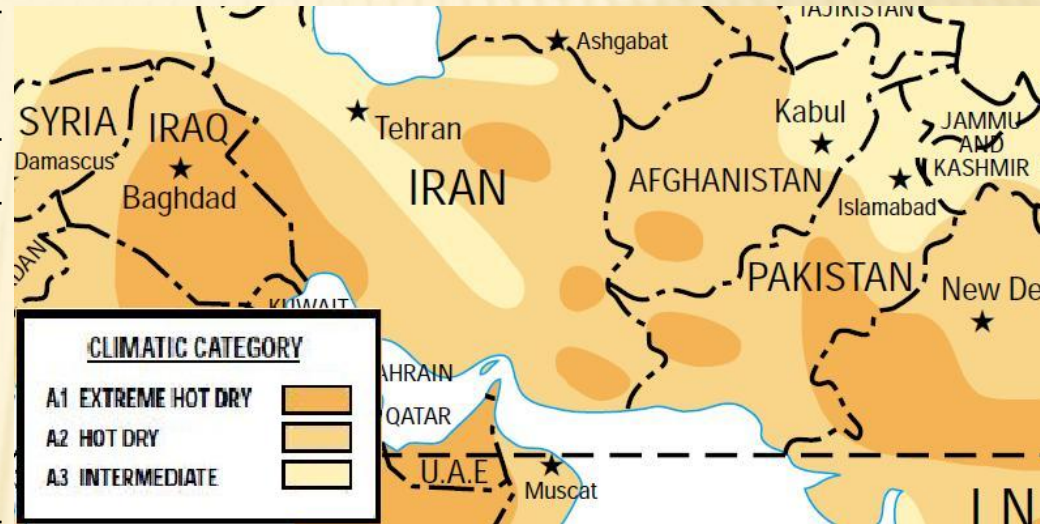




# MODELING OF FIELD STORAGE CONDITIONS

- ❖ STANAG 2895 determines climatic categories and time-temperature loadings.

Temperature at storage [°C]	Period of temperature loading during one year [hours]
71	5,2
69	26,2
67	49,5
65	77,4
63	108,7



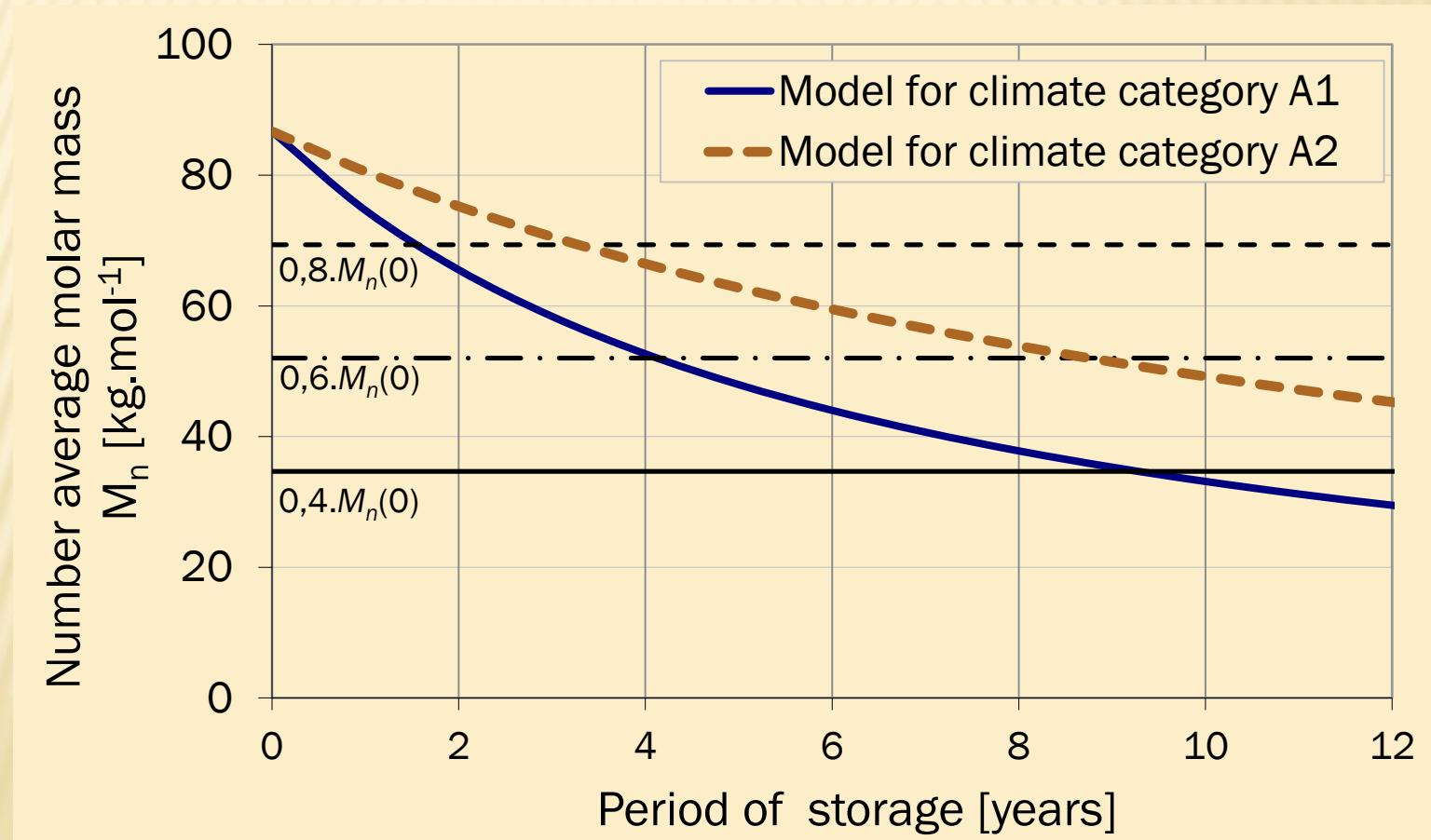
- ❖ Data were used to establish predictive model based on Arrhenius equation in form:

$$M_n(t_n, T_n) = M_n(0) - \sum_i^n \left( M_n(t_{i-1}, T_{i-1}) - \frac{m}{\frac{m}{M_n(t_{i-1}, T_{i-1})} + A_i \exp\left(-\frac{E_{ai}}{RT_i}\right)} t_i \right)$$

# NC CHAIN DECOMPOSITION IN FIELD STORAGE

Service life related to NC chain decomposition:

- ❖ 9,5 years and 11,5 years for DB type 1 and type 2 in climate category A1 (limiting condition  $0,4 M_n(0)$ )



# CONCLUSION

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Performed artificial ageing of two types of DB propellant at 65 °C during 129.7 days leads to decrease of values of chemical and mechanical properties:

- ❖  $M_n$  by 34 % and 33 %
- ❖  $\sigma_m$  at 21 °C in compression by 15 % and 18 %
- ❖  $\varepsilon_m$  at 21 °C in compression by 4 % and 6 %
- ❖  $T_\alpha$  by 4 °C (46 °C -> 42 °C)
- ❖  $E_a$  of NC chain scission at temperature range 65 °C to 80 °C were established to be 85 kJ.mol<sup>-1</sup> and 105 kJ.mol<sup>-1</sup>.



# CONCLUSION

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Described processes and changes lead to:

DB propellants tend to get markedly softer at temperatures near upper operational limit ( $\sim 50$  °C) after ageing.

Service life of DB propellants related to NC decomposition and mechanical characteristics changes could determine overall service life.

Service life of DB related to  $M_n$ , when stored in field conditions in extreme climates, could be limited to  $\sim 10$  years (accepted condition of limiting decomposition  $0,4.M_n(0)$  ).



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**Thank you for your attention**

**Questions?**