Silesian University of Technology

RESEARCH UNIVERSITY
EXCELLENCE INITIATIVE
Ministry of Science and Higher Education

Materials Engineering Faculty

Materials Technologies Department

CARBON IN TITANIUM ALLOYS – PROBLEMS OR BENEFITS

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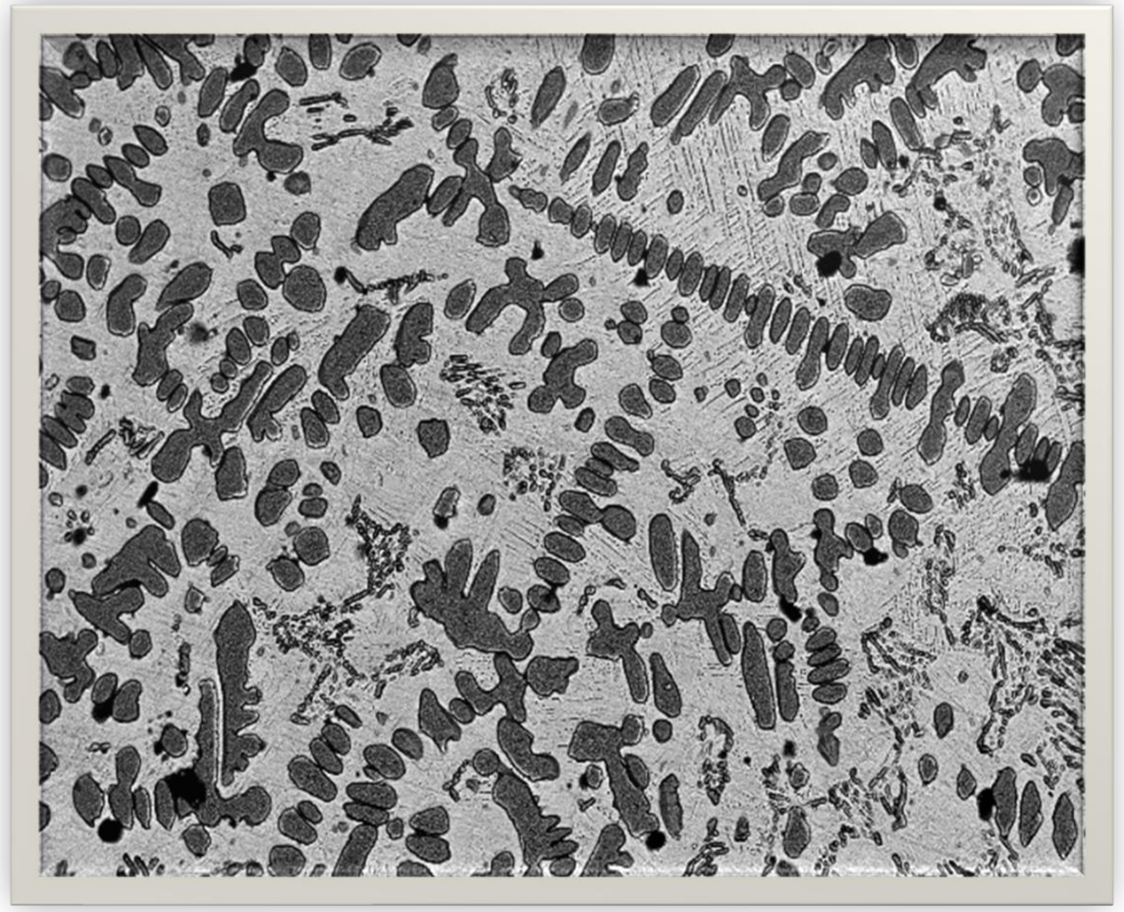
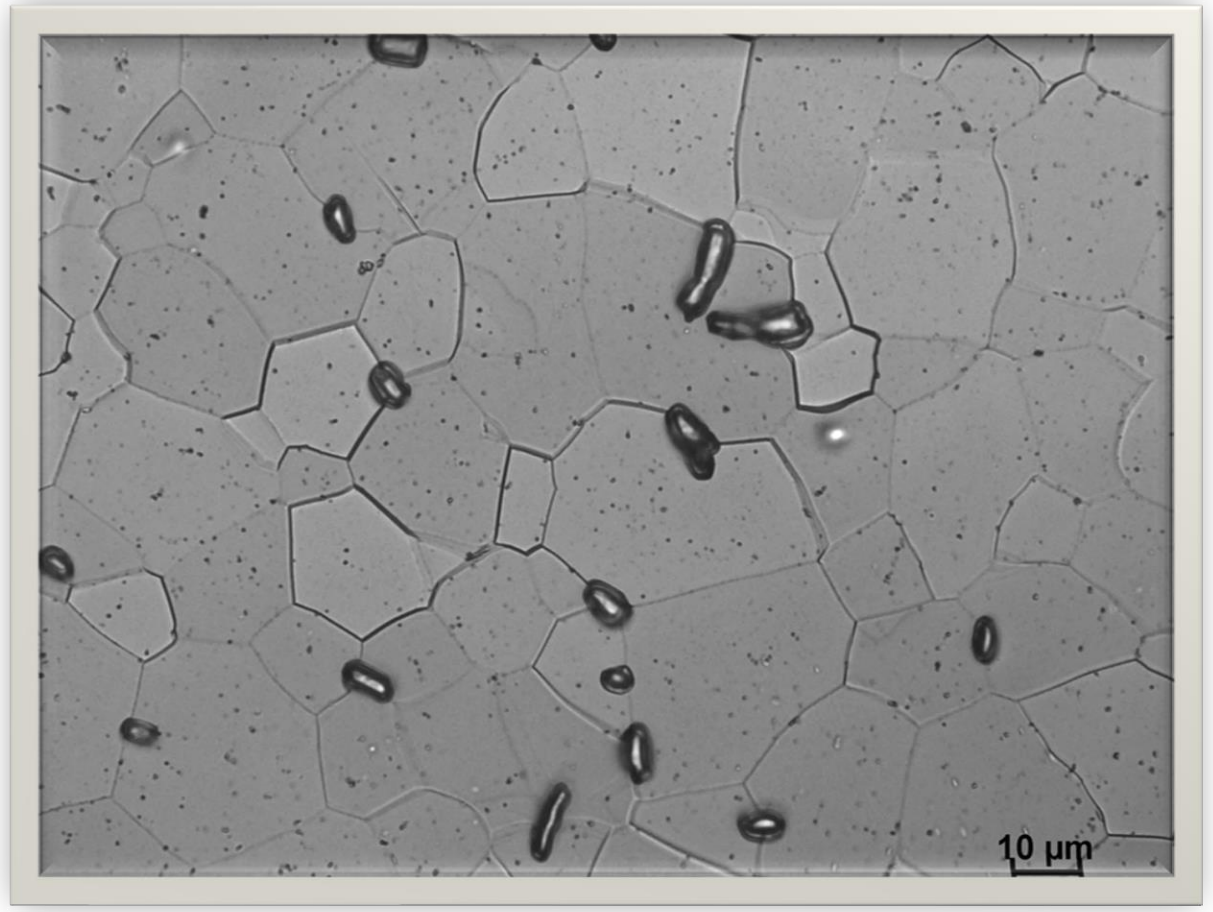
Materials Engineering Forum 30.06.2022

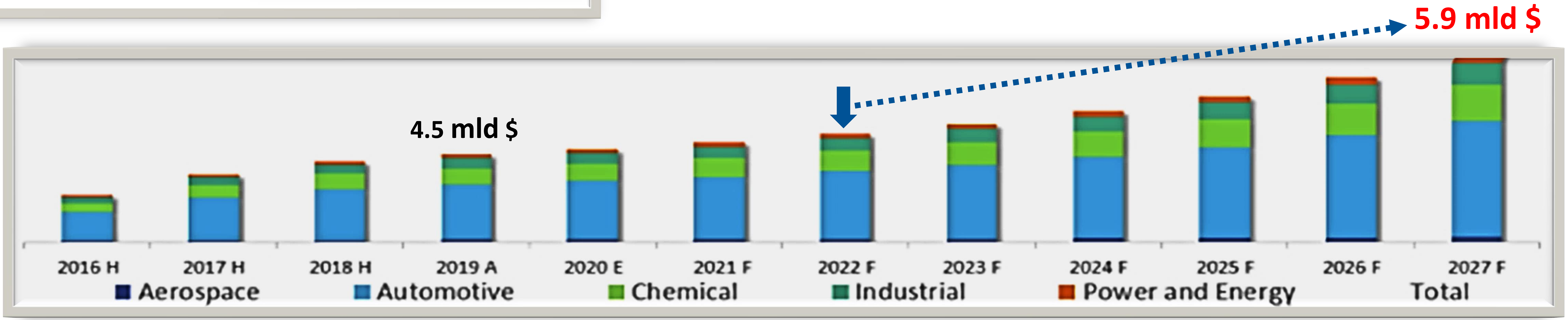
Plan of presentation





Introduction: Market of titanium

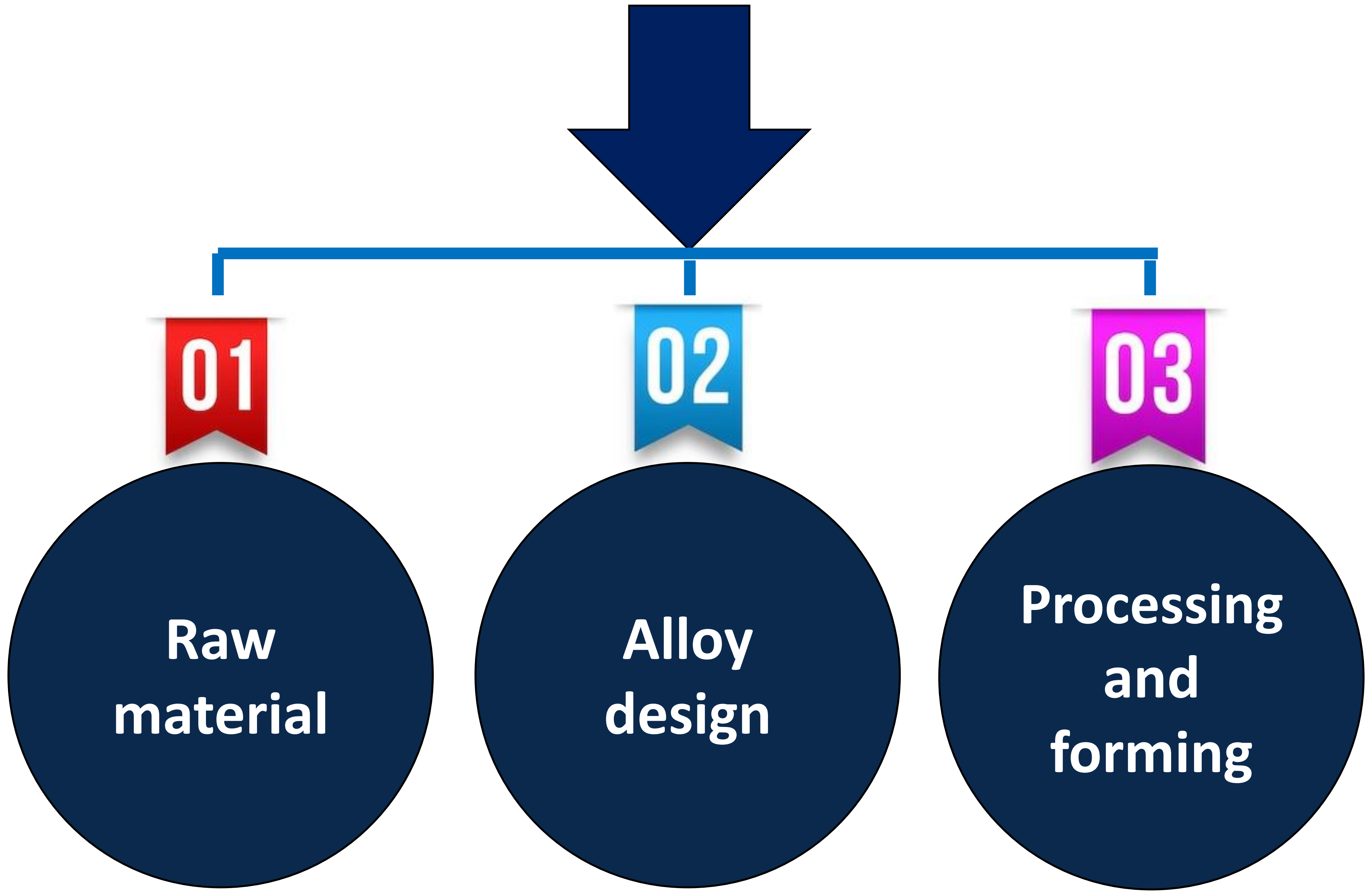
Aerospace | **Biomaterials** | **Military** | **Automotive**

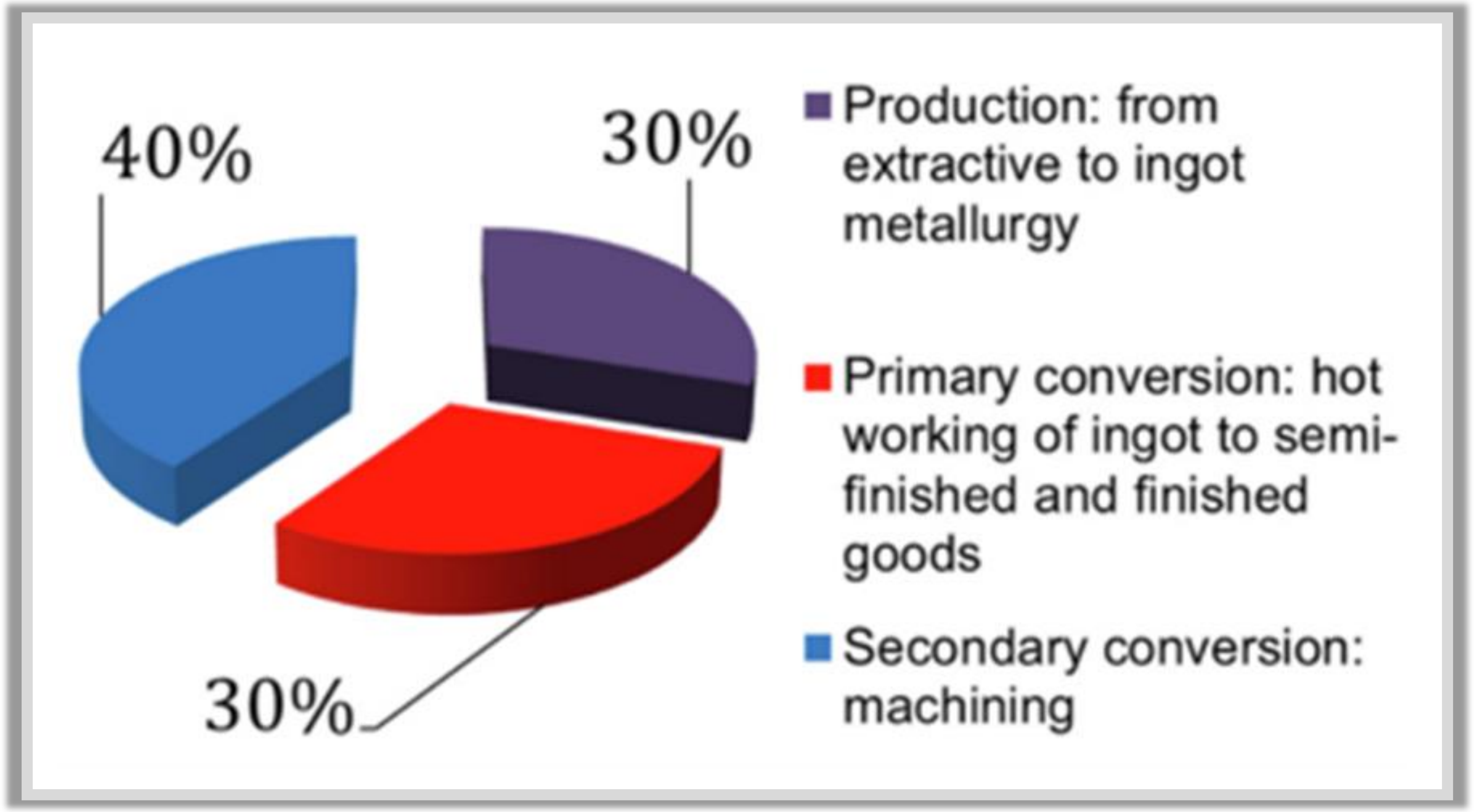


Introduction: Low cost titanium alloys

Critical factors contribute to the cost of producing titanium alloys:

- High cost of titanium sponge production
- expensive and rare alloying elements
- complex and multi-staged hot working
- difficult machining





Processing step to total cost of titanium alloys

Based on M. Bodurin et alDevelopment of low-cost titanium alloys: A chronicle of challenges and opportunities. Materials Today: Proceedings. 2021

Introduction: Low cost titanium alloys – possibility of cost reduction

Development of cheapest and easy method of pure titanium production

- titanium tetrachloride electrolysis method,
- continuous liquid reduction method,
- flow continuous gas phase smelting method,
- direct electrolysis reduction of titanium dioxide,
- use of revert materials,
- compact processes for high efficiency fabrication based on electron beam (EB) cold hearth smelting.

Substitution of expensive alloying elements

- use cheap alloying elements to instead of expensive alloying elements without reducing the performance of the alloy
- design low cost titanium alloy which is not sensitive to impurity elements and made with revert material

5-20%

Optimization of hot working and machining processes

- near net forming technology: low-cost powder metallurgy technology. superplastic forming/ diffusion bonding. casting. laser melting deposition additive manufacturing
- Conception of „fast technology"

50%

IMPORTANT! **Establish the classification standards for low-cost titanium alloys used in different industries**

Based on M. Bodurin et al.: Development of low-cost titanium alloys: A chronicle of challenges and opportunities. Materials Today: Proceedings. 2021

Ti 6AL-4V

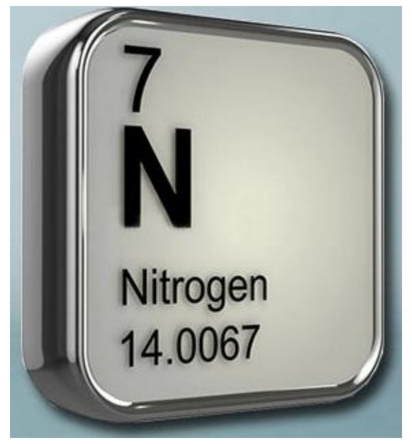
Cost reduction approach

reduce Al
replace Al with O and N
replace V with Fe
replace V with Cr and Mn

Experimental titanium alloys

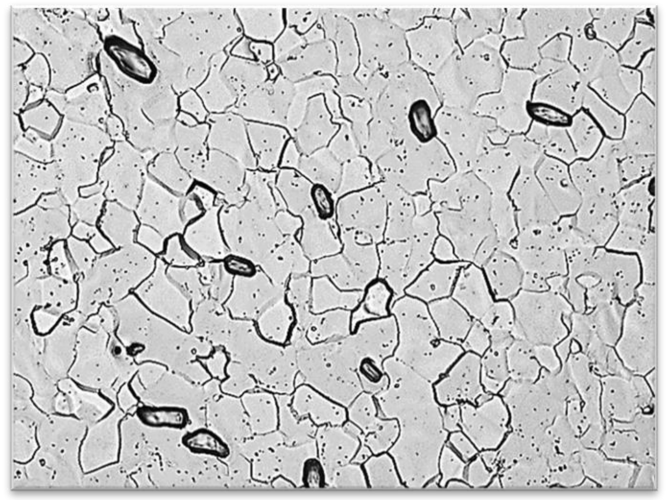
Ti-1.5Fe-0.49O-0.05N
Ti-3.5Al-1Fe. Ti-5.5Al-1Fe.
Ti-3Al-2.1Cr-1.3Fe
Ti-4.5Al-6.9Cr-2.3Mn
Ti-4.5Al-1V-3Fe. Ti-6Al-1V-3Fe

Interstitial elements
Alpha phase stabilizer



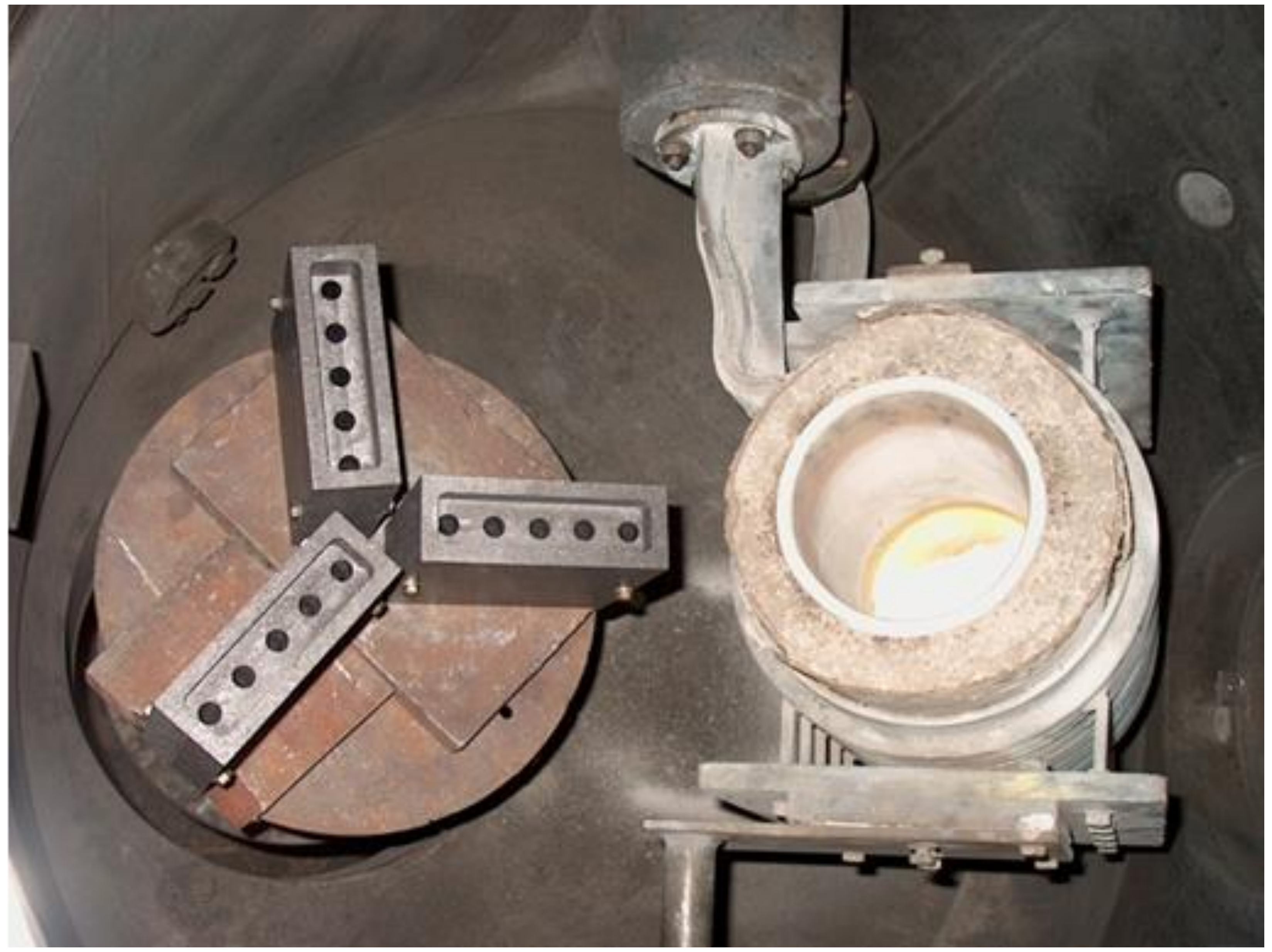
Ti-xC

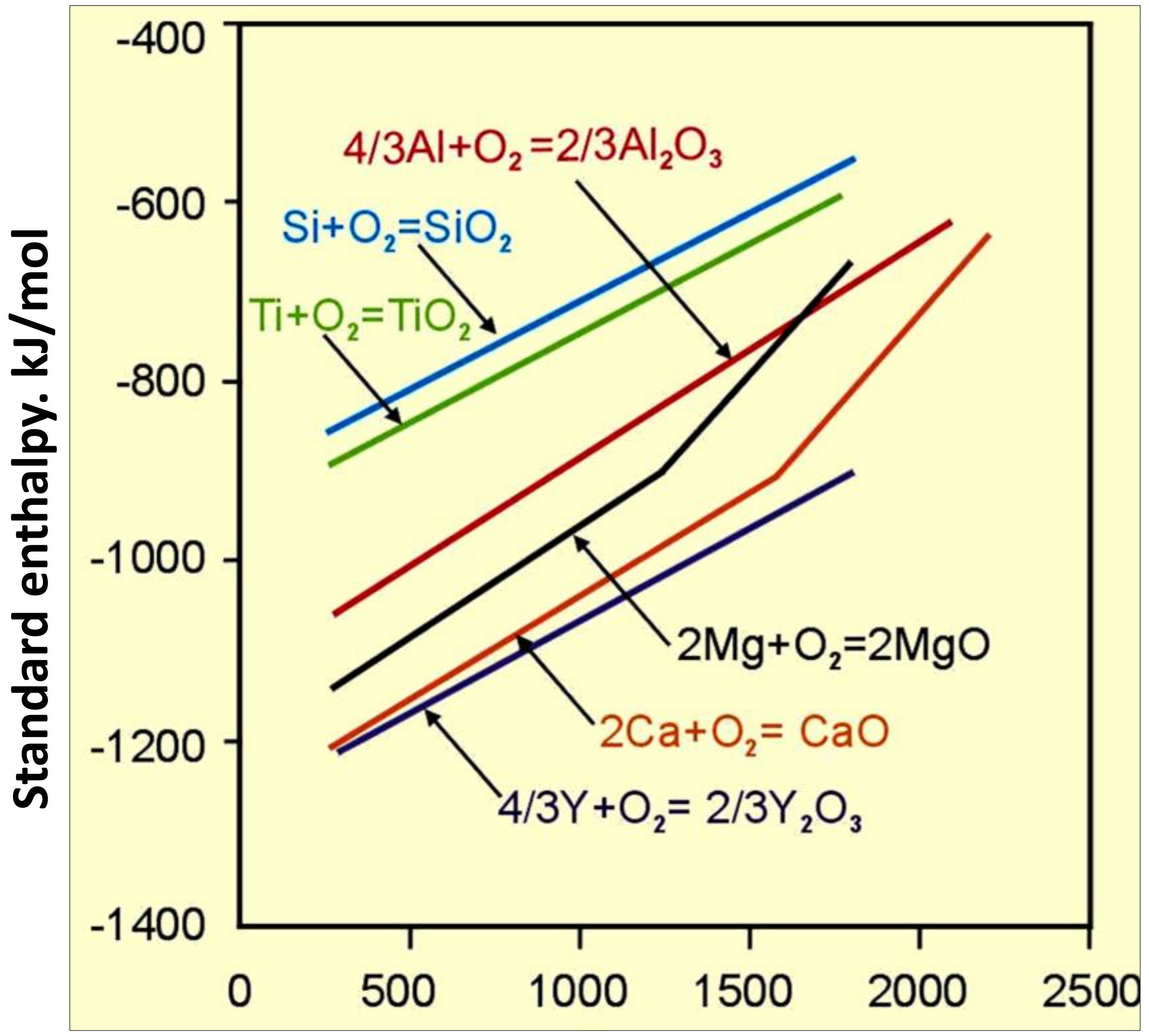
+

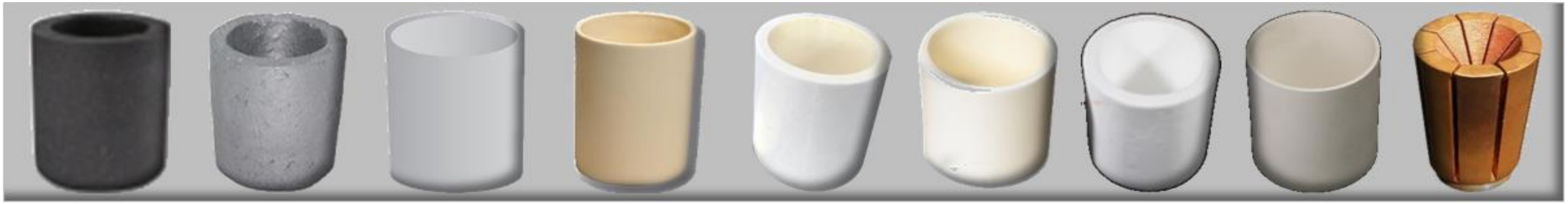


2. TITANIUM ALLOYS MELTED IN CERAMIC CRUCIBLES

Titanium and titanium alloys melted in ceramic crucible





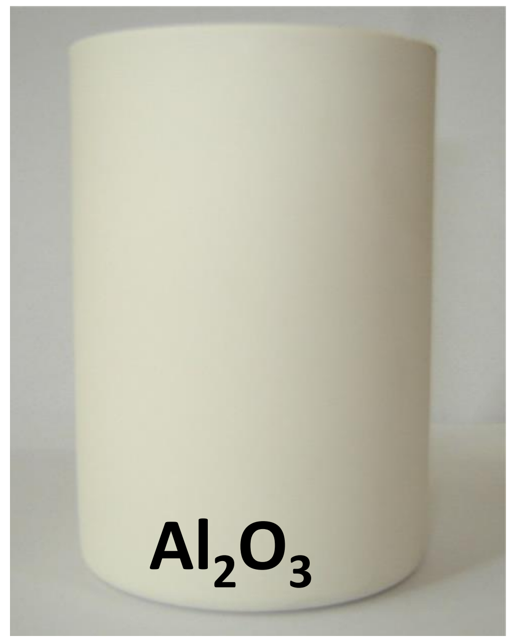


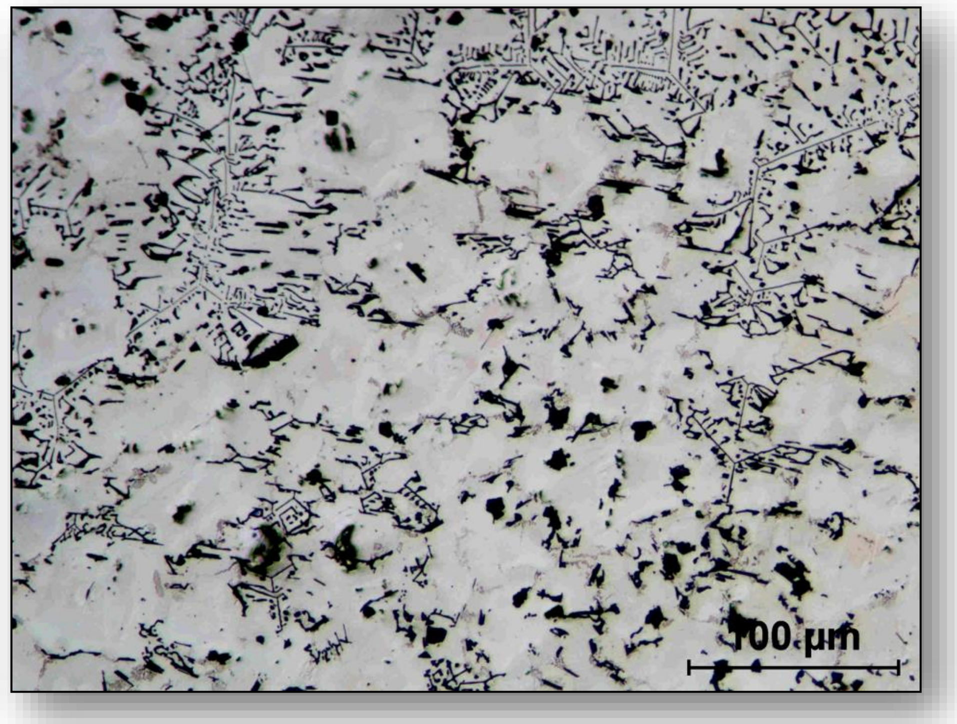
C(grafit) → SiC → SiO_2 → MgO → Al_2O_3 → ZrO_2 → CaO → Y_2O_3 → Cu

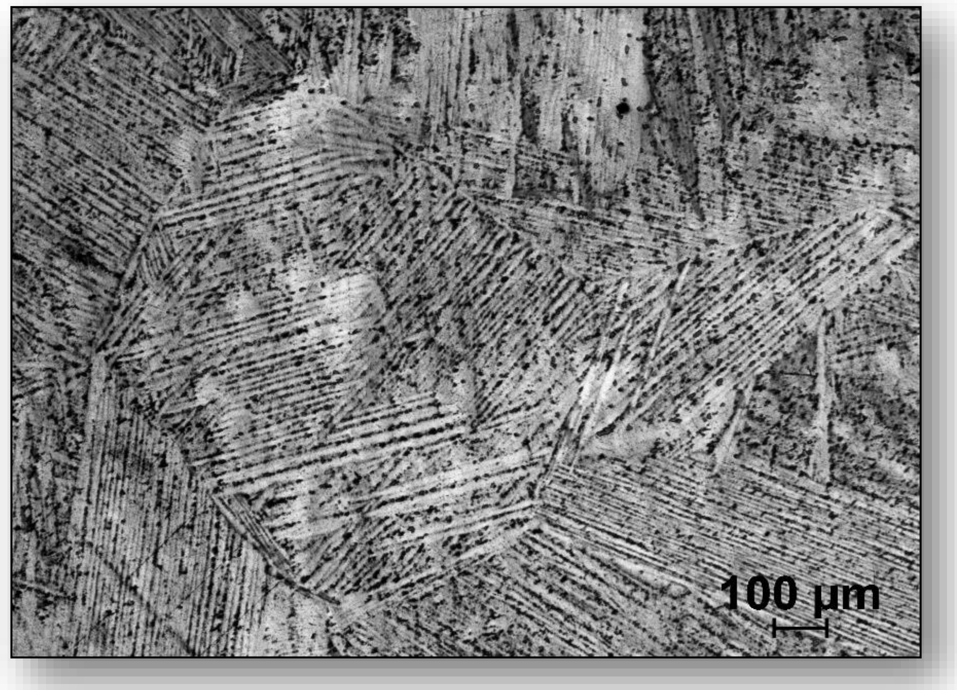
Effect of titanium melting in ceramic crucible

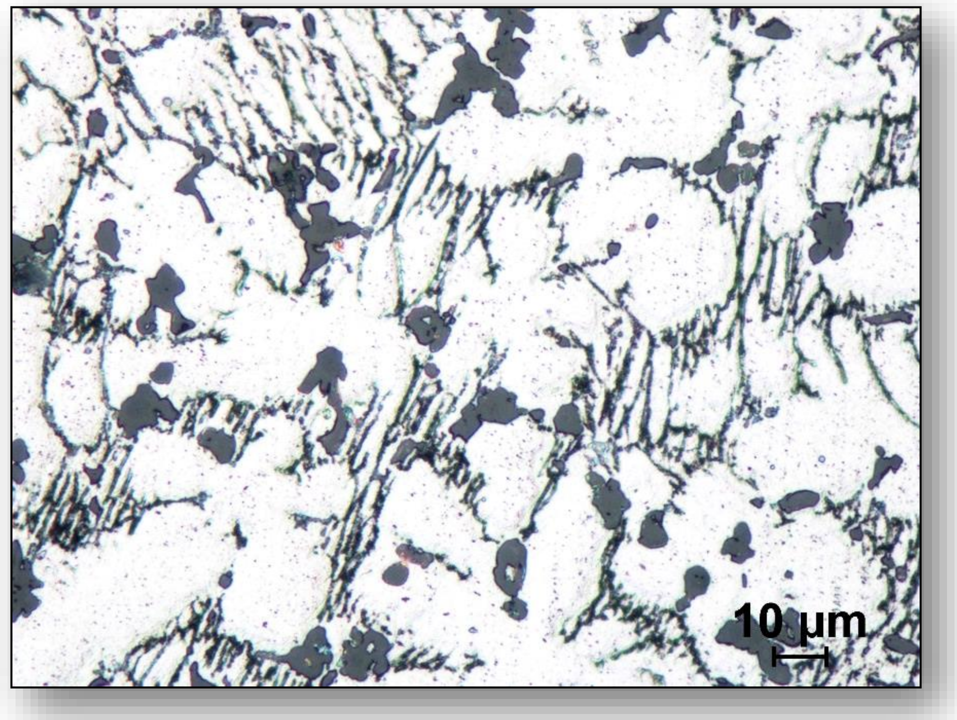
Crucible materials			Elements content, mas. %	
			O	Rest
Bulk crucible	1	Al_2O_3	8.9	Al: 8
	2	MgO	0.69	Mg: 0.26
	3	$ZrO_2 \cdot Y_2O_3$	1.1	Zr: 19.1, Y: 0.13
	4	$ZrO_2 \cdot Al_2O_3 \cdot Y_2O_3$	5.9	Zr: 9.2, Al: 1.66, Y: 0.038
	5	$ZrO_2 \cdot MgO$	1.2	Zr: 0.93, Mg: 0.001
	6	$ZrO_2 \cdot TiO_2$	0.3	Zr: 0.06, Y: 0.001, N: 0.7
	7	$ZrO_2 \cdot MgF_2$	0.16	Zr: 0.036, Mg: 0.001
	8	ZrO_2·Foskor	0.3	Zr: 0.004, Y: 0.001, N: 0.7
	9	$ZrO_2 \cdot HfO_2 \cdot MgO$	29.5	Zr: 18.06, Mg: 0.026
	10	$ZrO_2 \cdot HfO_2 \cdot CeO_2$	Intensive reaction during melting	
	11	$Y_2O_3 \cdot ZrO_2$	1.1	Y: 0.013, Zr: 0.3
	12	CaO	2.0	Ca: 0.005
	13	$CaO \cdot TiO_2$	0.35	Ca: 0.005
	14	$CaO \cdot CaF_2$	0.29	Ca: 0.005
	15	BN(1)	0.08	N: 0.05
	16	BN(2)	0.27	N: 0.02
	17	BN(3)	1.75	N: 0.05
	18	$BN \cdot ZrO_2$	0.3	N:0.4
	19	Graphite(1)	0.45	C: 1,53
	20	Graphite(2)	0.32	C: 1.44
	21	Graphite(3)	0.30	C: 1.88
	22	Graphite(4)	0.25	C: 1.87
	23	Graphite(5)	0.22	C:2.23
	24	Isostatic graphite(1)	0.92	C: 1.84
	25	Isostatic graphite(2)	0.37	C: 1.47
	26	Isostatic graphite(3)	0.29	C: 1.7
	27	Isostatic graphite(4)	0.17	C: 1.61
	28	Isostatic graphite(5)	0.39	C: 2.67

Before | After









Szkliniarz A., Szkliniarz W., Mikuszewski T.: Ocena możliwości topienia czystego tytanu w litych tyglach ceramicznych. Archiwum Technologii Maszyn i Automatyzacji 1 (2011) 27-35.

Effect of Ti-6Al-4V melting in a crucible by VIM

Table 1. Chemical composition of alloy Ti-6Al-4V melted in a crucible in induction furnaces.

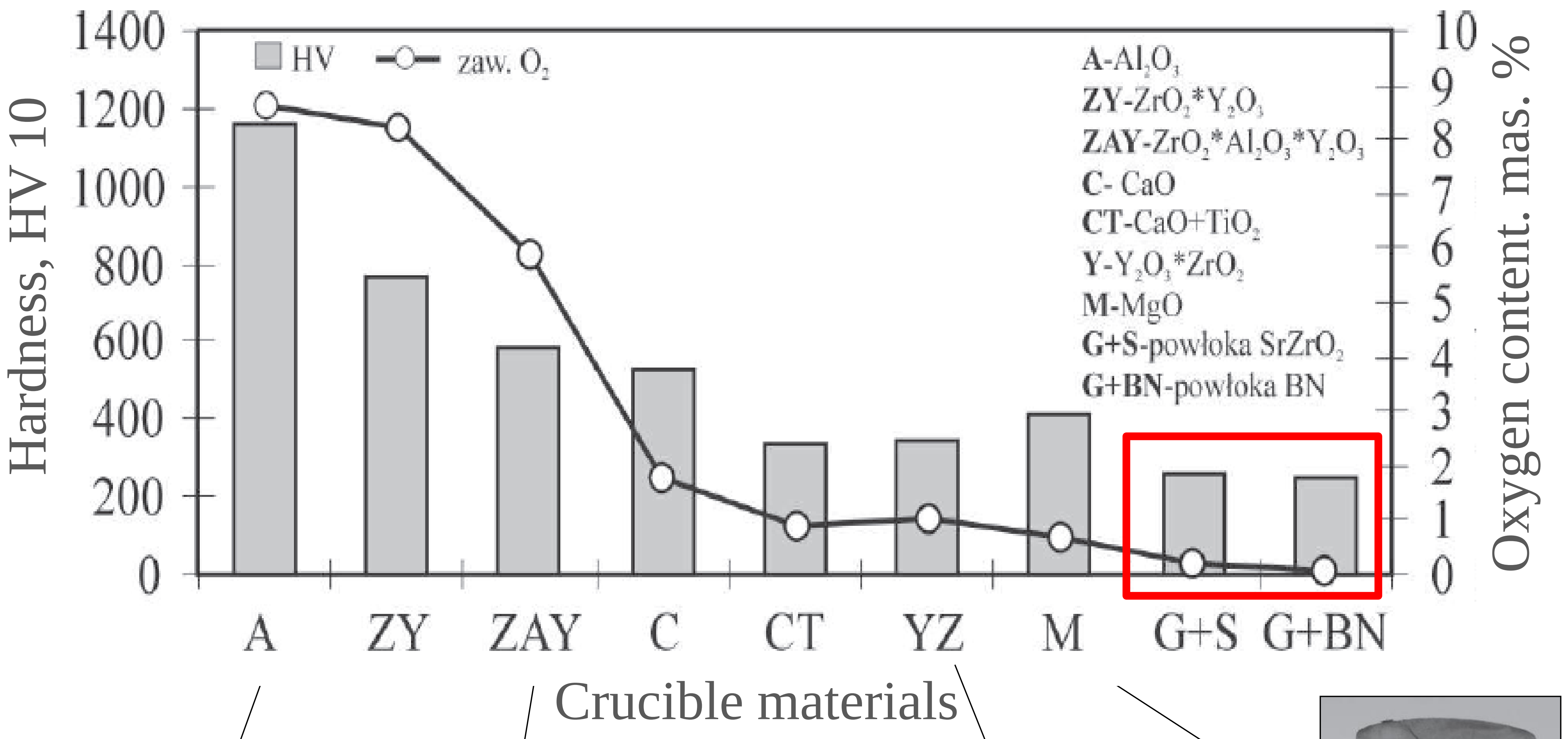
Crucible material			Elemental content, [wt.%]			
			O	Al	V	Remainder
Solid crucibles	1	Cu (cold crucible)	0.12	6.11	3. 89	C: 0.026
	2	W	0.25	5.94	3.99	W: 27.20
	3	Mo	0.30	5.98	3.27	Mo: 34.90
	4	Ta	0.25	6.08	3.77	Ta: 53.60
	5	BN·ZrO_2	0.55	5.51	3.86	Zr: 0.76; N: 0.55
	6	Isostatic graphite (1)	0.15	5.81	3.87	C: 1.48
	7	Isostatic graphite (2)	0.15	5.92	4.10	C: 0.71
Plasma-sprayed coatings	8	SiC + $SrZrO_3$ (1)	0.82	5.61	3.78	C: 0.63; Zr: 0.81
	9	SiC + $SrZrO_3$ (2)	0.32	5.44	3.78	C: 0.76; Zr: 0.14
	10	SiC + $SrZrO_3$ (3)	0.29	5.90	3.92	C: 0.74; Zr: 0.03
	11	SiC + ZrO_2·24MgO (1)	0.80	5.97	4.30	C: 0.26; Zr: 1.30; Mg: 0.02
	12	SiC + ZrO_2·24MgO (2)	1.10	5.77	4.19	C: 0.35; Zr: 1.57; Mg: 0.02
	13	SiC + ZrO_2·8Y_2O_3 (1)	0.60	5.72	3.97	C: 0.16; Zr: 1.19; Y: 0.015
	14	SiC + ZrO_2·8Y_2O_3 (2)	0.76	5.67	3.94	C: 0.35; Zr: 1.53; Y: 0.033
	15	SiC + ZrO_2·20Y_2O_3 (1)	0.66	5.80	4.02	C: 0.26; Zr: 0.94; Y: 0.042
	16	SiC + ZrO_2·20Y_2O_3 (2)	0.86	5.66	4.02	C: 0.35; Zr: 1.10; Y: 0.051
	17	SiC + ZrO_2·25CeO·10Y_2O_3 (1)	0.77	5.73	4.30	C: 0.10; Zr: 1.37; Y: 0.023
	18	SiC + ZrO_2·25CeO·10Y_2O_3 (2)	0.90	5.40	3.70	C: 0.29; Zr: 1.47, Y: 0.028
	19	SiC + ZrO_2·5CaO·0.5Al_2O_3·0.4SiO_2 (1)	0.70	6.54	3.79	C: 0.29; Zr: 1.26; Ca: 0.072
	20	SiC + ZrO_2·5CaO·0.5Al_2O_3·0.4SiO_2 (2)	1.00	6.12	3.65	C: 0.34; Zr: 1.87; Ca: 0.079
Manually applied coatings	21	Isostatic graphite + Y_2O_3 + BN + BN (1)	0.12	6.14	3.72	C: 0.74; N: 0.03
	22	Isostatic graphite + Y_2O_3 + BN + BN (2)	0.13	6.07	3.68	C: 0.71; N: 0.02
	23	Isostatic graphite + $SrZrO_3$ (1)	0.24	5.66	3.90	C: 0.82; Zr: 0.05; Sr < 0.001
	24	Isostatic graphite + $SrZrO_3$ (2)	0.23	5.86	3.81	C: 0.83; Zr: 0.02; Sr < 0.001
	25	SiC + $SrZrO_3$ (1)	0.15	5.80	3.80	C: 0.26; Zr: 0.04; Sr < 0.002
	26	SiC + $SrZrO_3$ (2)	0.16	5.70	3.63	C: 0.44; Zr: 0.014; Sr < 0.002
	27	SiC + $SrZrO_3$ + BN (1)	0.23	5.95	3.63	C: 0.33; Zr: 0.18; Sr < 0.002; N: 0.53
	28	SiC + $SrZrO_3$ + BN (2)	0.20	5.70	2.77	C: 0.59; Zr: 0.04; Sr < 0.002; N: 0.60
	29	SiC + MgO + BN	0.70	5.76	3.83	C: 0.42; Mg: 0.11; N: 0.70
	30	SiC + ZrO_2 + BN	0.34	5.75	3.65	C: 0.34; Zr: 0.47; N: 0.40
	31	SiC + Y_2O_3 + BN	0.25	5.66	3.96	C: 0.25; Y: 0.05; N: 0.28
	32	SiC + BN + Y_2O_3	0.20	5.78	3.89	C: 0.63; N: 0.61; Y: 0.007
	33	SiC + Y_2O_3 + BN + CaF_2 (1)	0.28	6.05	3.61	C: 0.20; N: 0.29
	34	SiC + Y_2O_3 + BN + CaF_2 (2)	0.29	6.08	3.64	C: 0.42; N: 0.69
	35	SiC + Y_2O_3 + BN + Y_2O_3 (1)	0.32	5.72	3.41	C: 0.27; N: 0.56
	36	SiC + Y_2O_3 + BN + Y_2O_3 (2)	0.25	6.06	3.50	C: 0.39; N: 0.41
	37	SiC + CaF_2 + ZrO_2 + BN	0.17	5.60	3.91	C: 0.22; Zr: 0.01; Ca: 0.001; N: 0.32
	38	SiC + CaF_2 + BN + Y_2O_3 + BN (1)	0.29	5.97	3.71	C: 0.28; N: 0.53
	39	SiC + CaF_2 + BN + Y_2O_3 + BN (2)	0.22	6.01	3.07	C: 0.40; N: 0.58

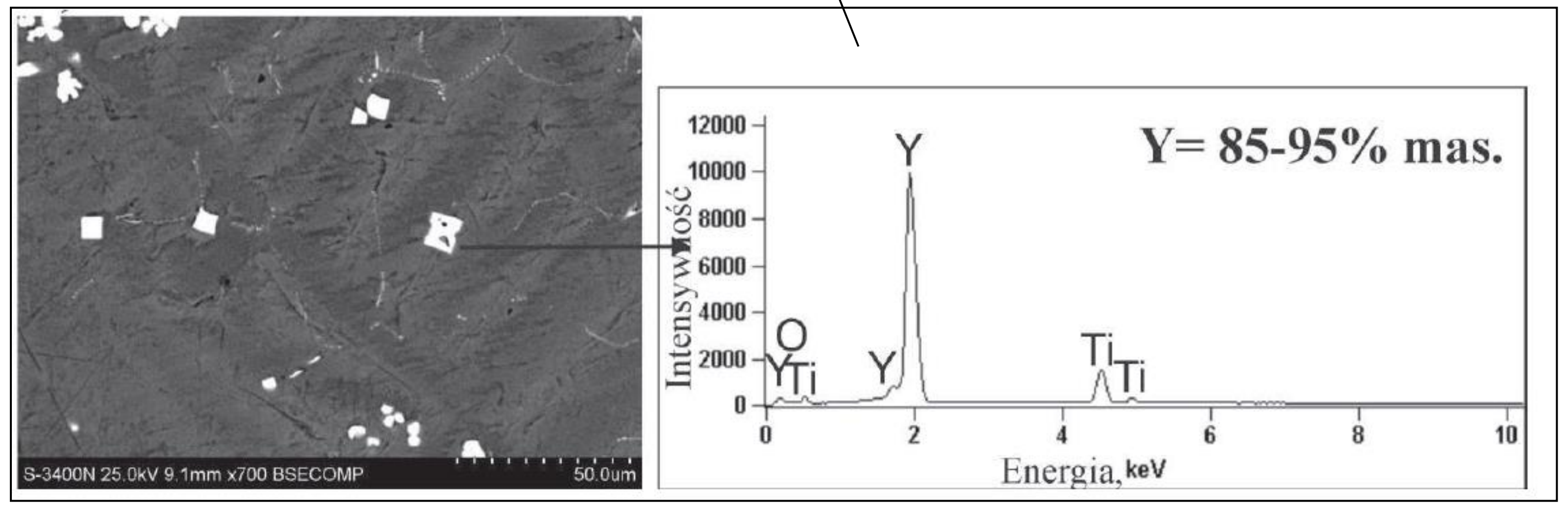
(1), (2) and (3)–adequately first, second and third melt in crucible

Szkliniarz A.. Szkliniarz W.: Assessment quality of Ti alloys melted in induction furnace with ceramic crucible. Solid State Phenomena 176 (2011) 139-148. DOI:10.4028/www.scientific.net/SSP.176.139.

Effect of titanium and titanium alloys melting in ceramic crucible

Ti



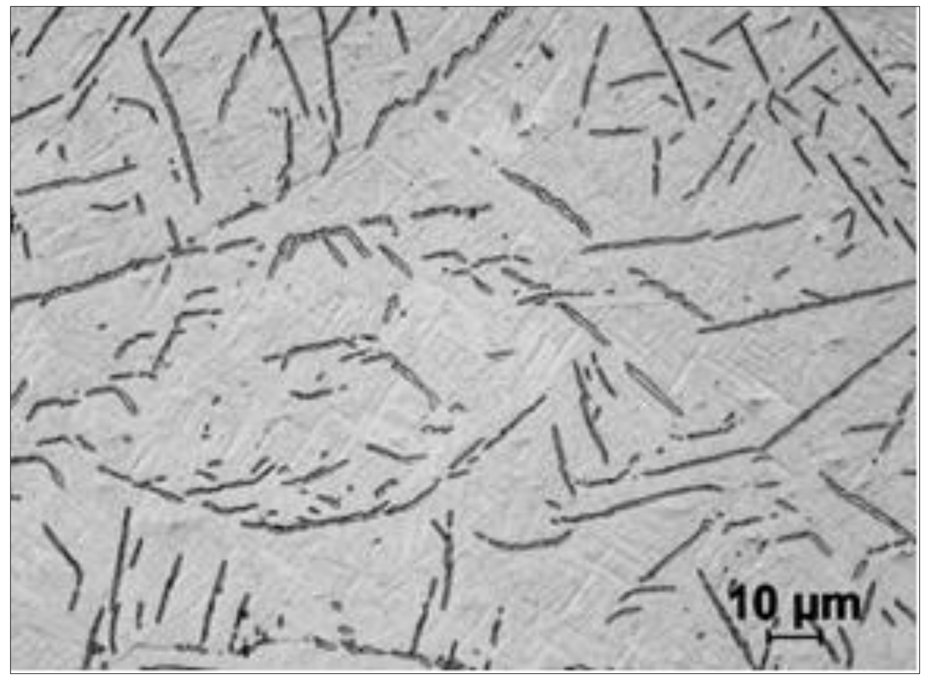


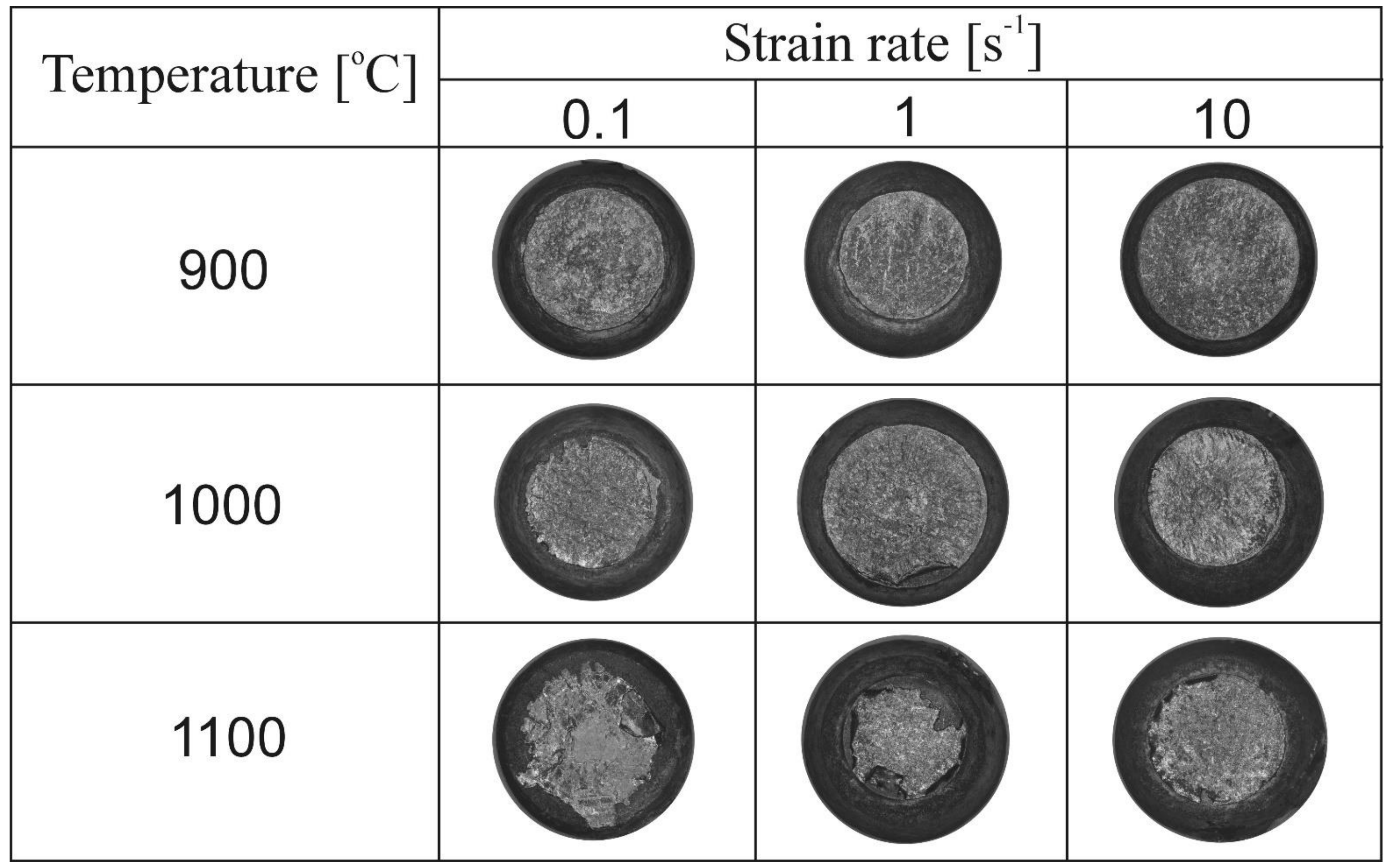
Ti-6Al-4V

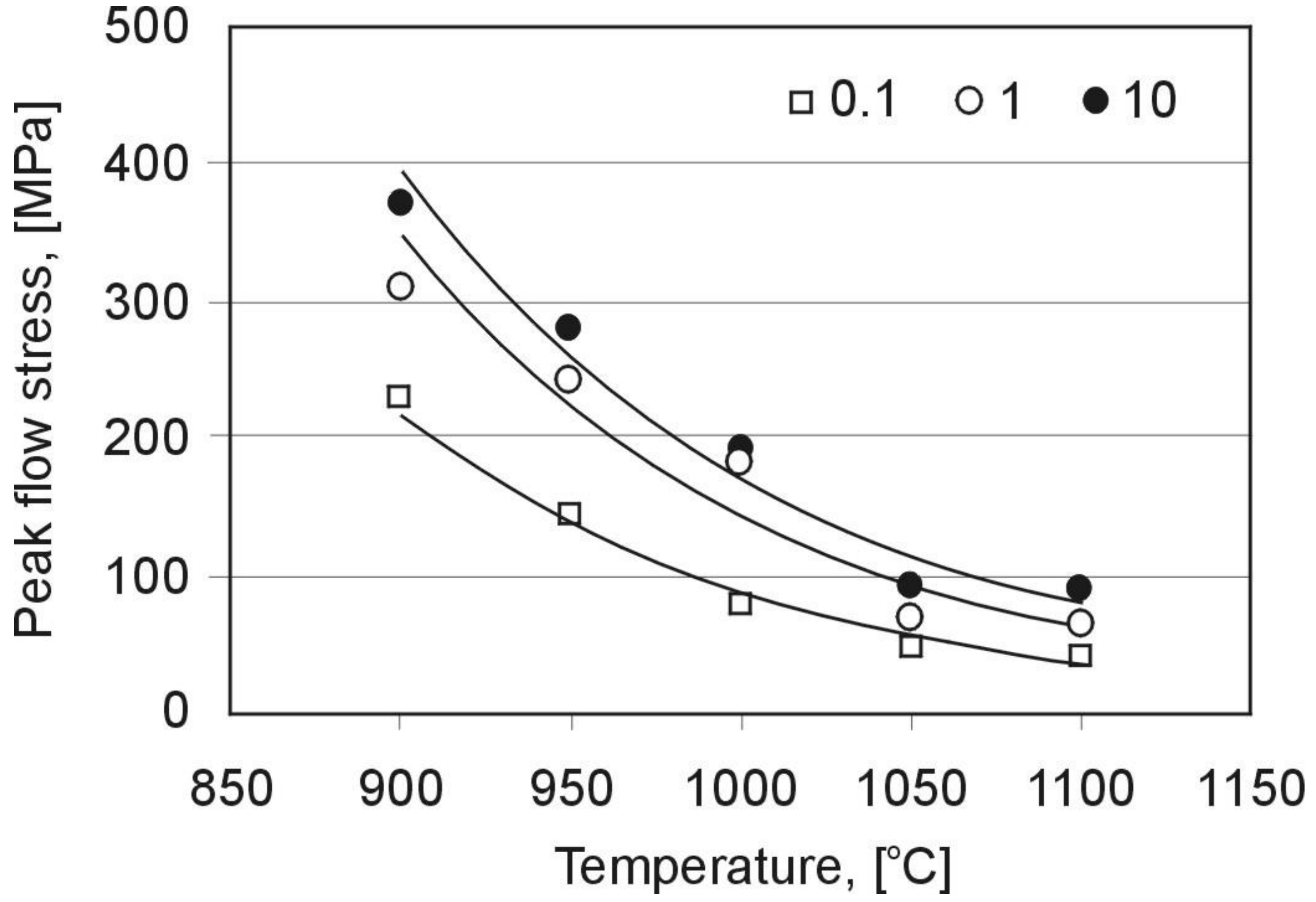
Crucible materials	Element content. mas. %			
	Oxygen	Al	V	Rest
Cu (cold crucible)	0.12	6.11	3.89	C: 0.002
SiC+$SrZrO_3$	0.22	5.80	3.63	C: 0.26
SiC+Y_2O_3+BN+CaF_2	0.16	5.78	3.89	C: 0.27
Graphite+$SrZrO_3$	0.20	5.86	3.81	C: 0.68
Isostatic pressed graphite+Y_2O_3+BN+BN	0.13	6.07	3.68	C: 0.71; N: 0.02
Isostatic pressed graphite+$SrZrO_3$	0.19	5.89	3.95	C: 0.71

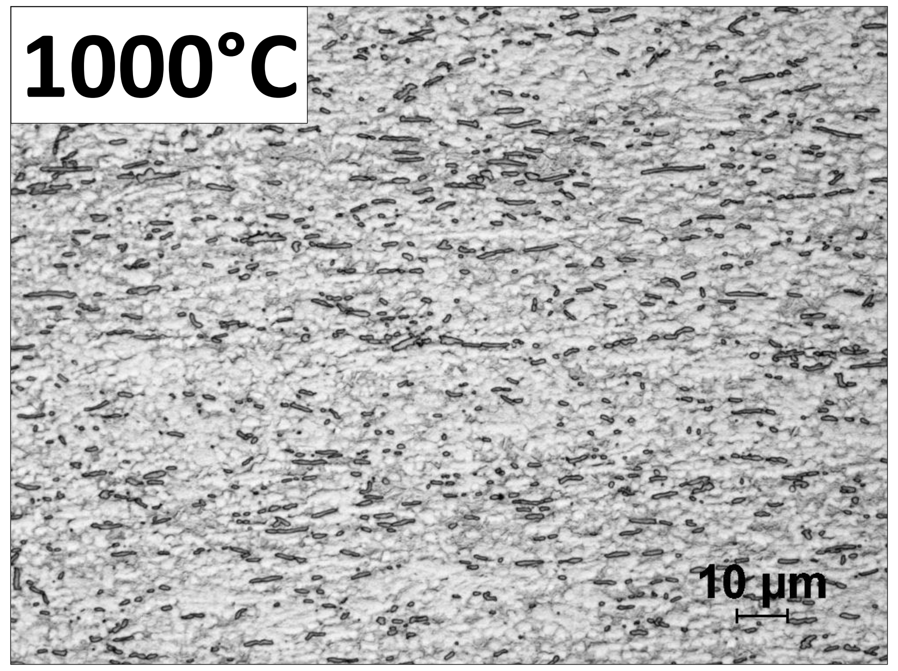
Is it possible to deform?

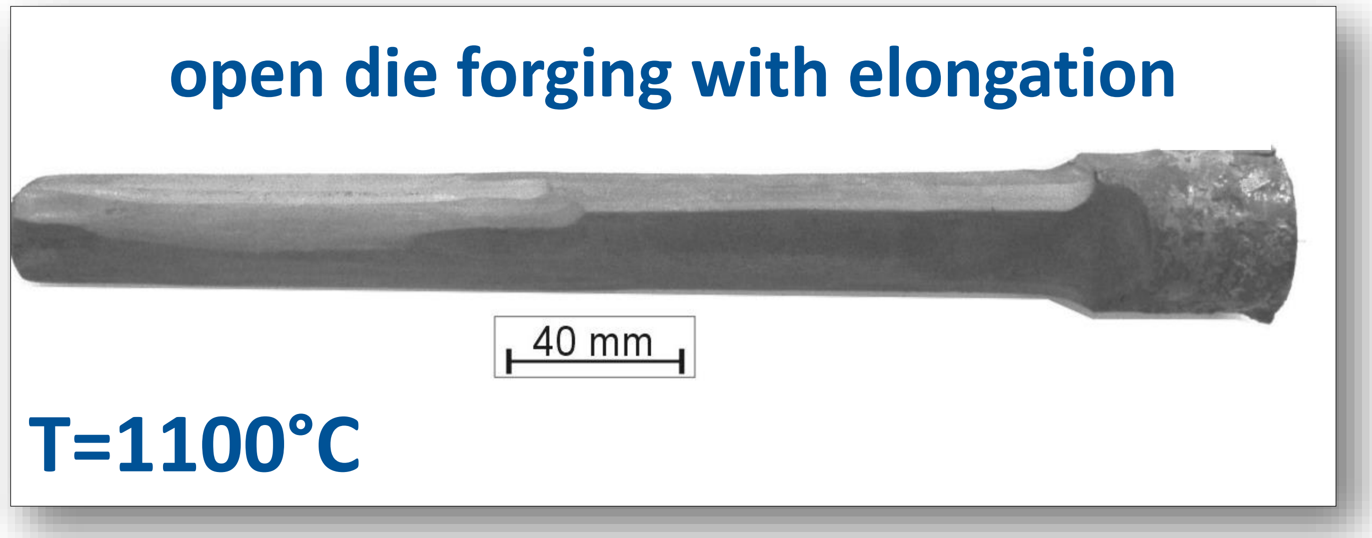
Deformation of titanium alloys with higher carbon content

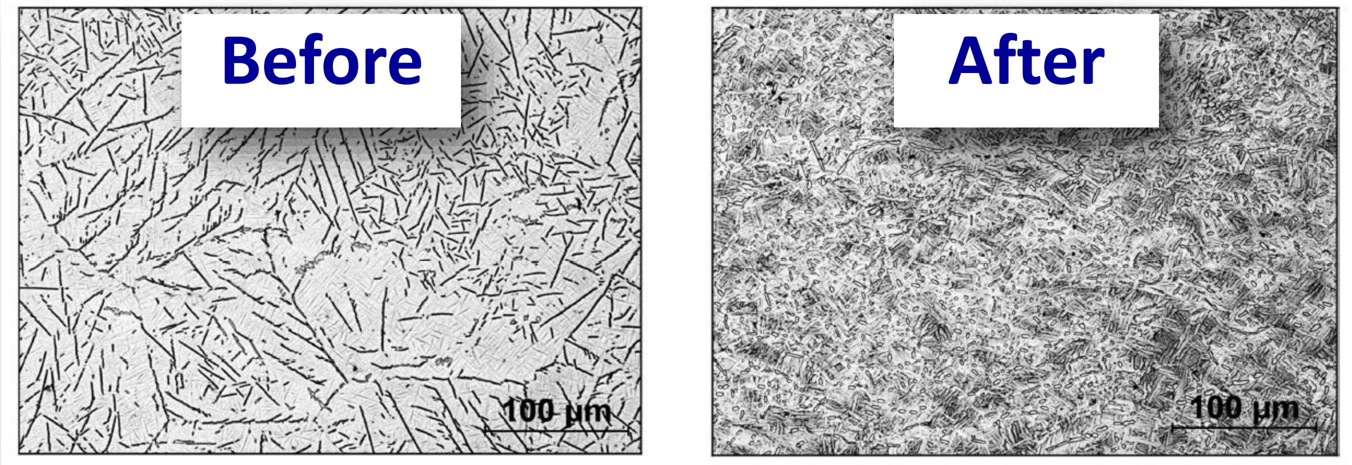


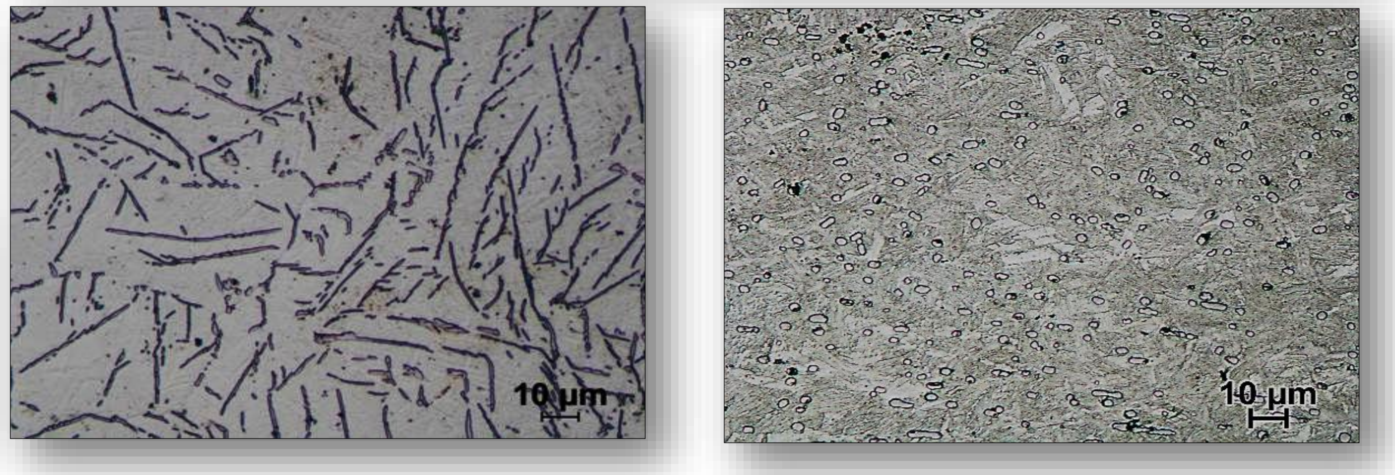












Alloy melted in	$A_{450°C}$ %	$RA_{450°C}$ %
	10.6	24
	19.7	40

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Szkliniarz A.: Deformation of Ti-6Al-4V alloy with carbon. Solid State Phenomena 176 (2011) 149-156.
DOI: 10.4028/www.scientific.net/SSP.176.149

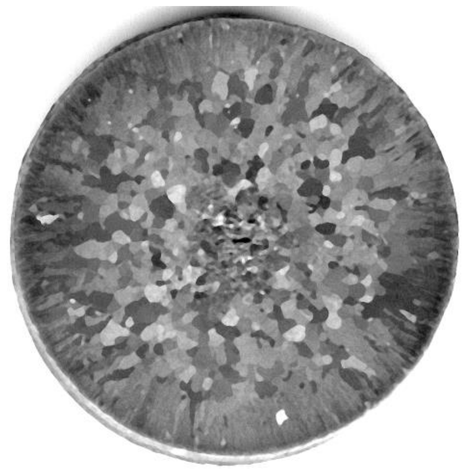
3. TITANIUM ALUMINIDES MELTED IN GRAPHITE CRUCIBLES

Titanium aluminides melted in special graphite crucibles

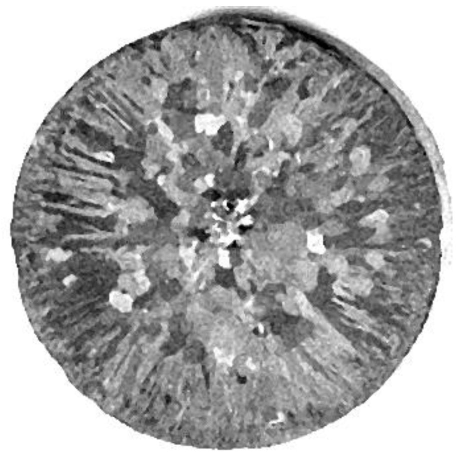
Second generations of TiAl based alloys:

Ti-47Al-2W-0.5Si

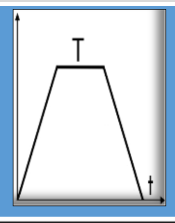
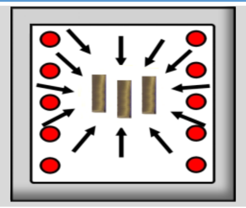
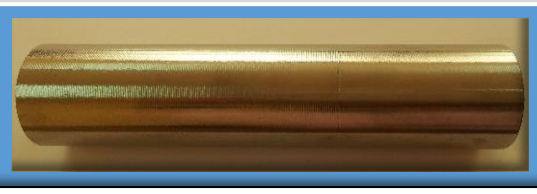
Ti-45Al-8Nb-0.5 (B. C)



Ti-45Al-5Nb-2Cr-1Mo-0.5(B.C)-0.2 Si)



Ti-45Al-8Nb-0,5(B, C) alloy

1.	Preparation of a casting moulds		Graphite
2.	Preparation of crucible		Isostically pressed graphite – 2.0 l
3.	Preparation of feedstock		Al-16Nb + Ti (Grade 2) + C + B
4.	Melting		1650°C/3 min.
5.	Casting to ingot form		Φ55×400 mm 4 kg
6.	Risers removed		
7.	Homogenization		1350°C/1h/furnace cooling
8	Hot isostatic pressing		1260°C/170 MPa/4h
9.	Ingot pre-machined (skinning)		

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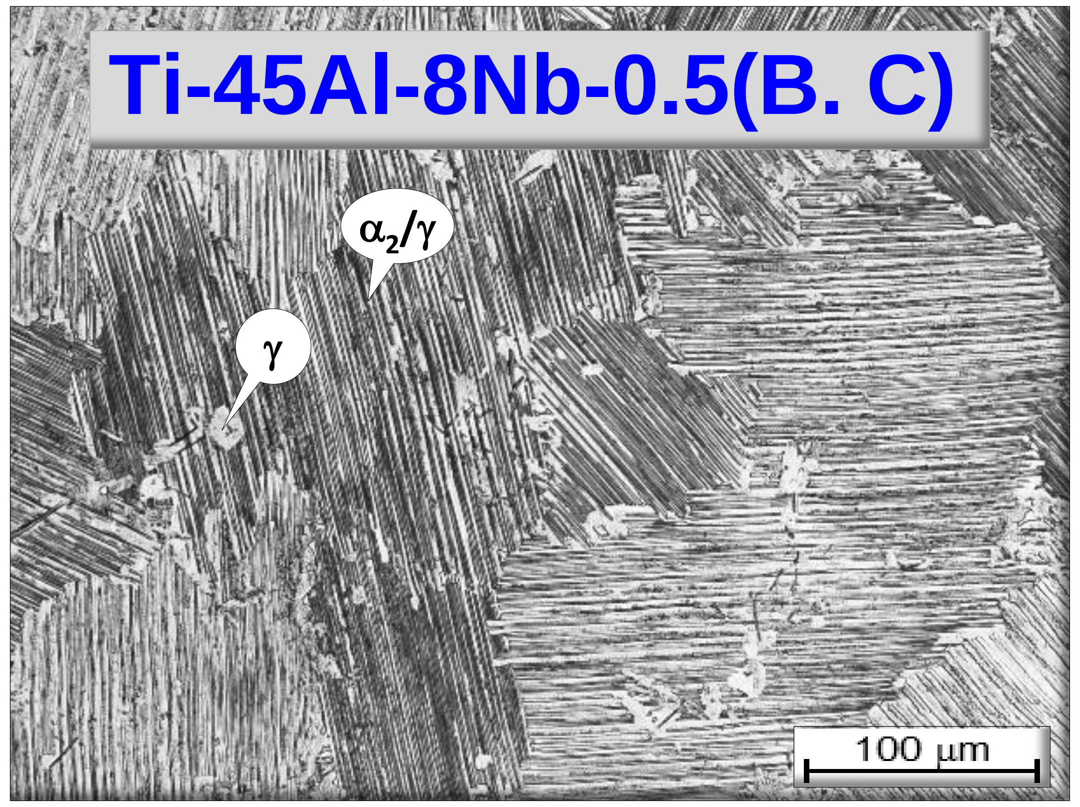
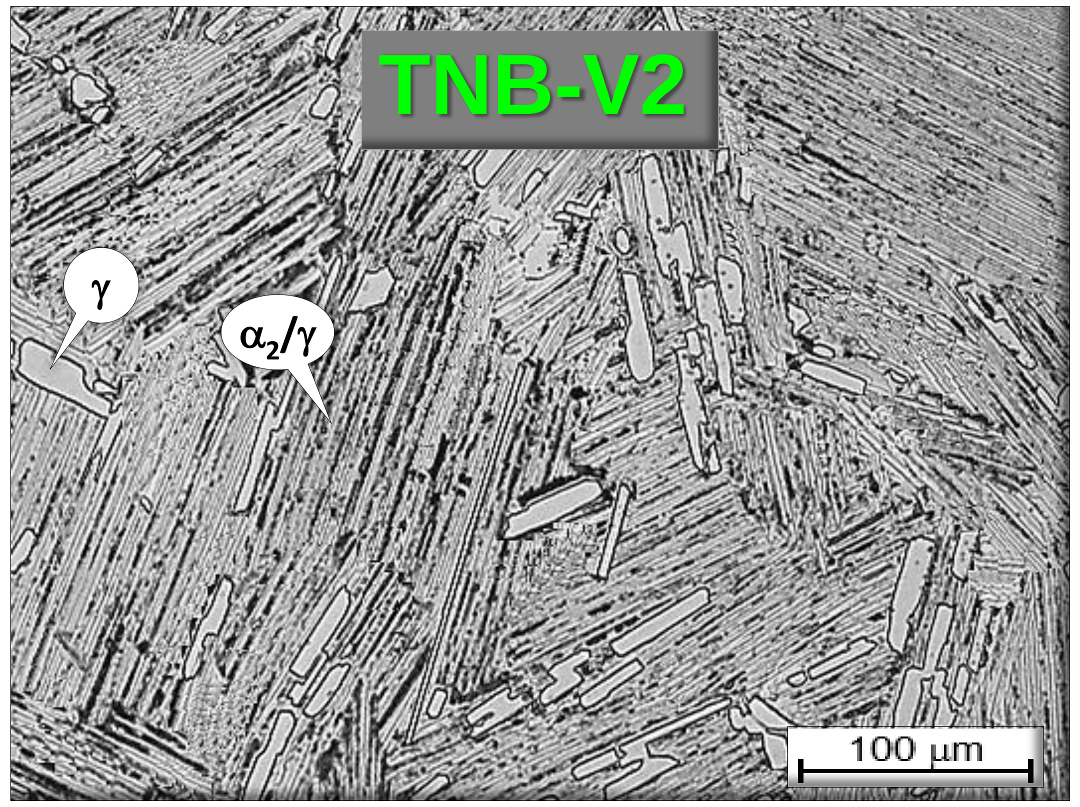
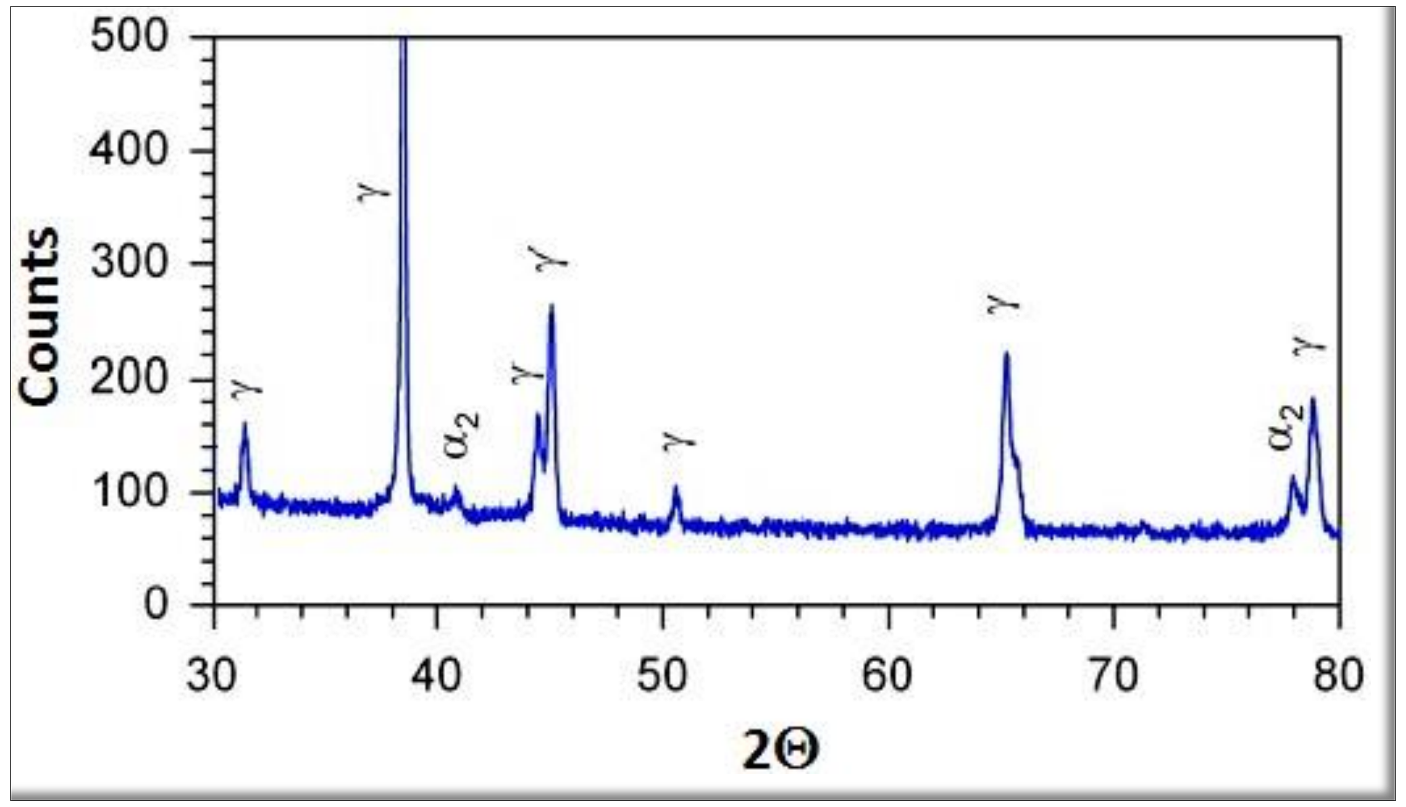
Szkliniarz W.. Szkliniarz A.: The characteristics of TiAl-based alloys melted in graphite crucibles. Materials Science and Technology. (2019) DOI: 10.1080/02670836.2017.1413036
Szkliniarz W.. Szkliniarz A.: Microstructure and properties of TiAl-based alloys melted in graphite crucible. Metals. (2021) DOI: 10.3390/met11040669

Titanium aluminides melted in special graphite crucibles

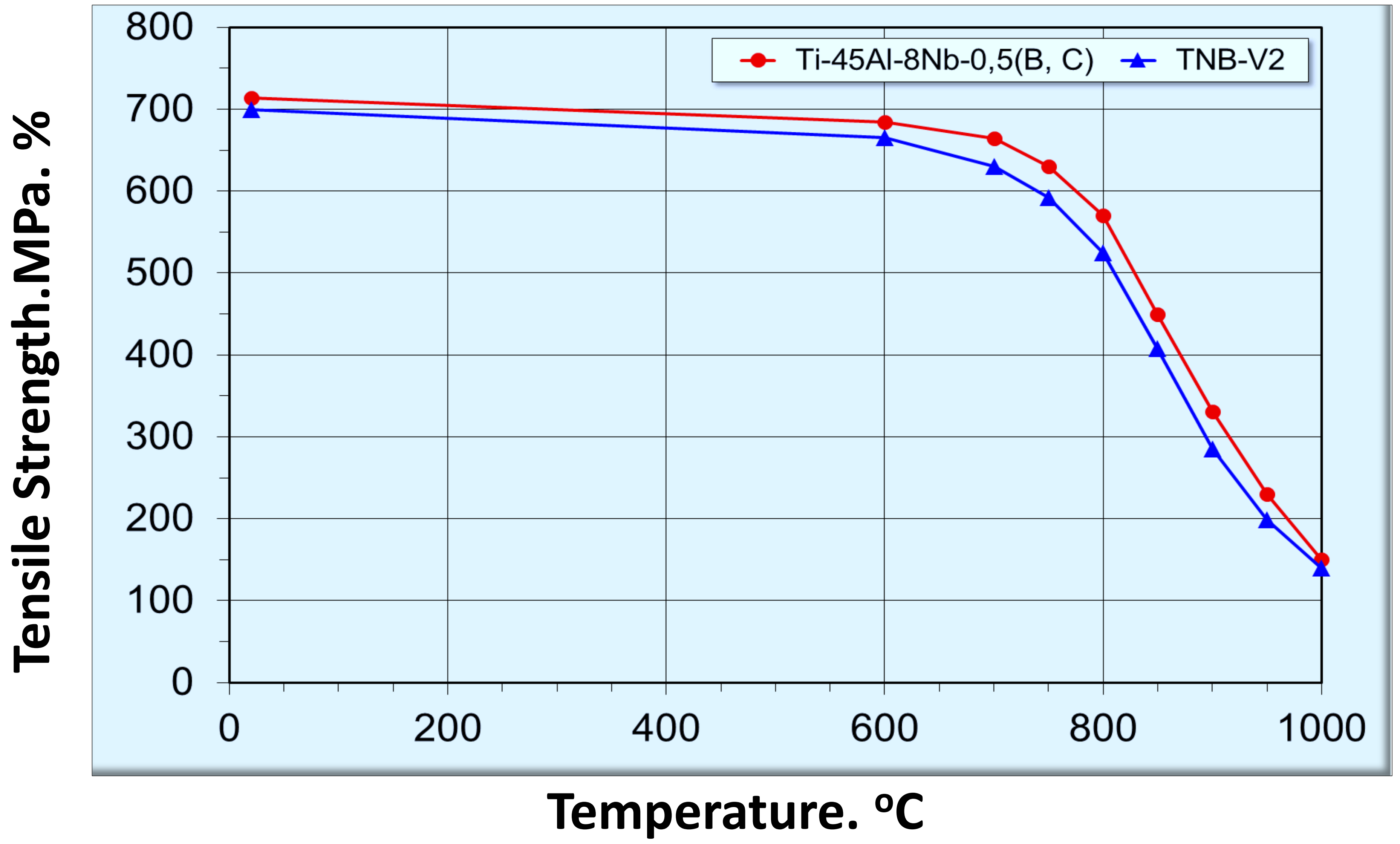
Element	Al	Nb	C	B	O	N	H	Ti
Alloy	at.%				ppm			at.%
Ti-45Al-8Nb-0.5(B. C)	44.25	7.34	0.34	0.15	935	96	17	Rest
TNB-V2	45.40	8.10	0.20	0.20	800	100	30	

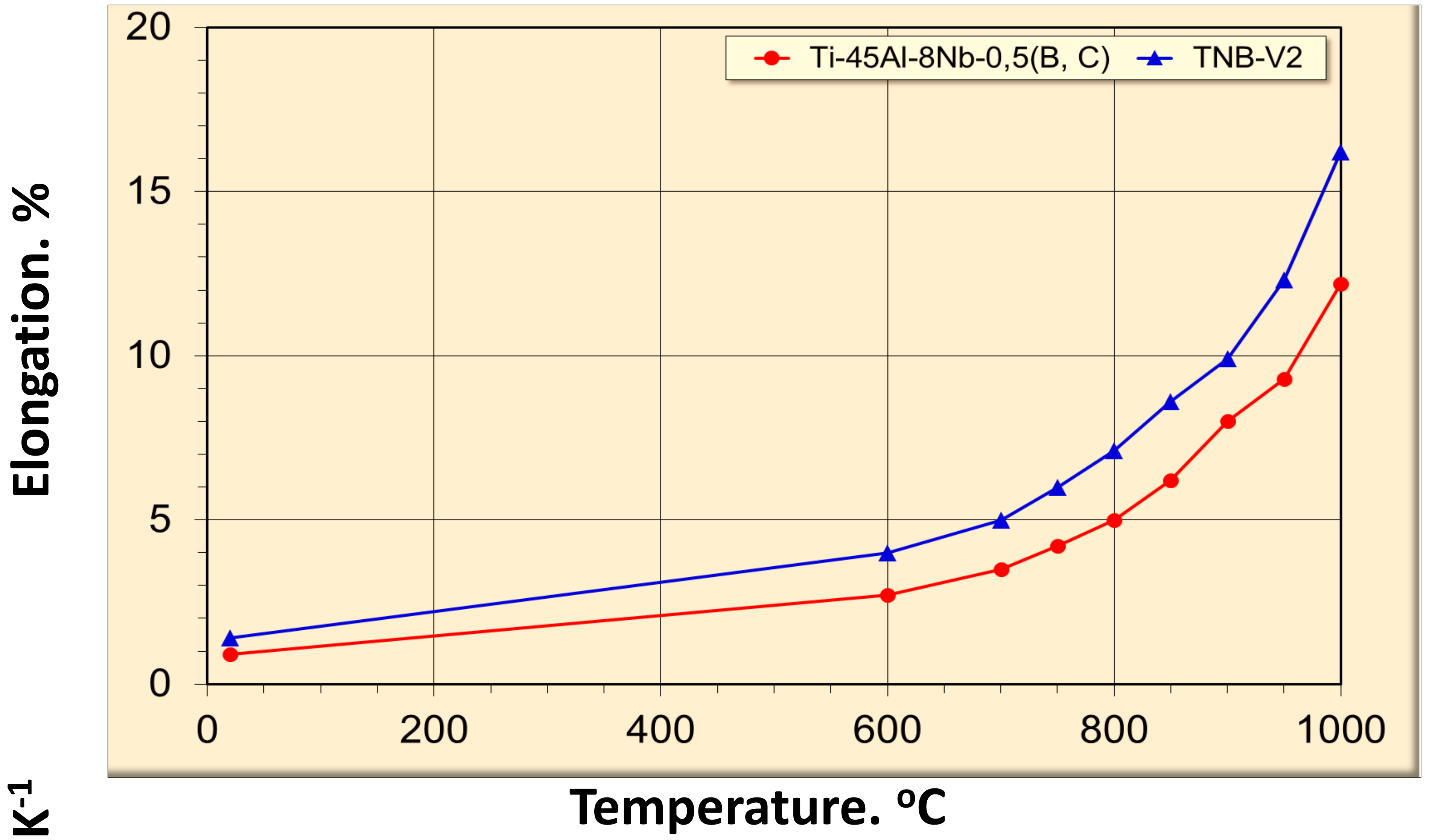


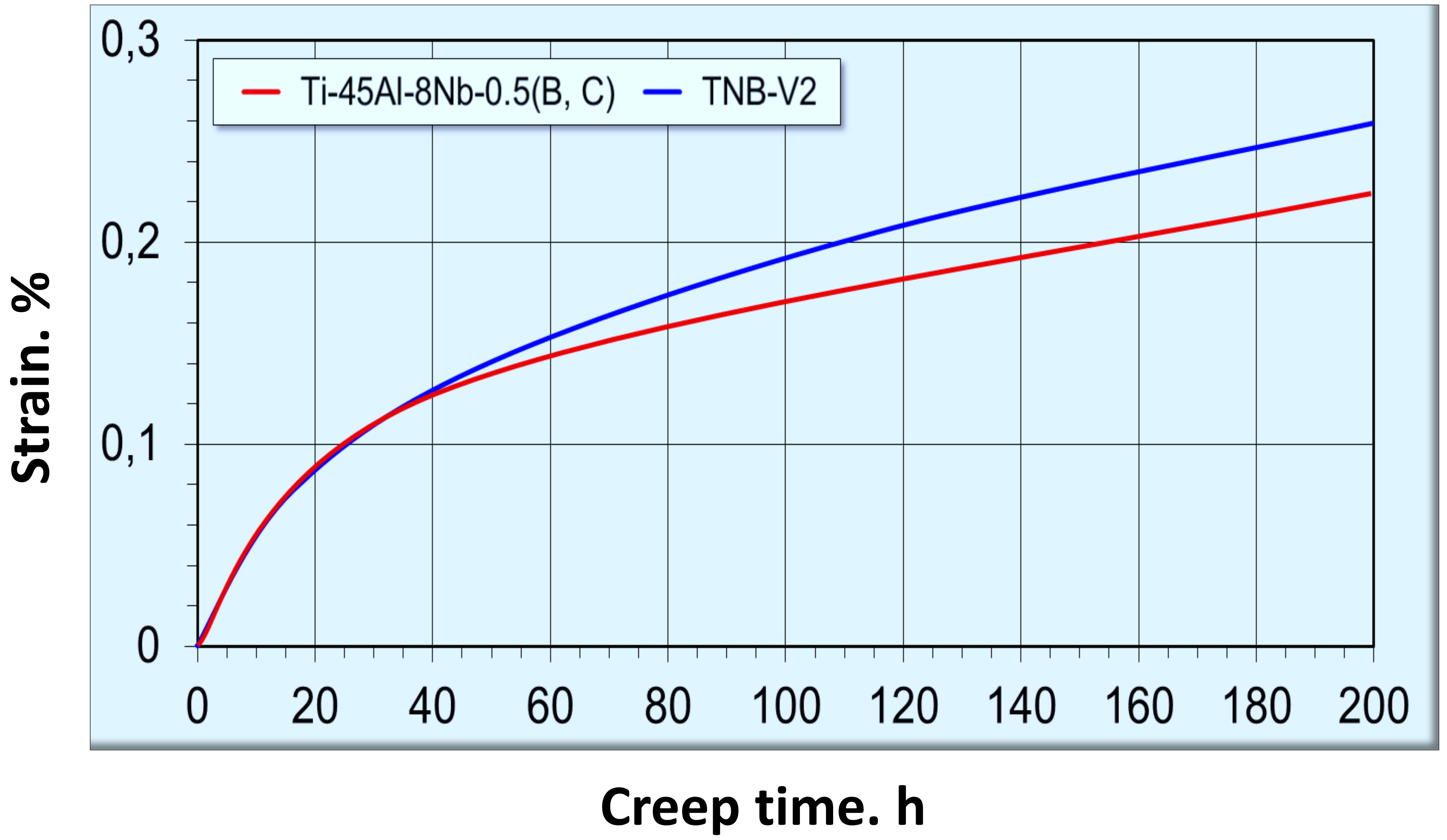


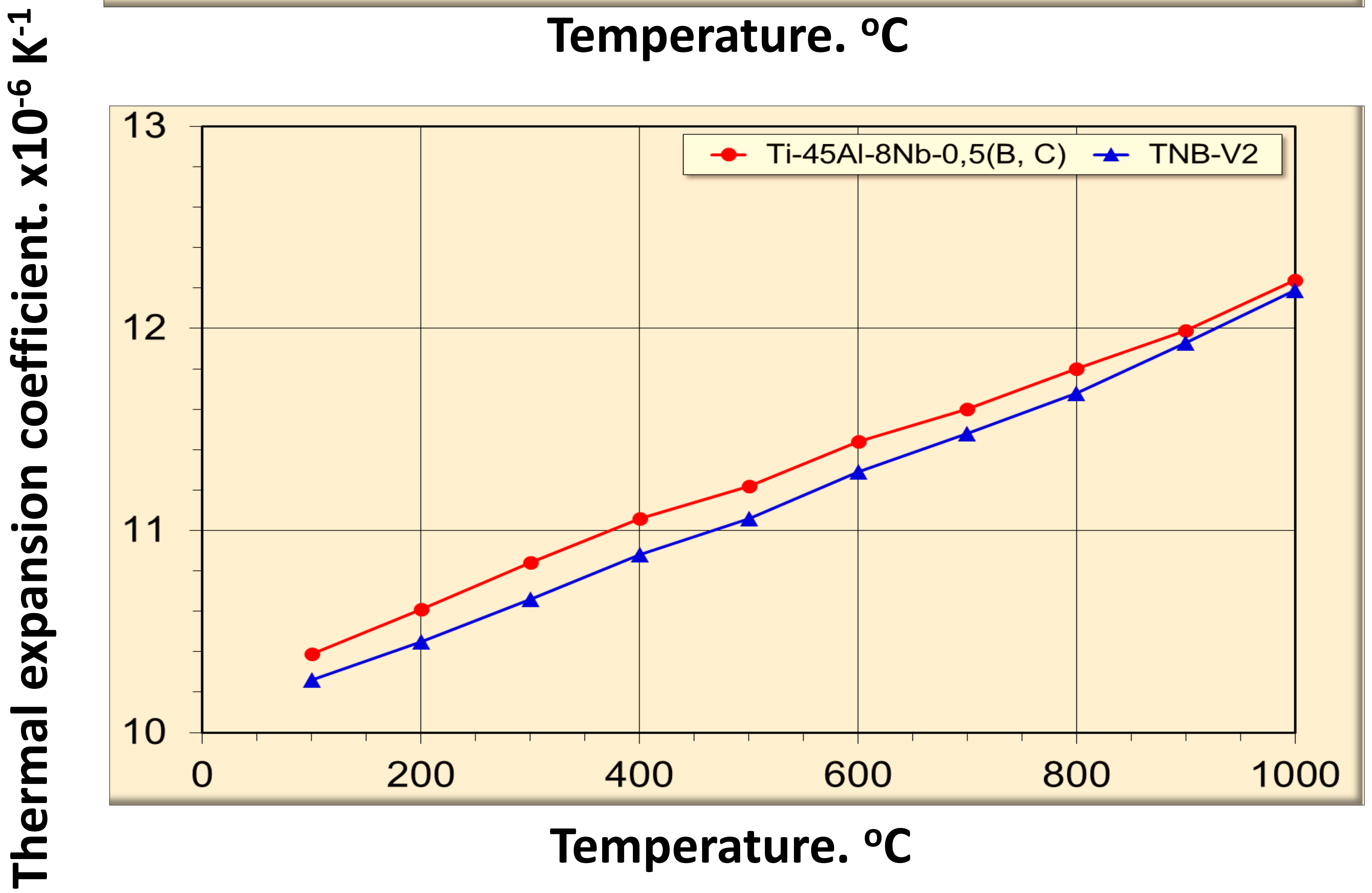


Properties of Ti-45Al-8Nb-0.5(B. C) – SUMMARY









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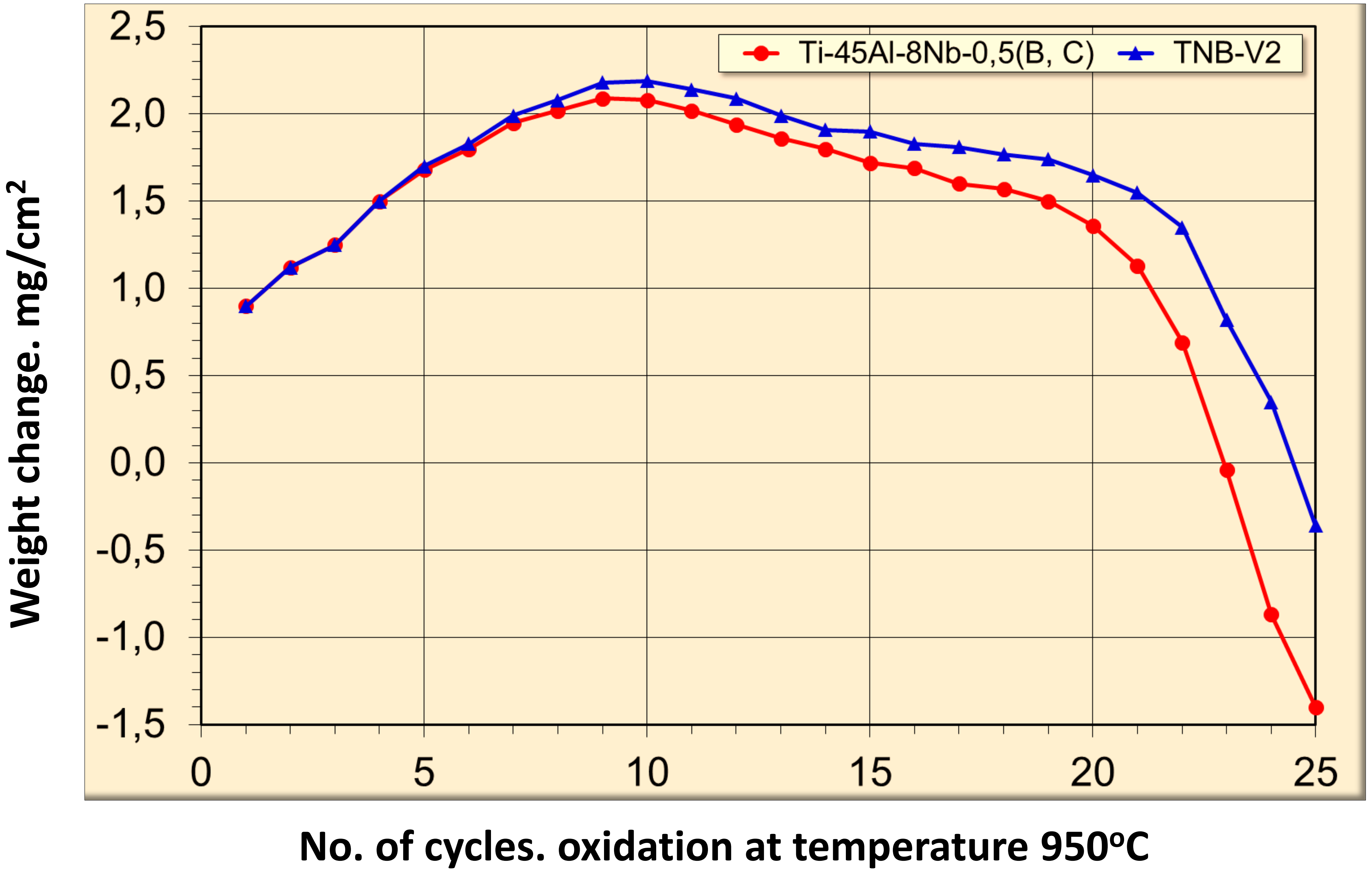
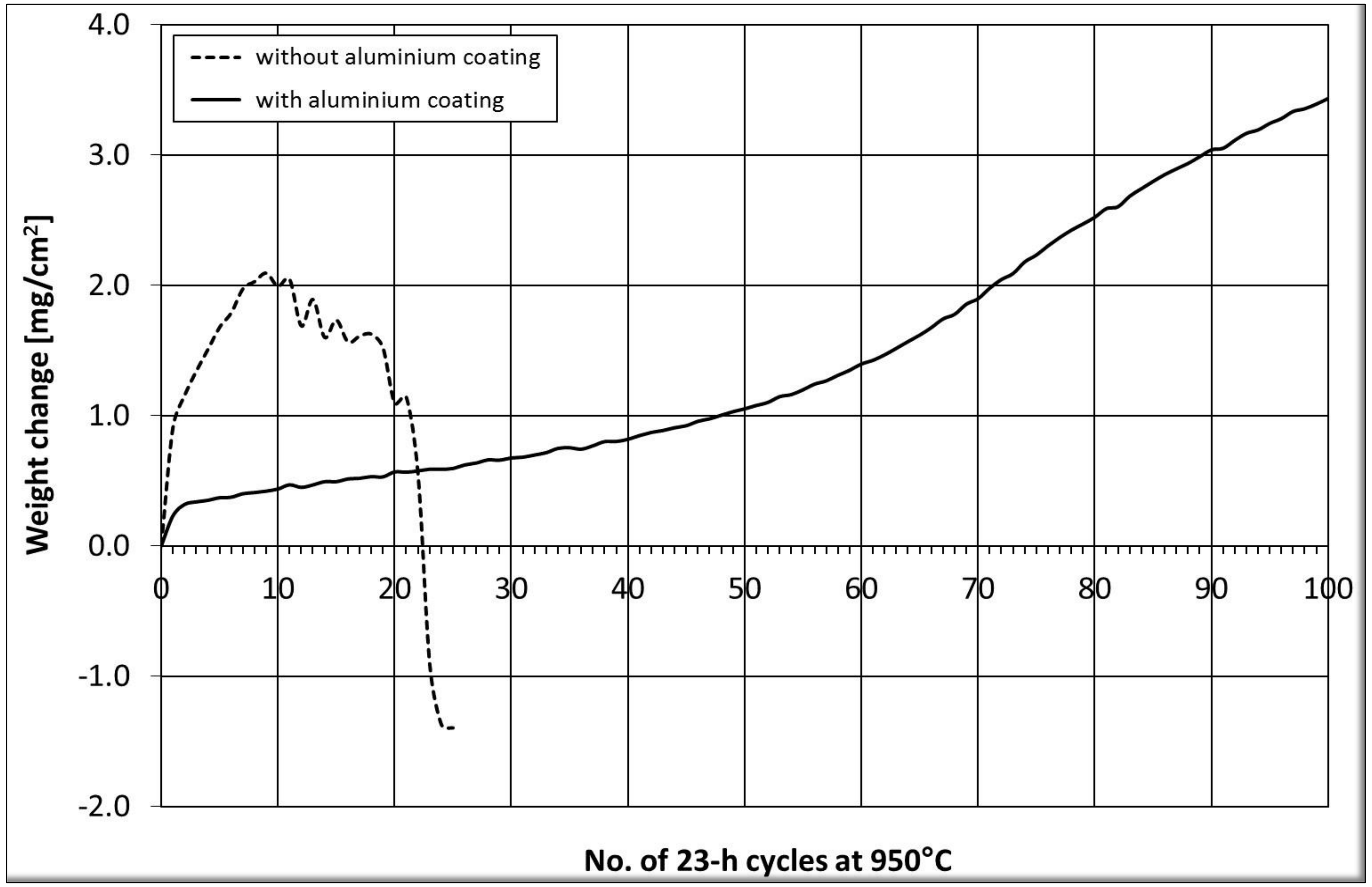
Properties of Ti-45Al-8Nb-0.5(B. C) – SUMMARY





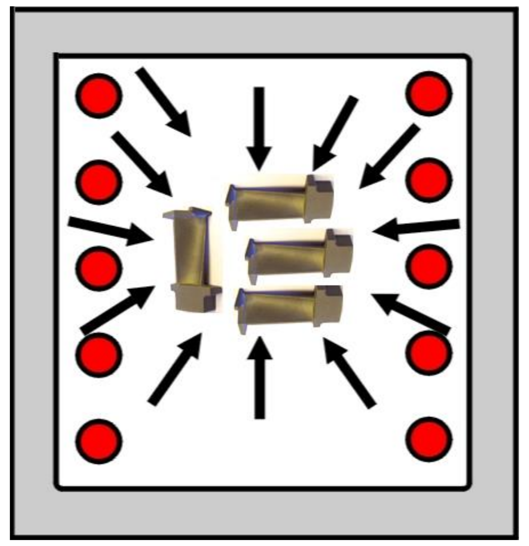
Alloy	λ	UTS	YS	EL	E	Creep resistance	Oxidation resistance
Ti-45Al-8Nb-0.5(B, C)							
TNB-V2							

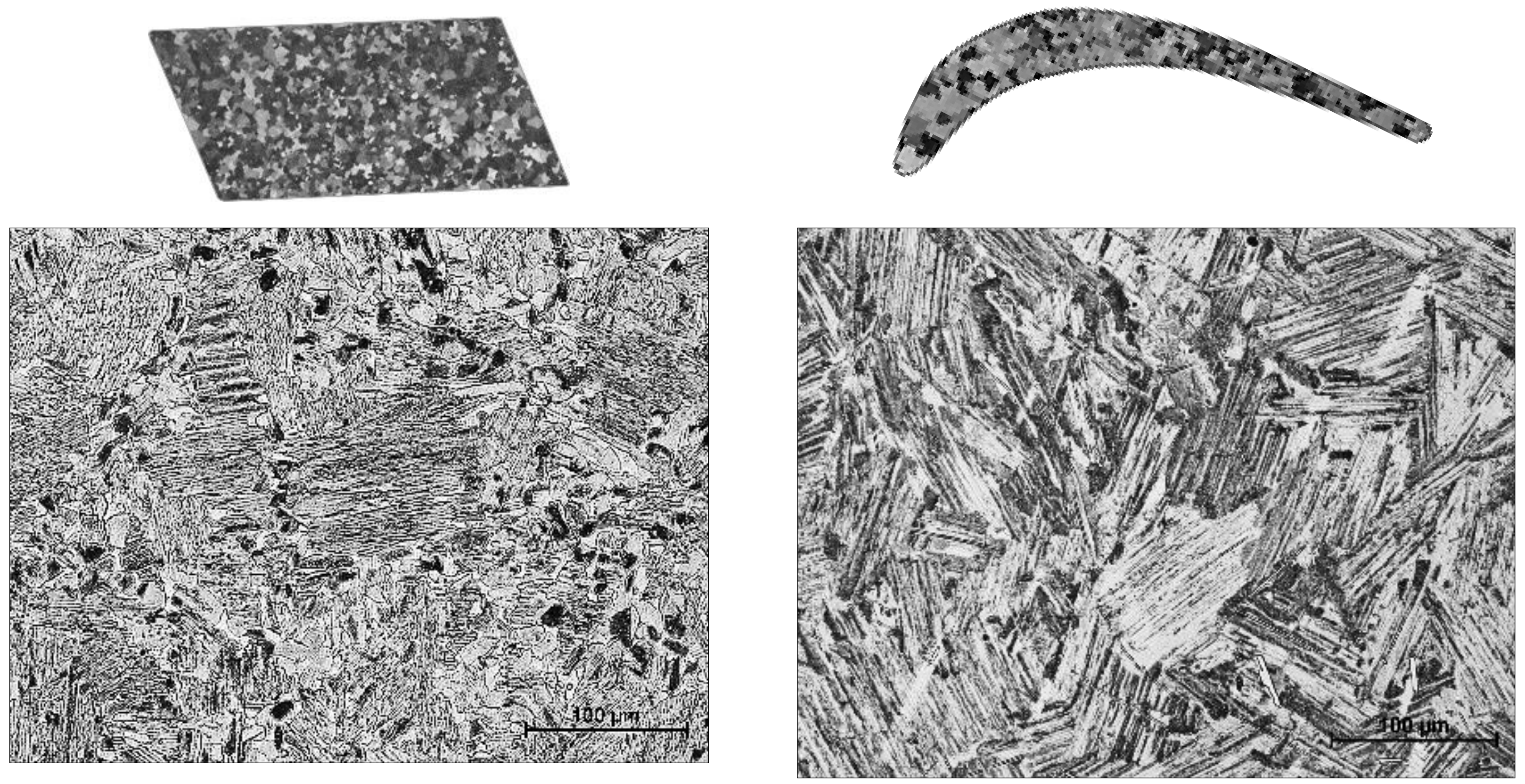
Szkliniarz W.. Moskal G.. Szkliniarz A.. Swadźba R.: The influence of aluminizing process on the surface condition and oxidation resistance of Ti-45Al-8Nb-0.5(B. C) alloy. Coatings 8 (2018) 1-12. DOI: 10.3390/coatings8030113

Manufacturing of blades (Ti-47Al-2W-0.5Si alloy)

Preparation of ceramic shell mould → **Alloy production** → **Melting and casting** → **Final treatment**

Hot isostatic pressing





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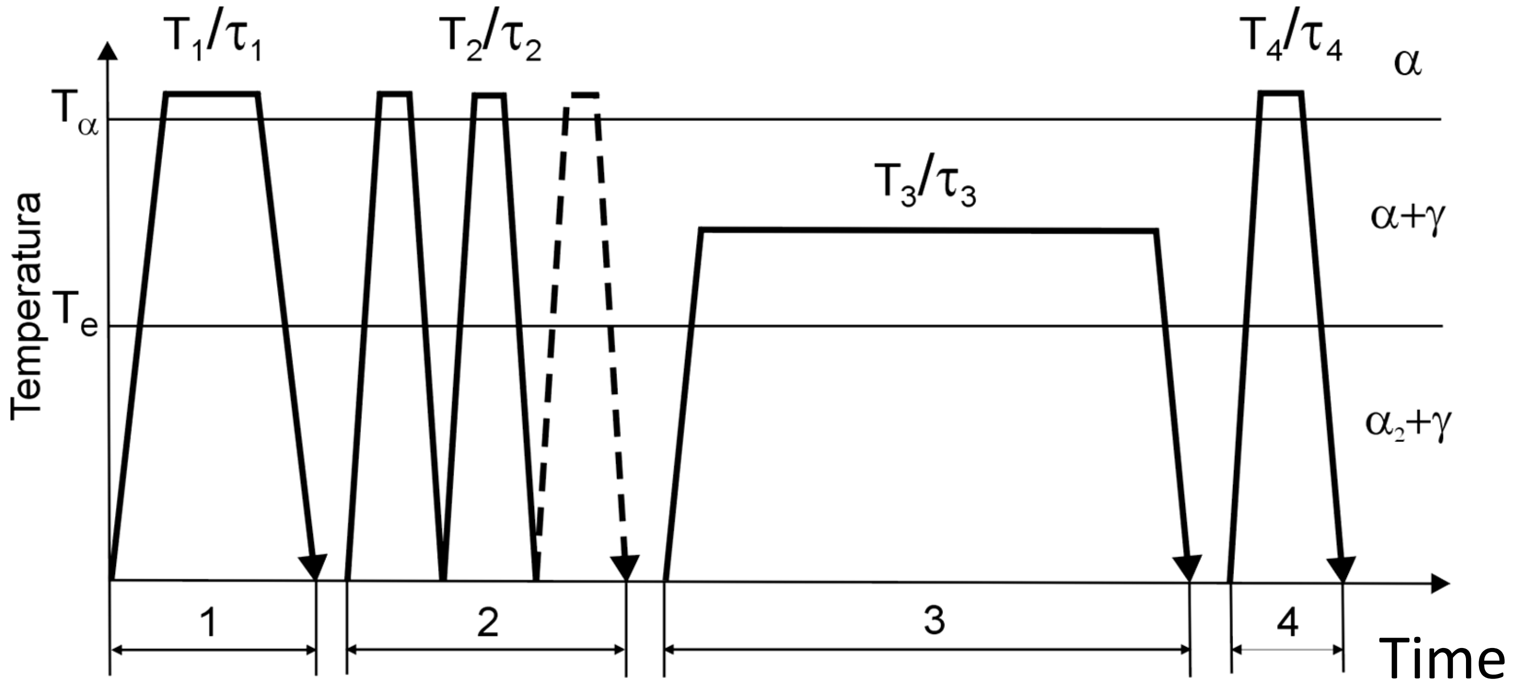
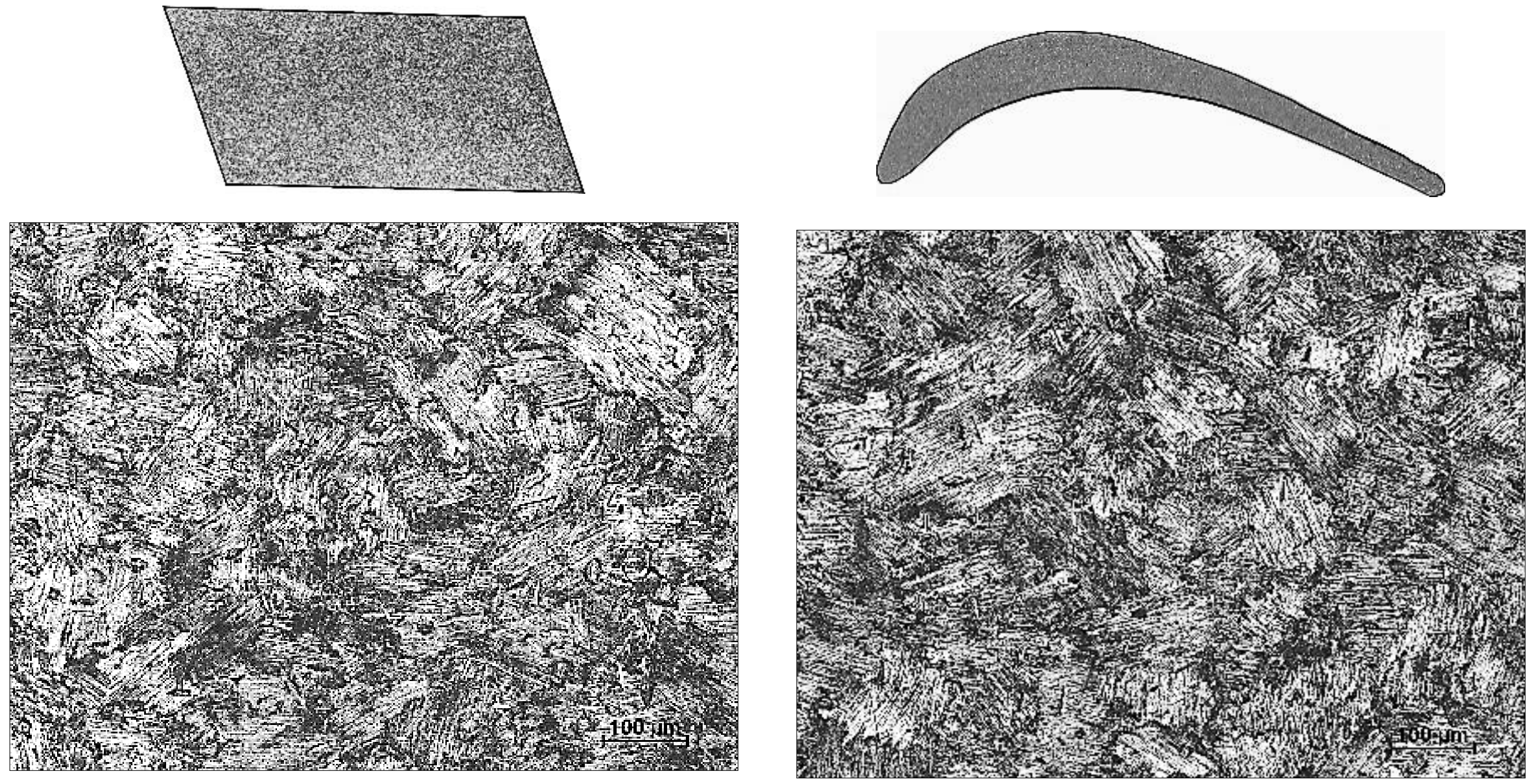
Special heat treatment





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Machining and surface treatment

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Szkliniarz W.. Szkliniarz A.: Fundamentals of manufacturing technologies for aircraft engine parts made of TiAl based alloys. Archives of Metallurgy and Materials 61 (2016). 1385-1390. DOI: 10.1515/amm-2016-0227.

4. TITANIUM ALLOYS WITH CARBON

Carbon in commercial titanium alloys

Alloy	Max. content of impurities. mas. %			
	O	N	H	C
Commerially pure titanium				
Ti Grade 1	0.18	0.03	0.015	0.08
Ti Grade 2	0.25	0.03	0.015	0.08
Ti Grade 3	0.35	0.05	0.015	0.08
Ti Grade 4	0.40	0.05	0.015	0.08
Ti-0.2Pd	0.25	0.03	0.015	0.08
α and near-α alloys				
Ti-5Al-2.5Sn	0.20	0.05	0.020	0.08
Ti-5Al-2.5Sn-ELI	0.12	0.07	0.012	0.08
Ti-8Al-1Mo-1V	0.12	0.05	0.015	0.08
Ti-6Al-2Sn-4Zr-2Mo	0.15	0.05	0.012	0.05
Ti-6Al-2Nb-1Ta-0.8Mo	0.10	0.02	0.012	0.03
Ti-2.25Al-11Sn-5Zr-1Mo	0.17	0.04	0.008	0.04
Ti-5.8Al-4Sn-3.5Zr-0.7Nb-0.5Mo-0.35Si	0.15	0.03	0.006	0.08
α+β alloys				
Ti-6Al-4V	0.20	0.05	0.012	0.10
Ti-6Al-4V-ELI	0.13	0.05	0.012	0.08
Ti-6Al-6V-2Sn	0.20	0.04	0.015	0.05
Ti-6Al-2Sn-4Zr-6Mo	0.15	0.04	0.012	0.04
Ti-5Al-2Sn-2Zr-4Mo-4 Cr	0.14	0.04	0.012	0.05
Ti-3Al-2.5V	0.12	0.02	0.015	0.05
Ti-4Al-4Mo-2Sn-0.25Si	0.12	0.05	0.012	0.02
near-β and β alloys				
Ti-15Mo	0.20	0.05	0.015	0.10
Ti-13V-11Cr-3Al	0.17	0.05	0.015	0.05
Ti-10V-2Fe-3Al	0.13	0.05	0.015	0.05
T-15Mo-3Nb-3Al-0.2Si	0.17	0.05	0.015	0.05
Ti-35V-15Cr	0.08	0.05	0.015	0.05

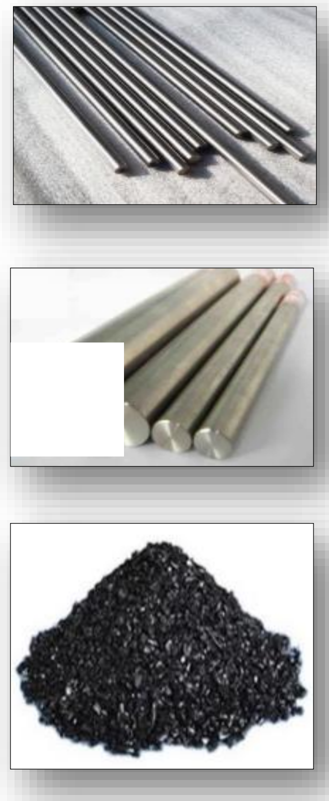
high alloy purity

↓

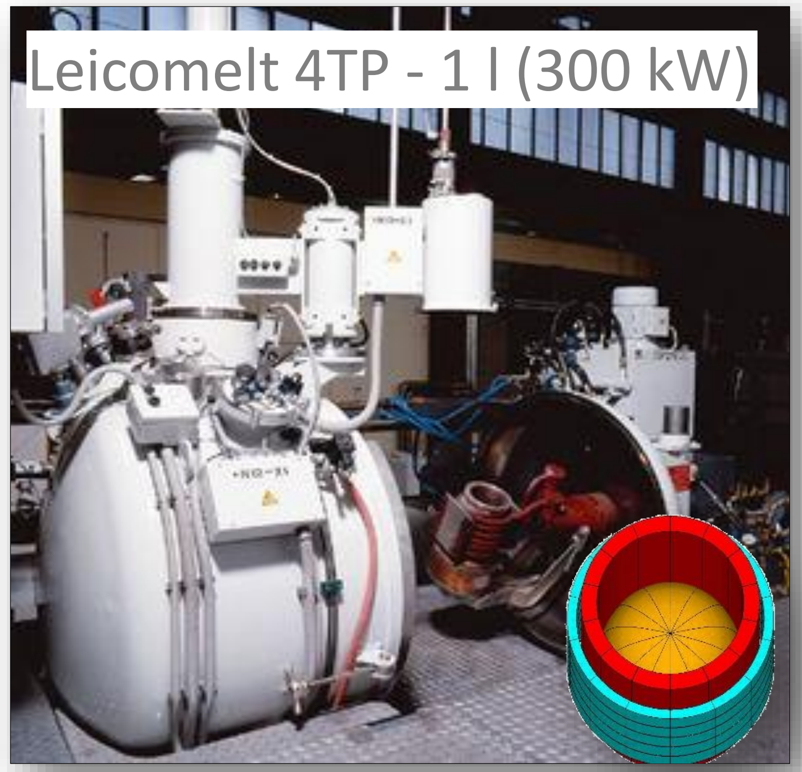
problem with obtaining high strength

4 Titanium and titanium alloys with carbon – production method

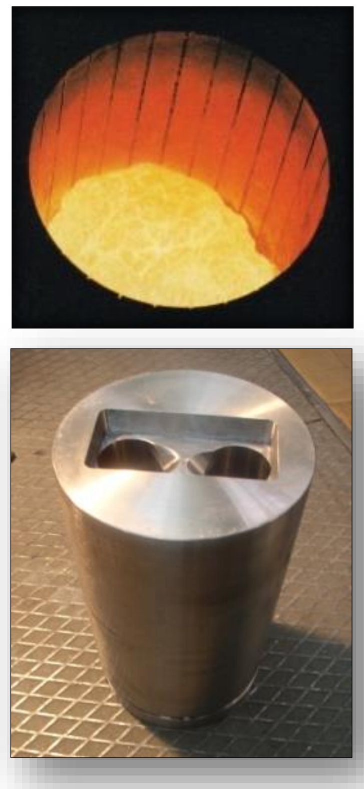
Feedstock



Melting



Casting



Ingot

Homogenization

Hot rolling

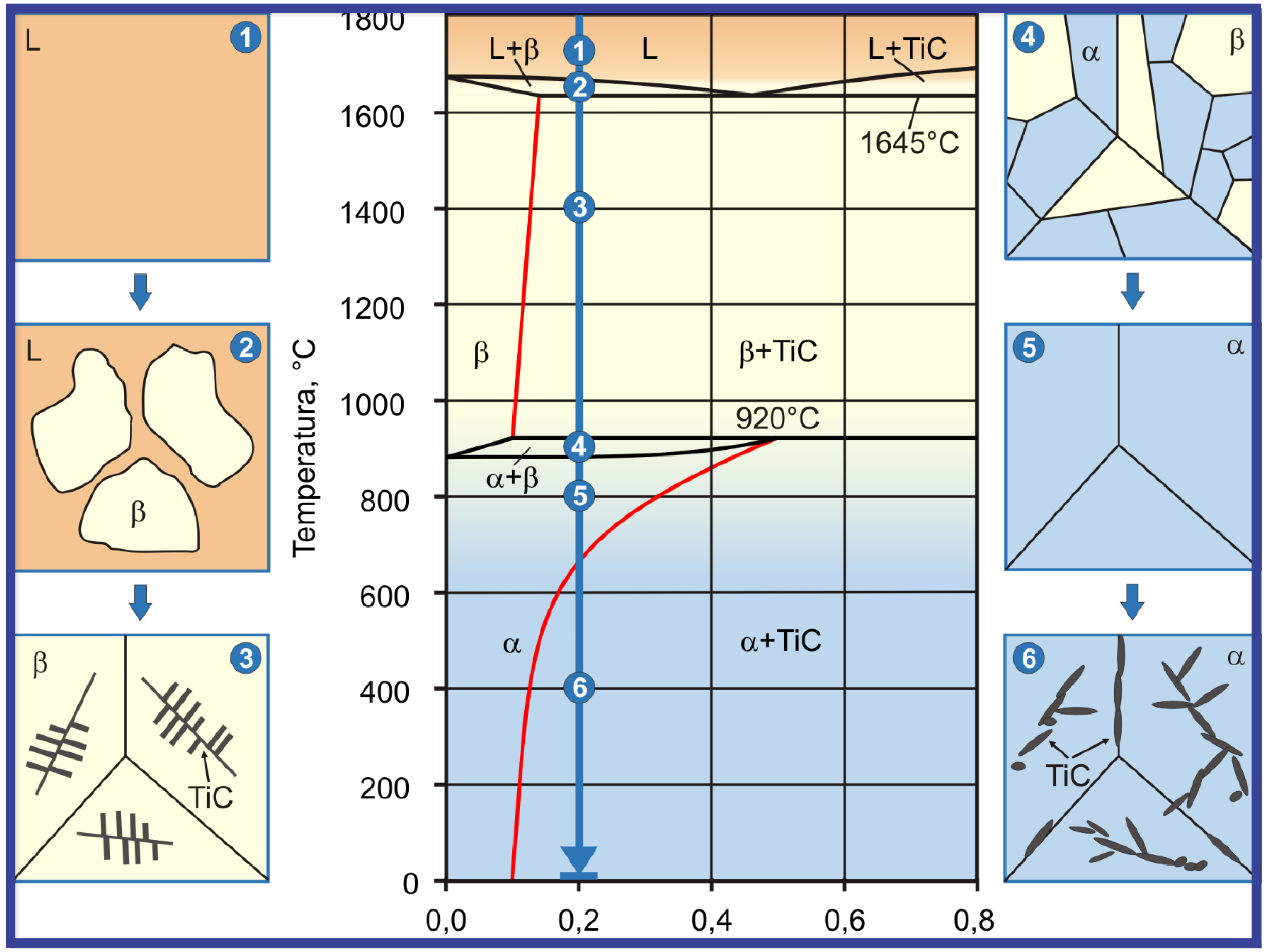
Rods

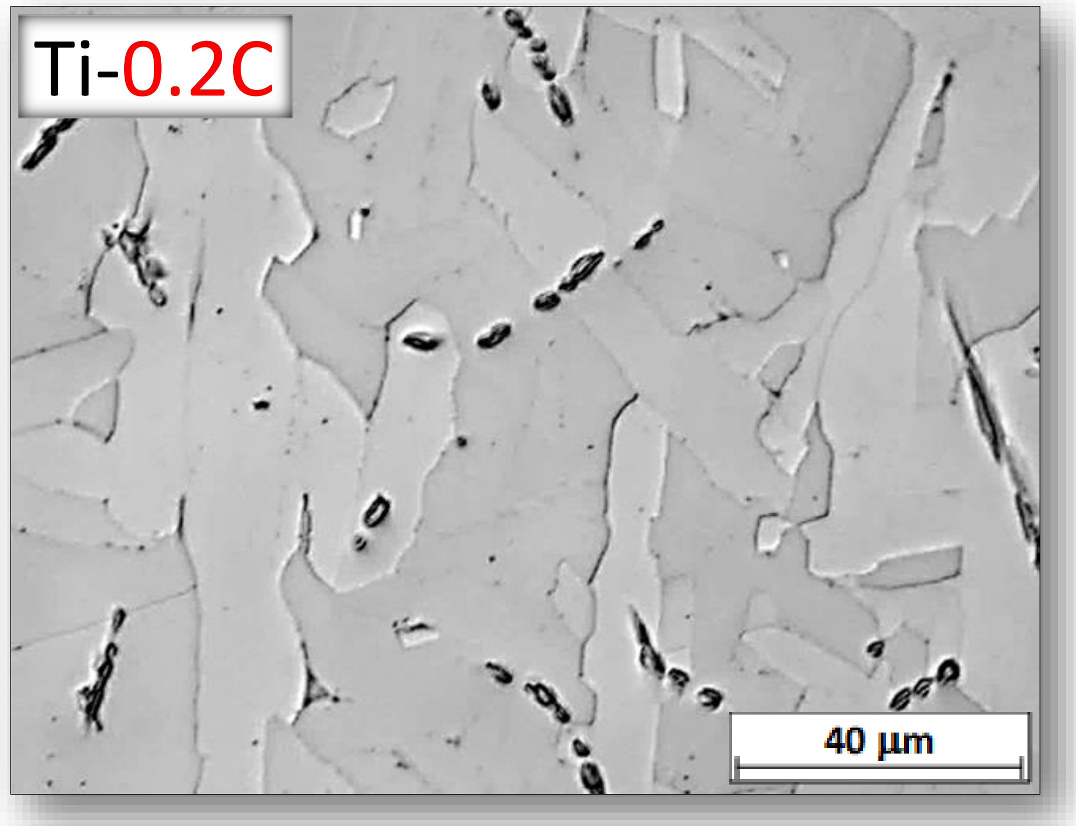
Heat treatment

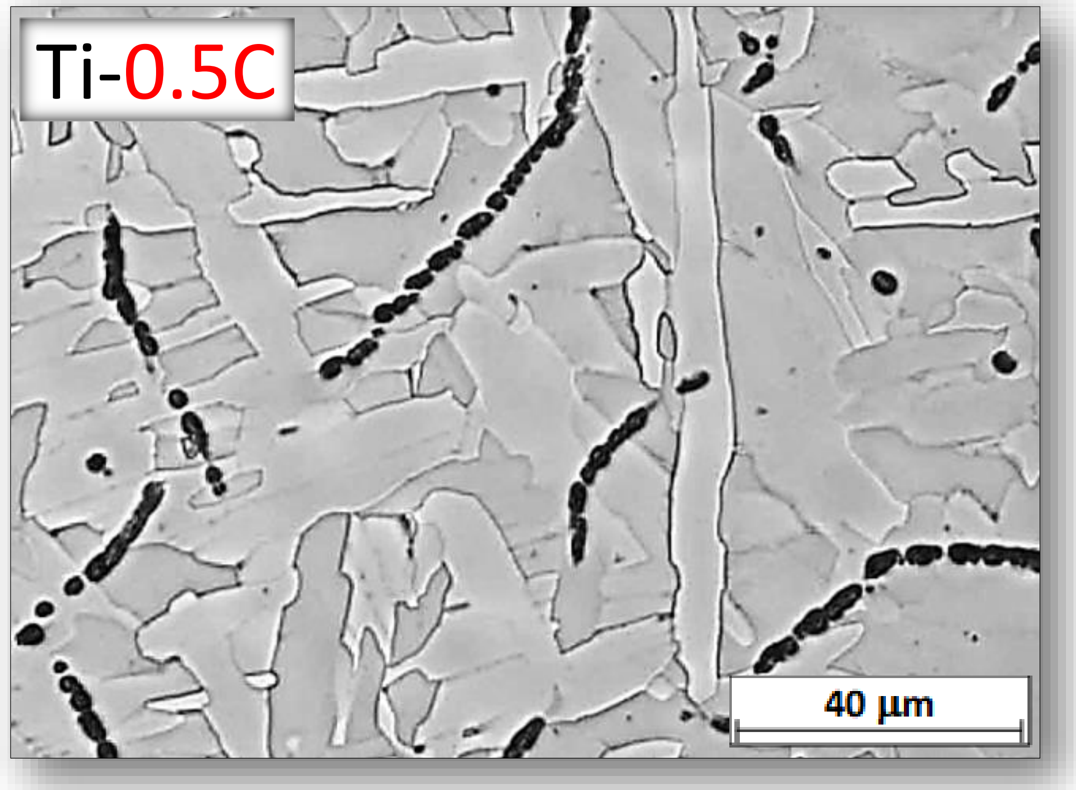
Institut Für Elektroprozesstechnik
Leibniz Universität Hannover

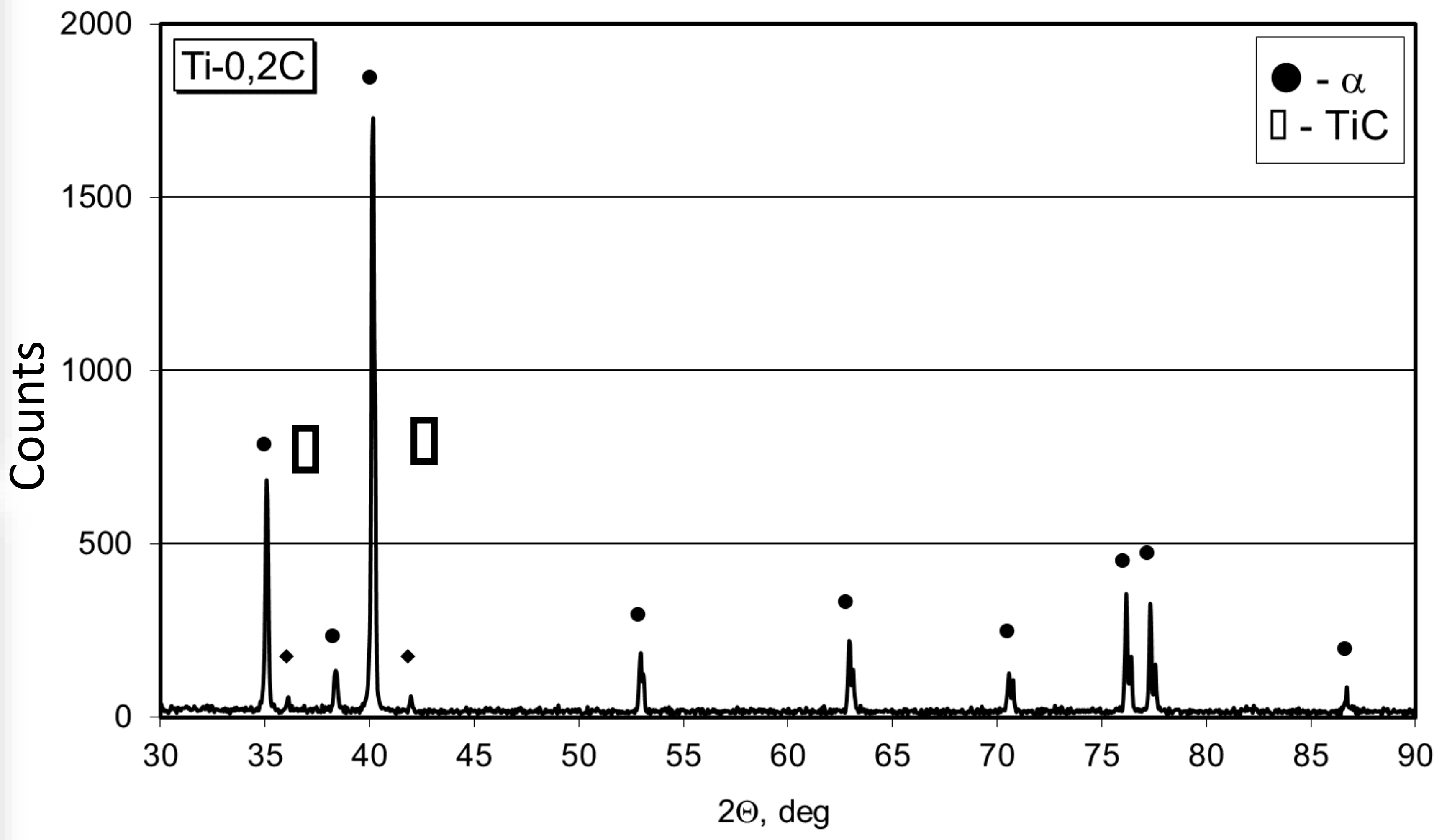
Bergakademie Freiberg

Effect of carbon on the crystallization process









Under phase equilibrium conditions the processes of microstructure formation follows the sequence:

0.0%C ➡ L → β → α

0.2%C ➡ L → β + L → β + TiC → α + β → α → α + TiC

0.5%C ➡ L → L+TiC → β + TiC → α → α + TiC

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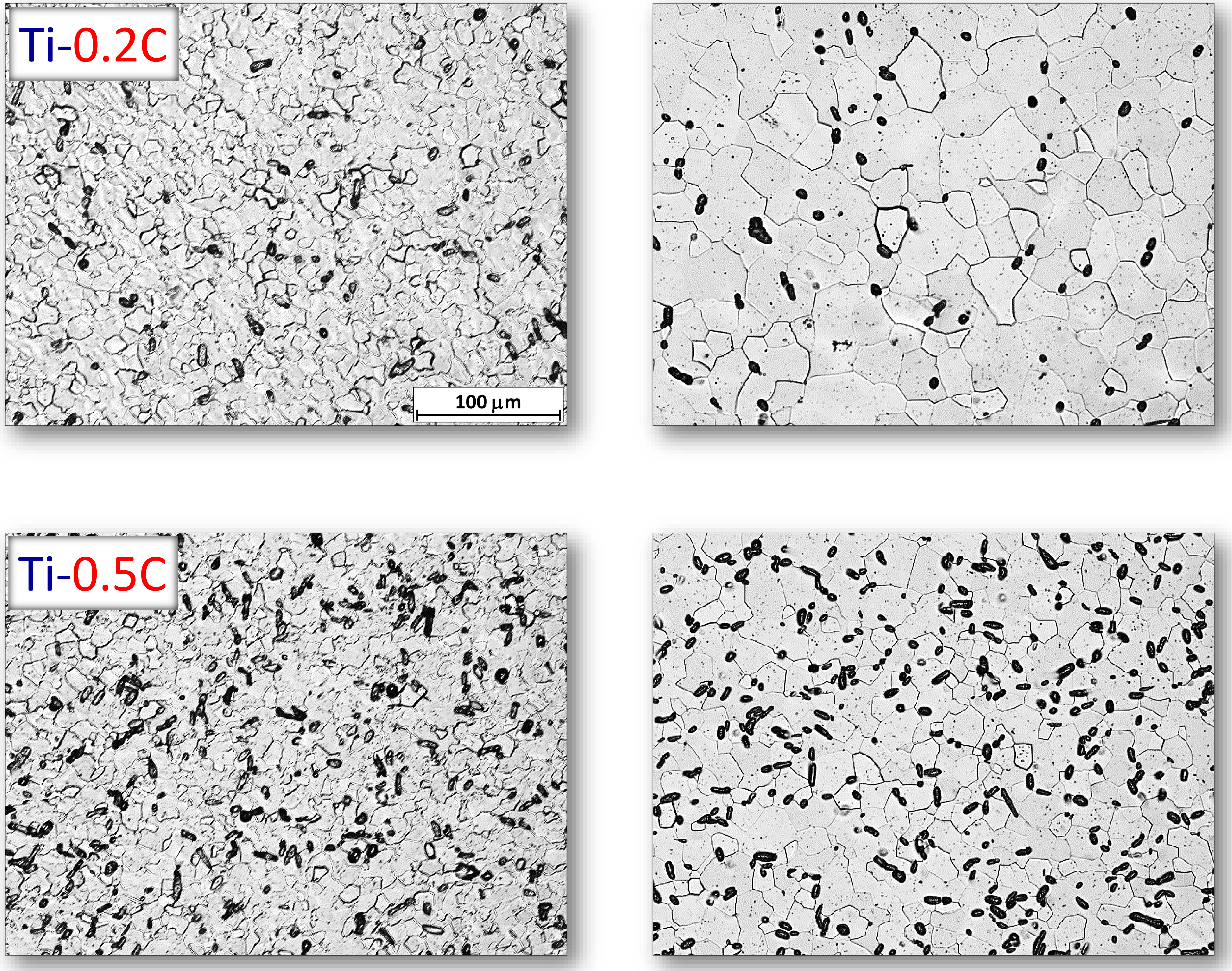
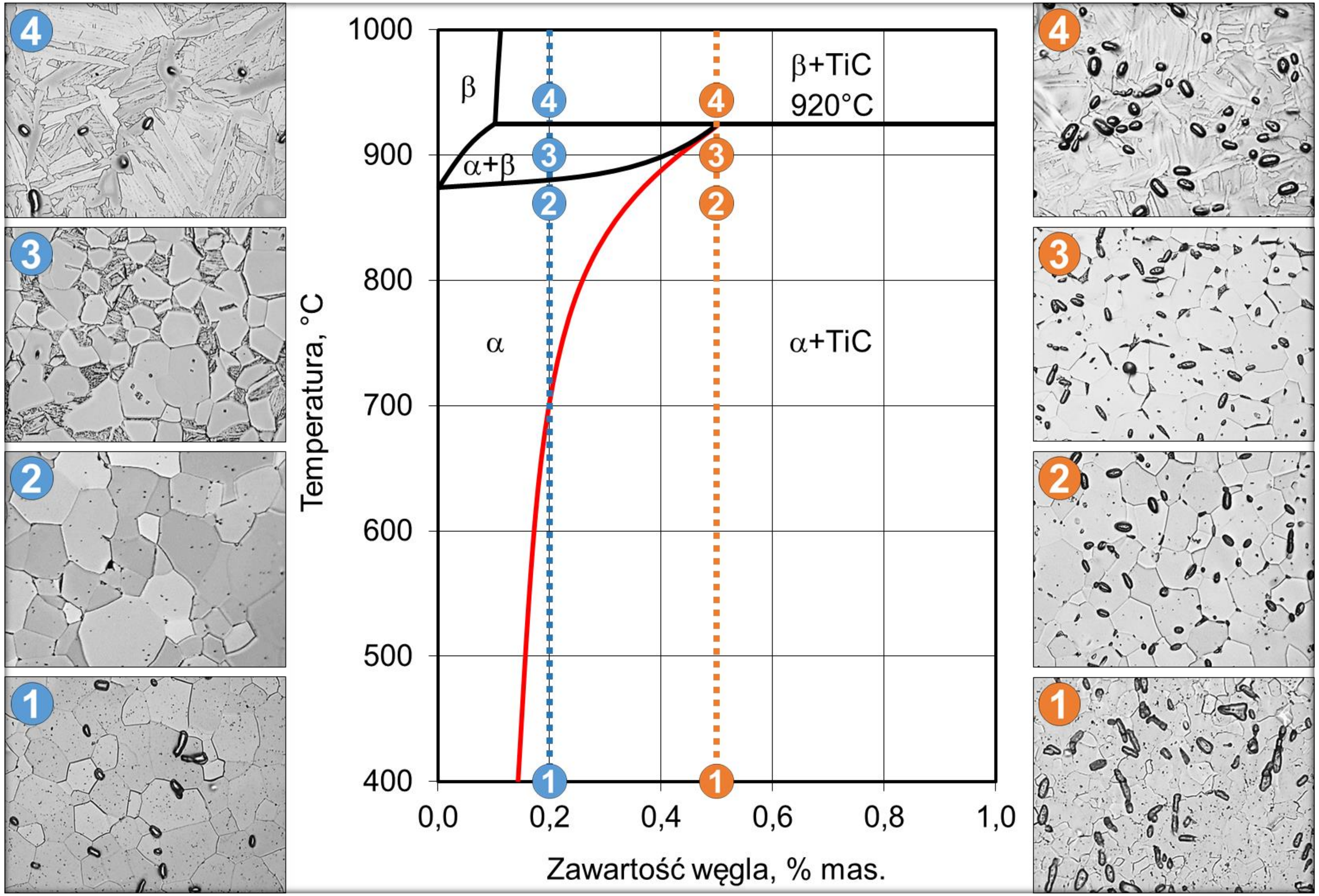
Effect of carbon on the susceptibility of grain growth

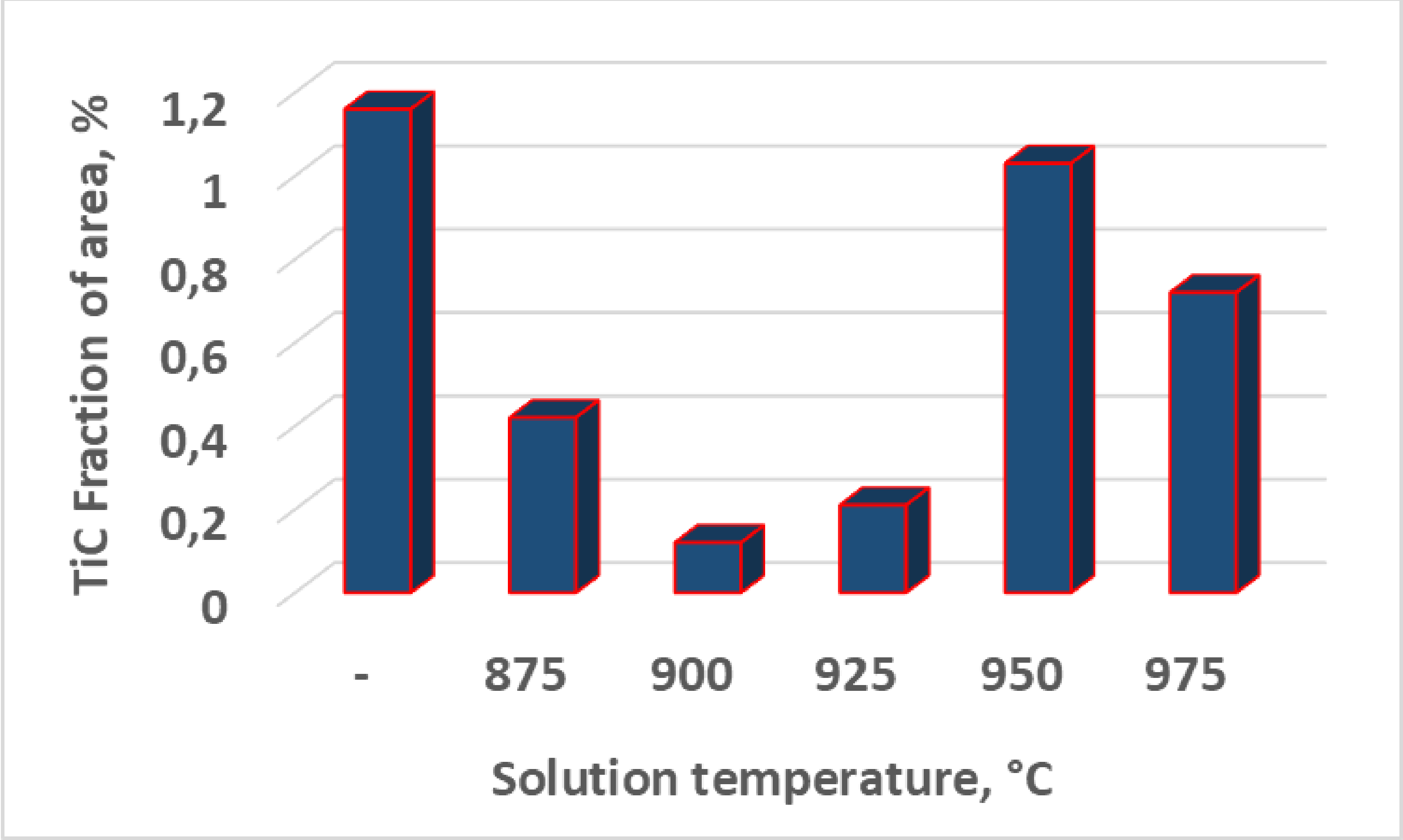


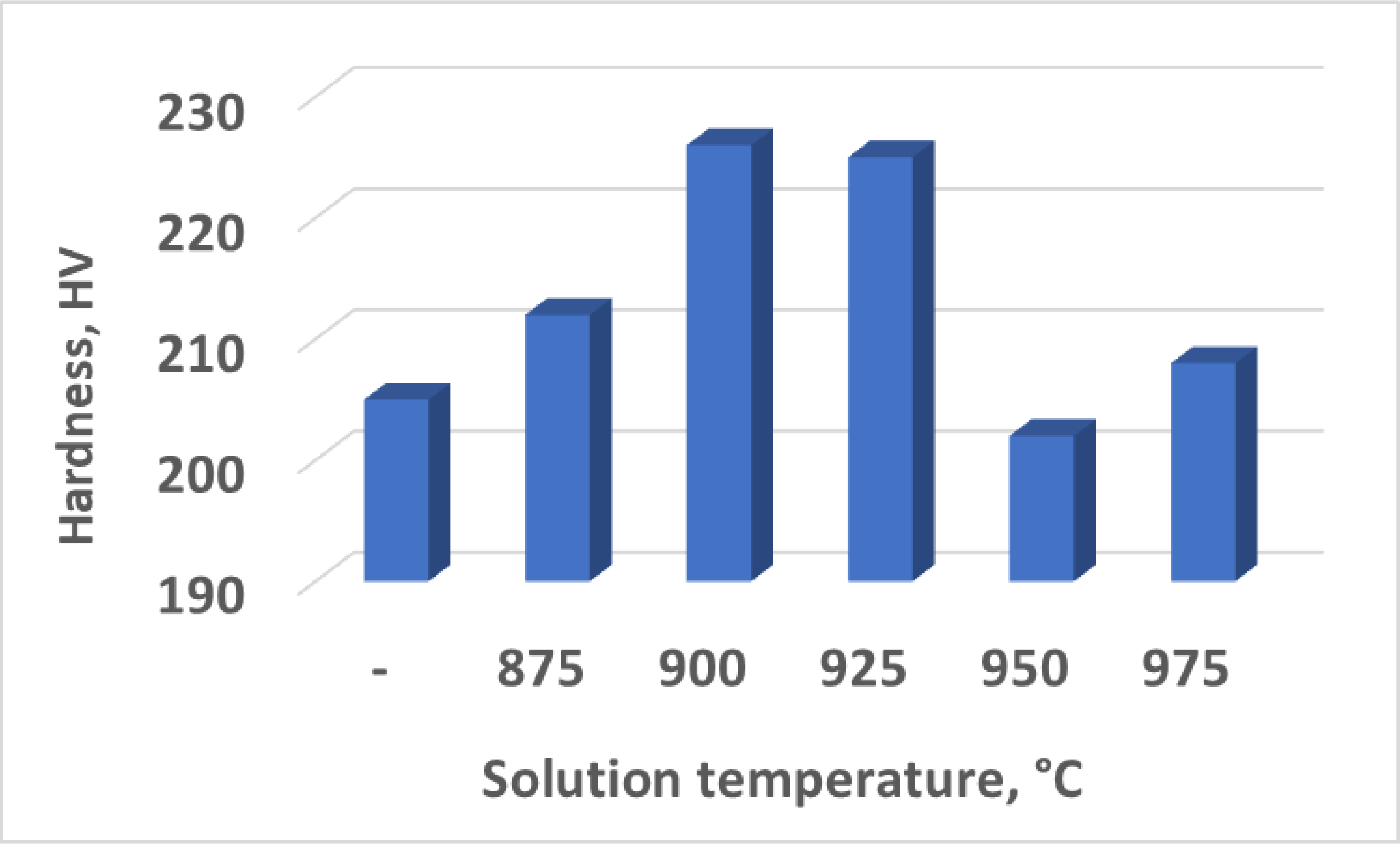
After hot working

After annealing

Whether Ti can be solutioned by carbon?

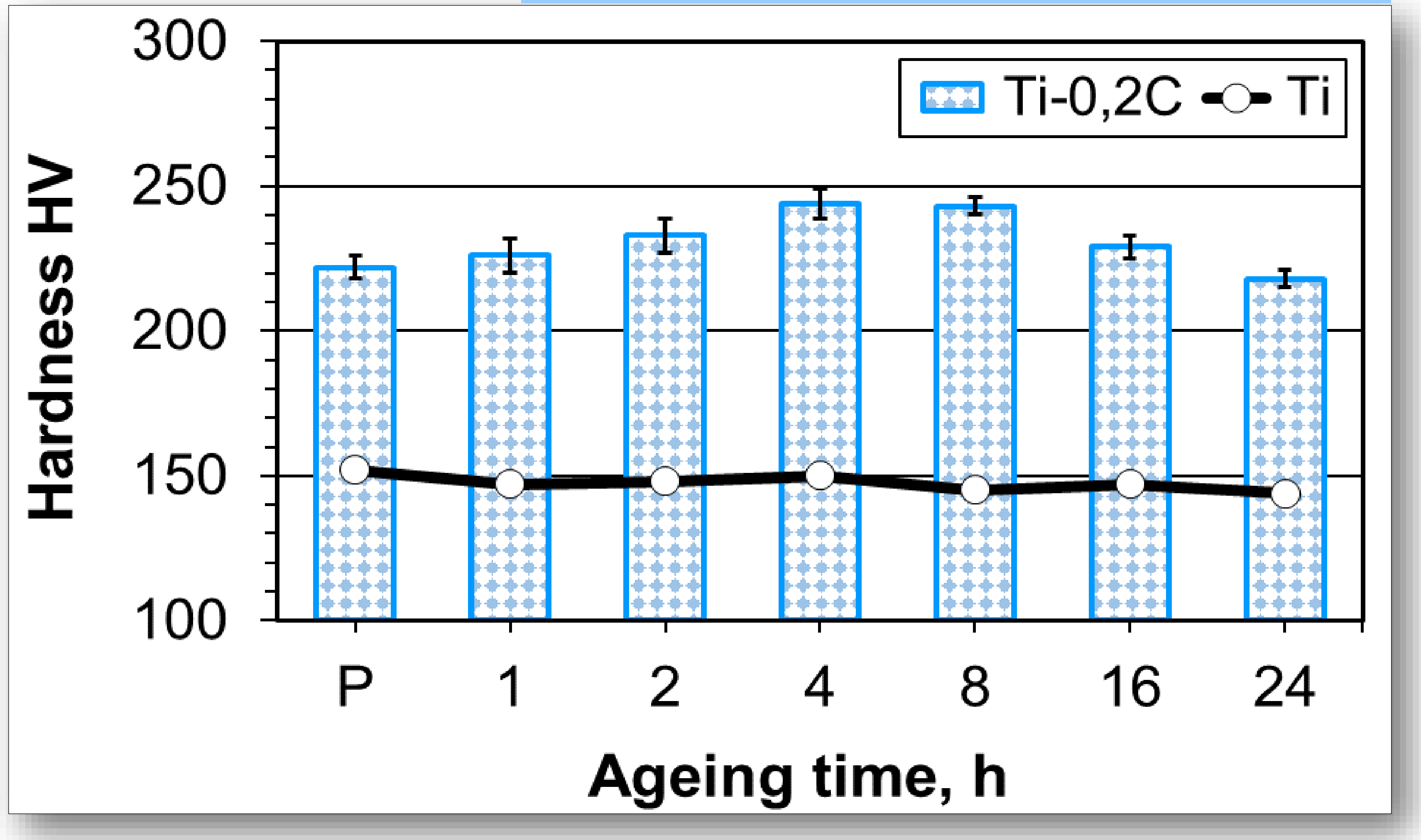




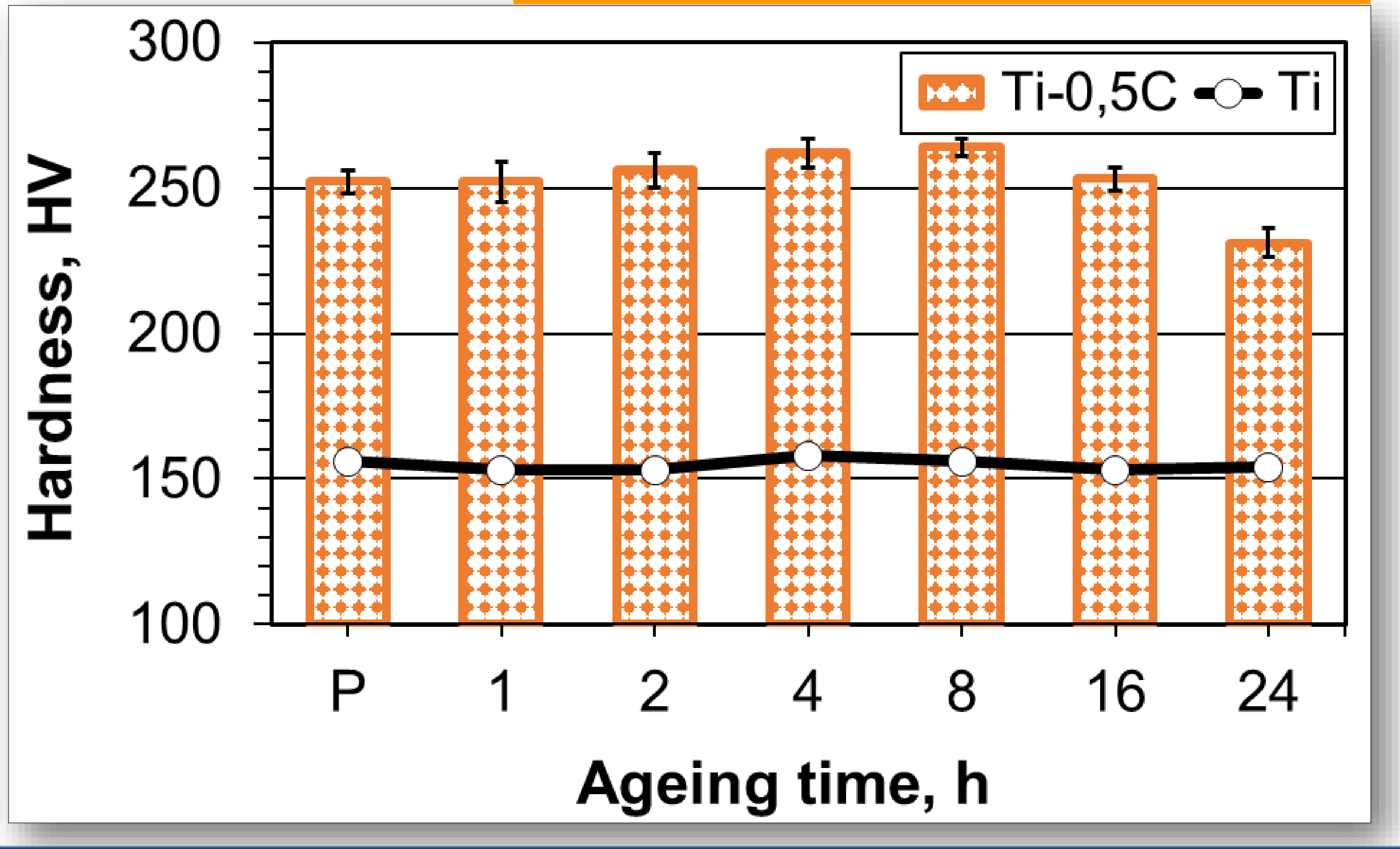


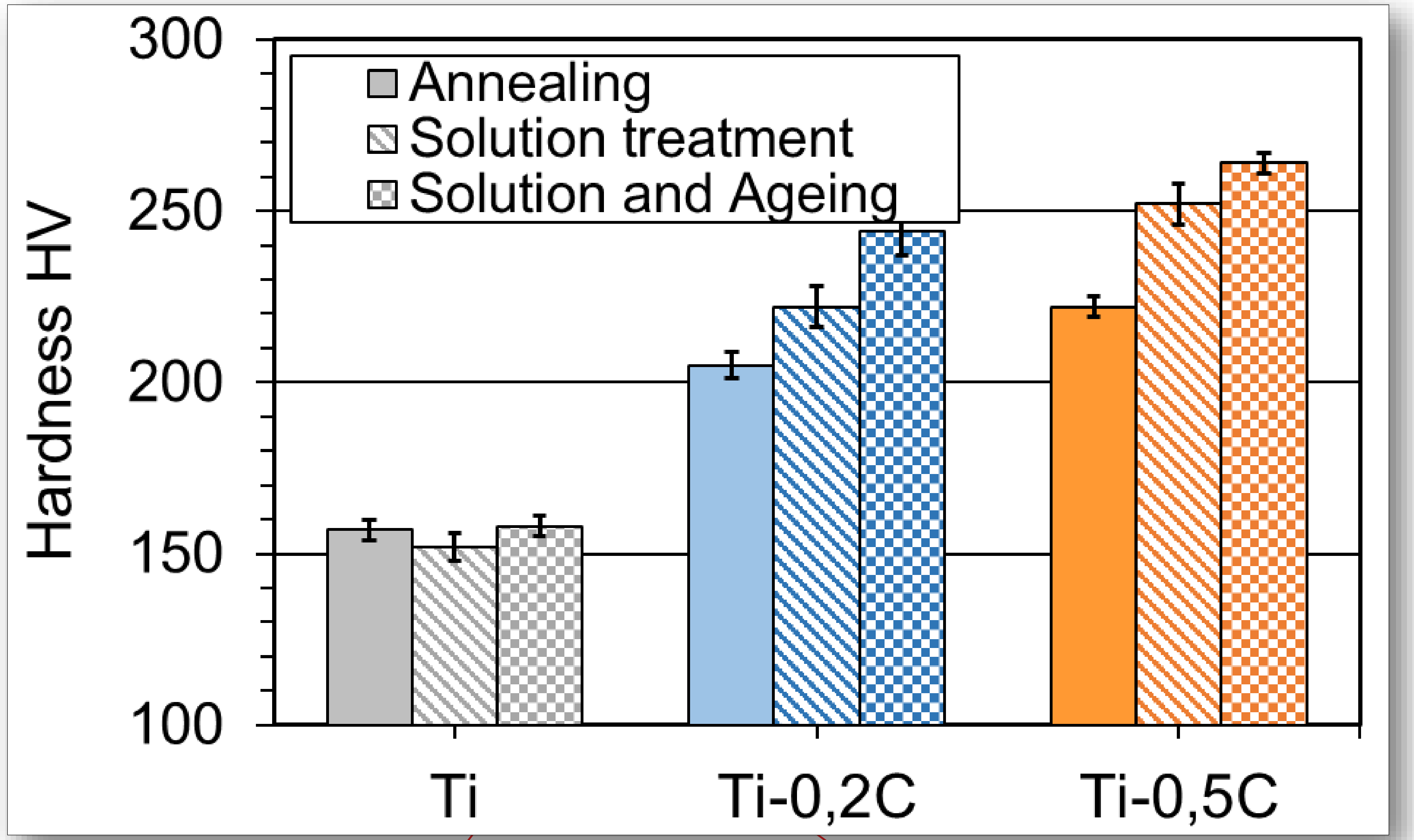
Age-hardening of Ti-0.2 (0.5)C

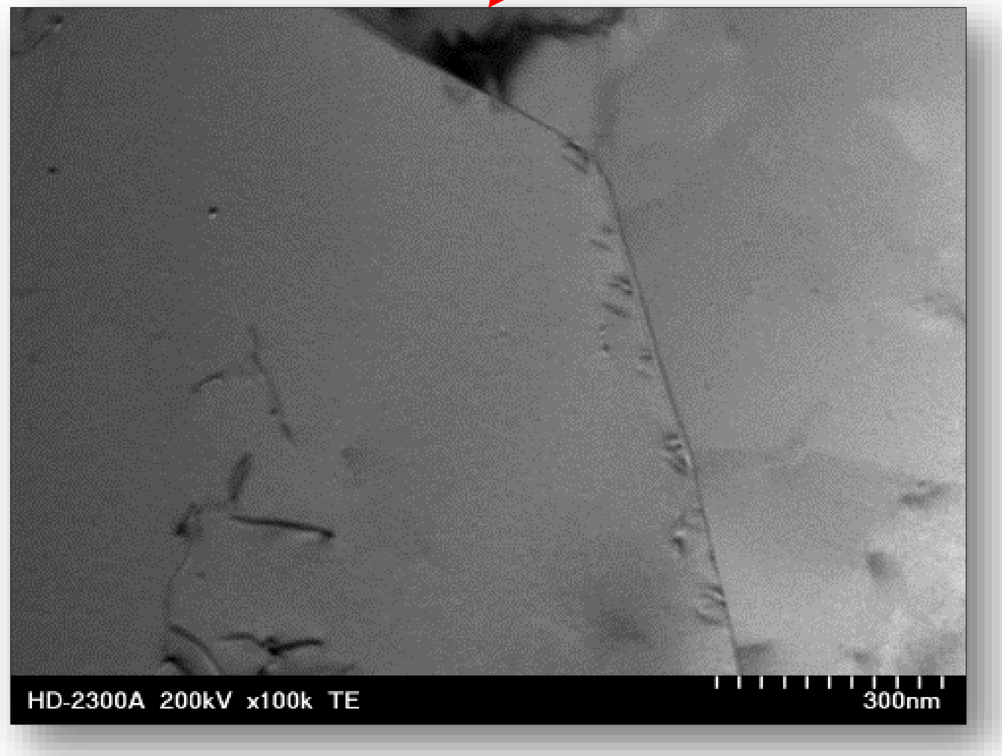
875°C/1h/water+550 °C/4h/air

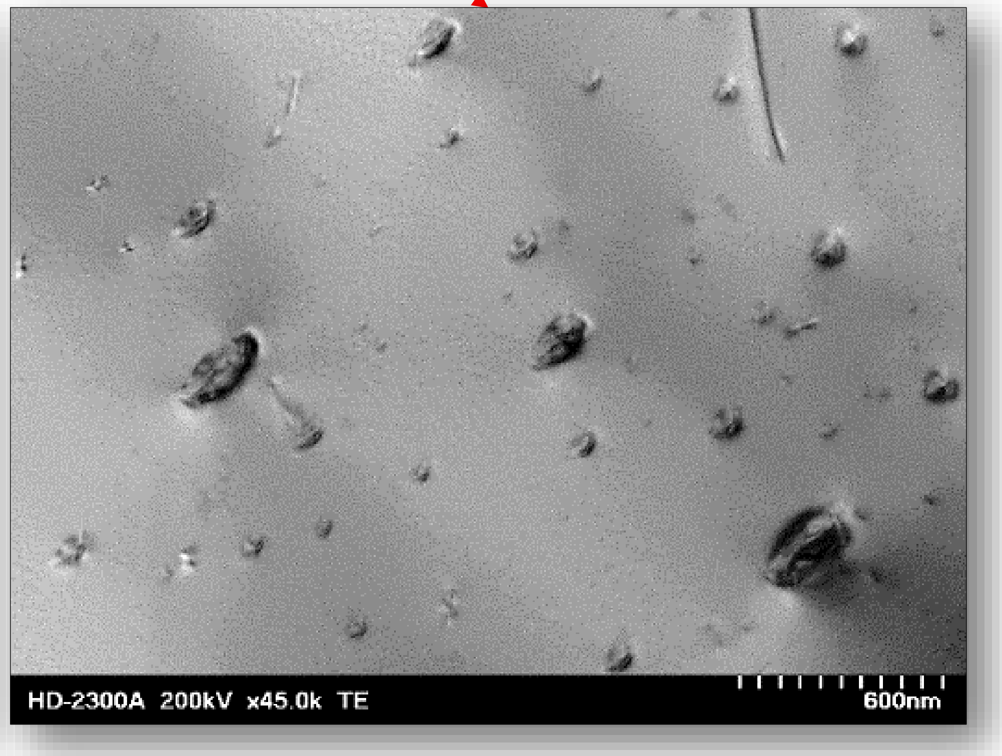


900°C/1h/water+550°C/8h/air

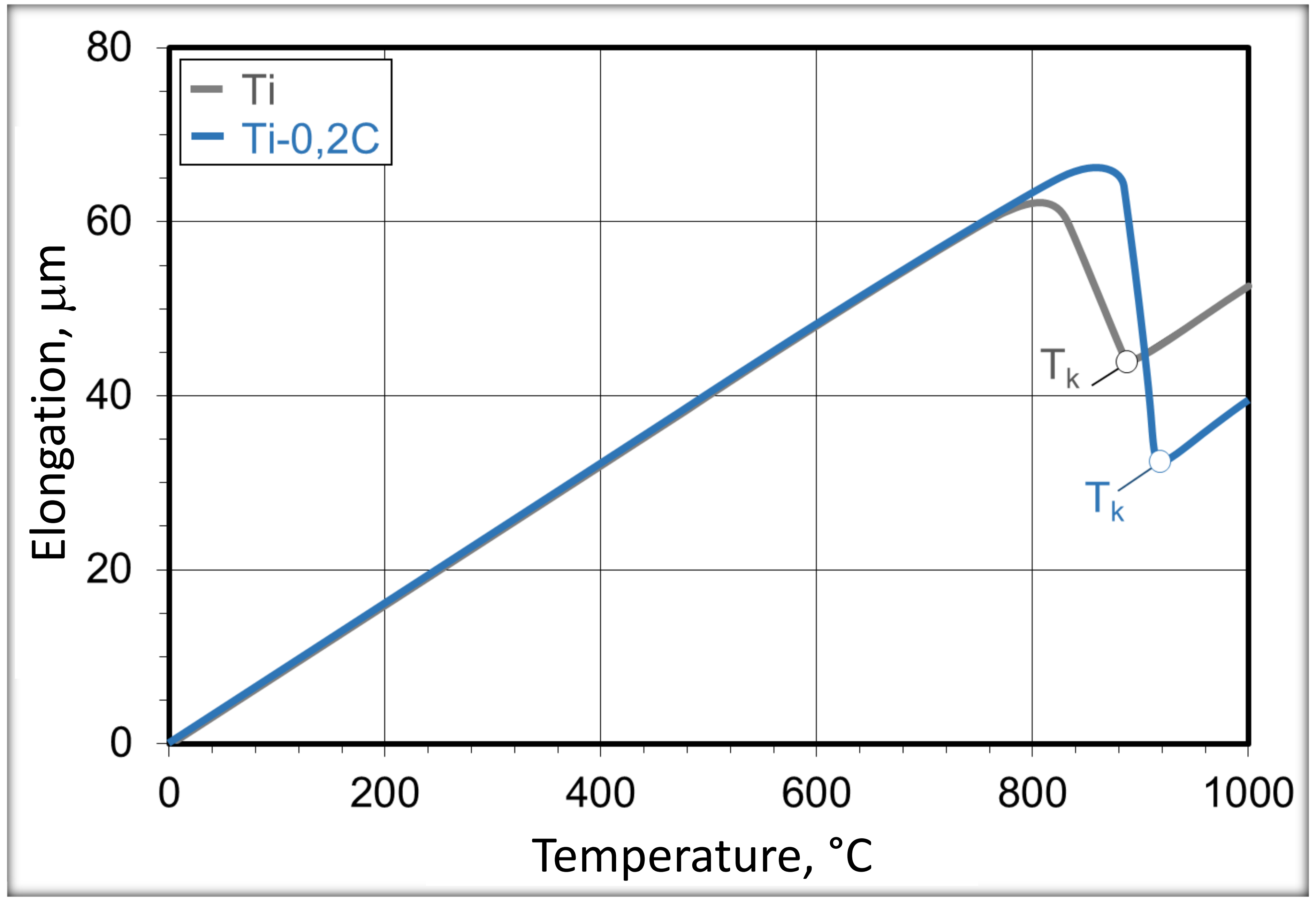








Effect of carbon on the temperature of phase transformation in titanium



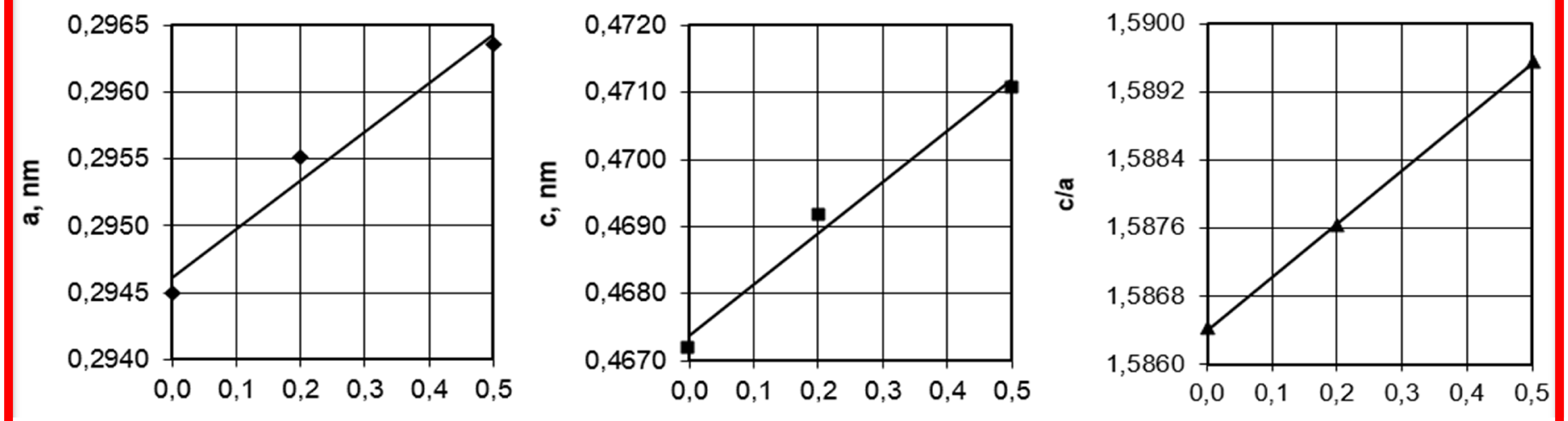
Alloy	Phase composition	Transformation temperature, °C	Carbon content. mas.%		
			0.0	0.2	0.5
Ti	α	α→β	890	920	945
Ti-5Al-2.5Sn			1035	1060	-
Ti-8Al-1Mo-1V	α+(β)	α+β→β	1040	1060	-
Ti-6Al-4V	α+β		975	995	1010
Ti-15Mo-3Nb-3Al-0.2Si	β+(α)		810	825	-
Ti-33Mo	β	not apply			

Effect of carbon on the lattice parameters

Alloy	Lattice parameters. nm				
	a_α	c_α	c_α/a_α	a_β	a_{TiCx}
Ti	0.2945	0.4672	1.5864		
Ti-0.2C	0.2952	0.4686	1.5874		0.4308
Ti-0.5C	0.2964	0.4711	1.5895		0.4311

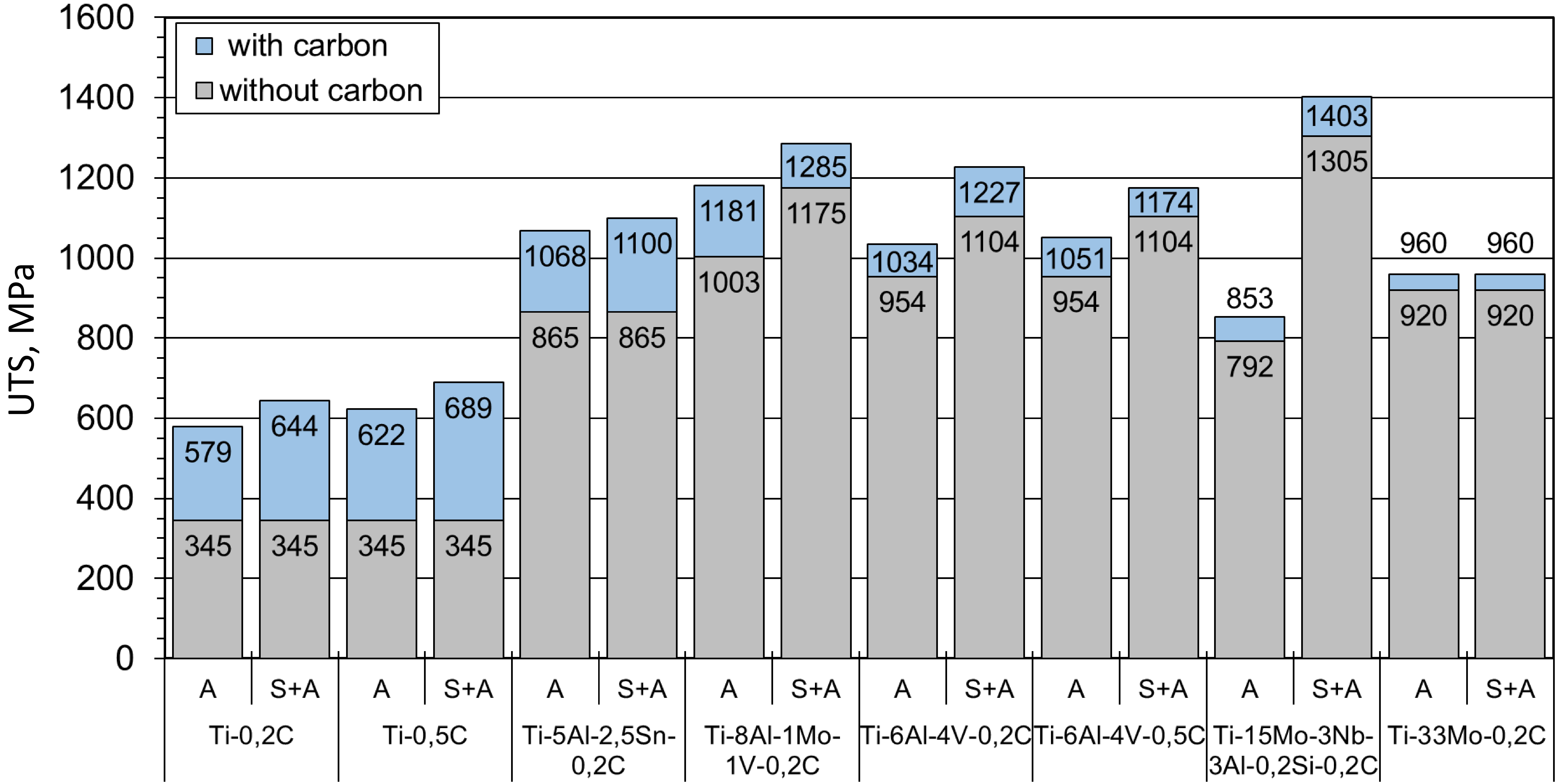
c_α/a_α=1.595

Limit of the good deformability of titanium alloys

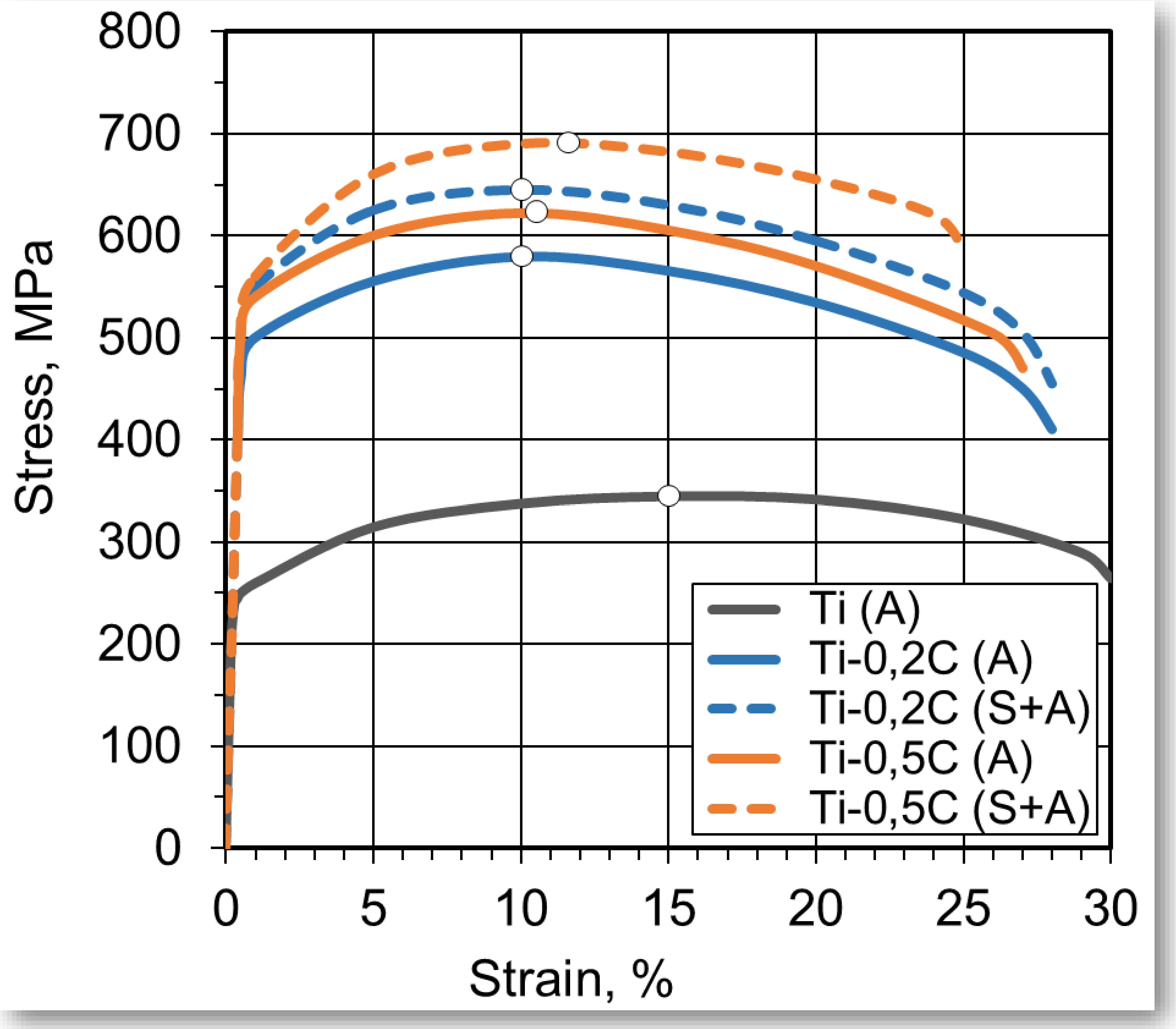


Naka S., Kubin L.P., Perrier C.: The plasticity of titanium at low and medium temperatures. „Philosophical Magazine A". Vol. 63. 1991. p. 1035.

Effect of carbon on the mechanical properties of titanium alloys

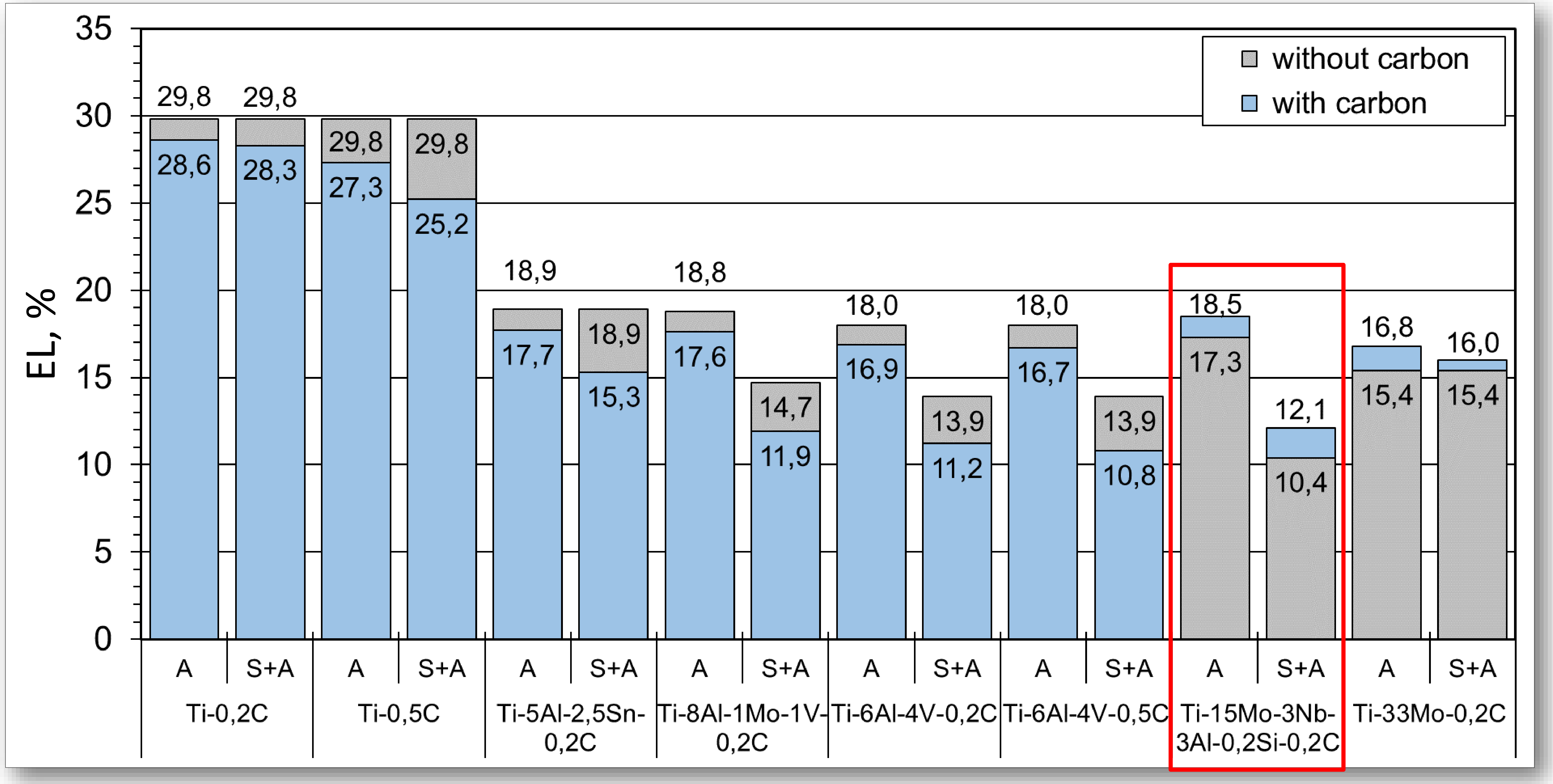


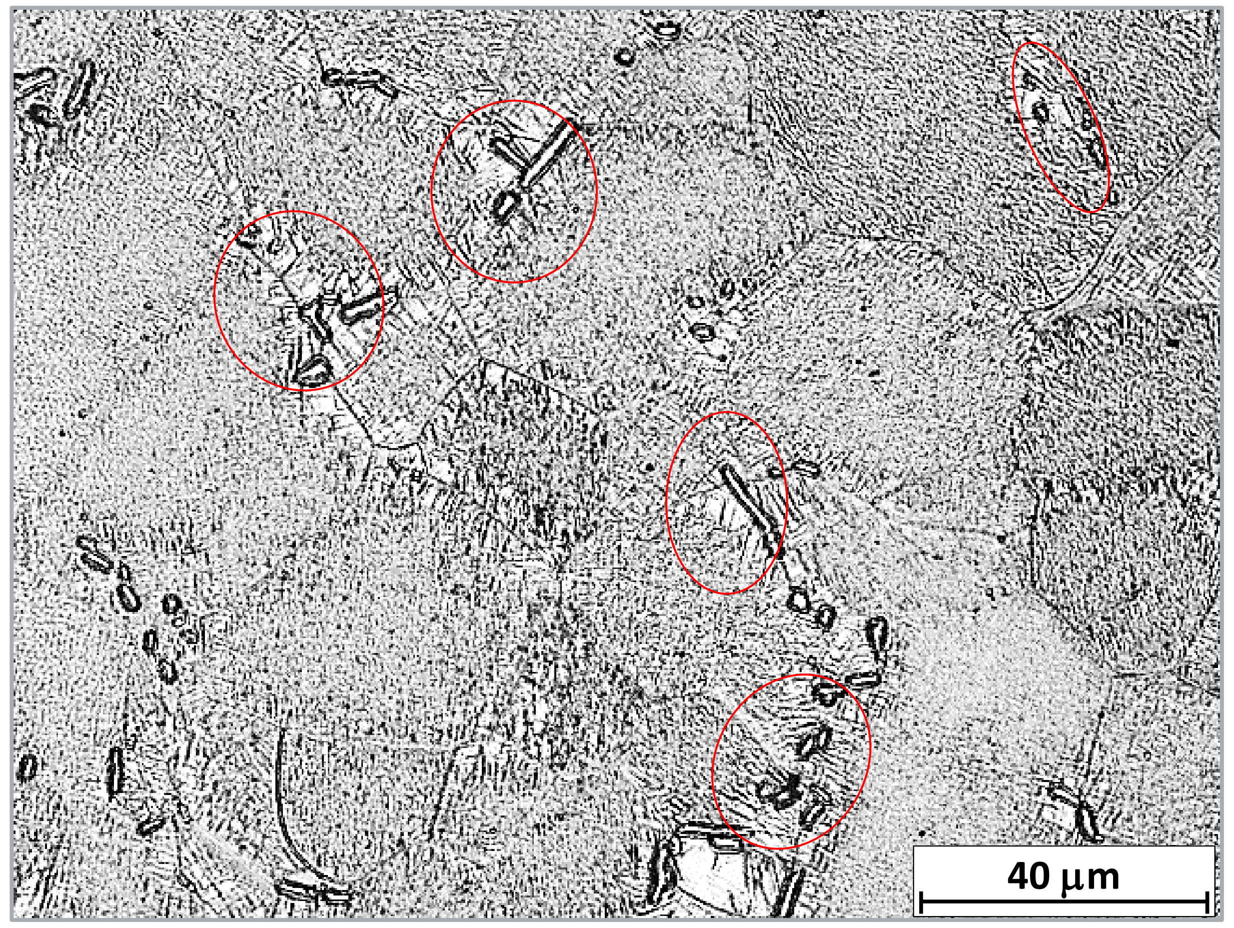
Effect of carbon on the mechanical properties of titanium alloys

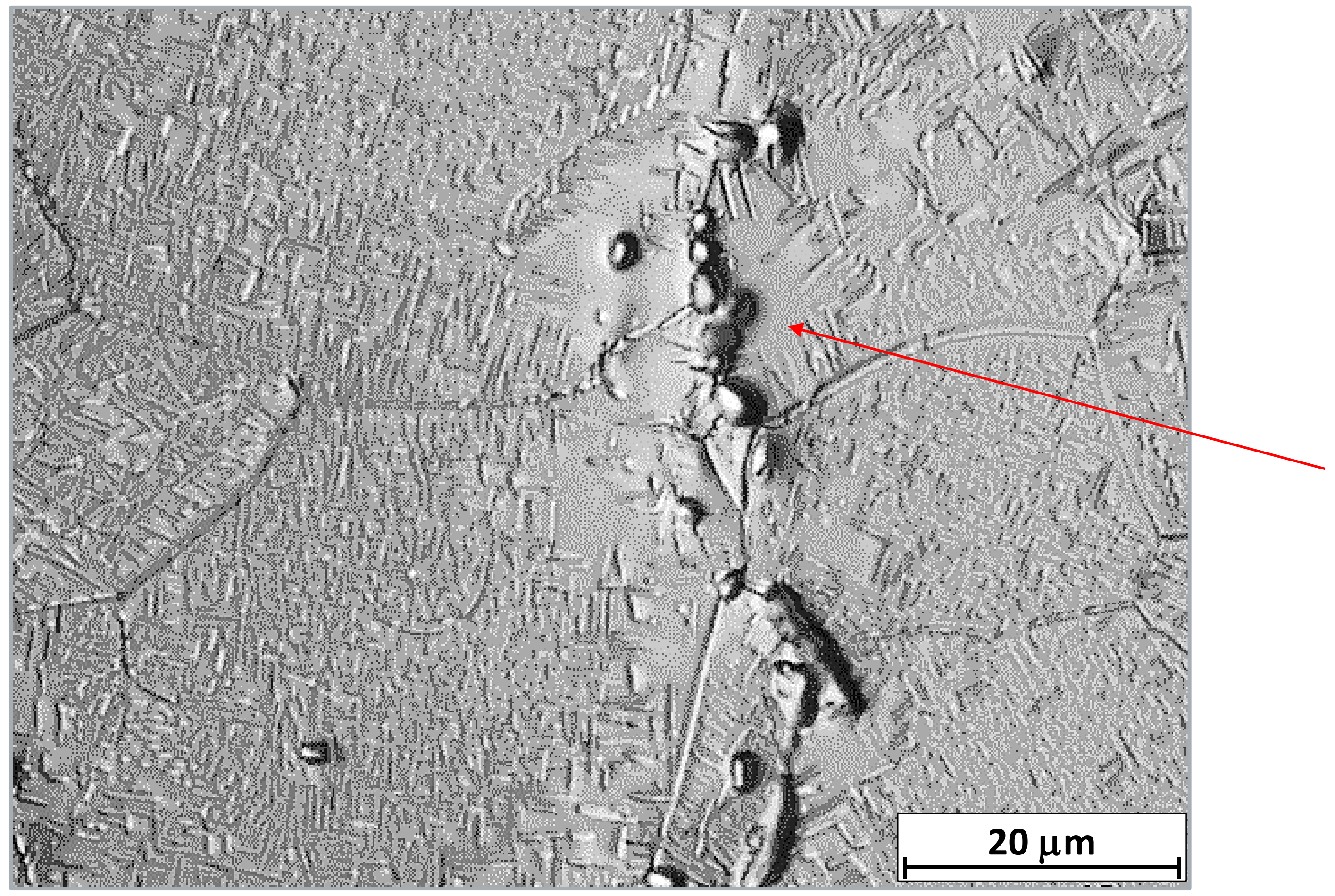


Alloy	State	UTS	YS	EL	RA
		MPa		%	
Ti	A	345	245	29.8	51.5
Ti-0.2C	**A**	**579**	**496**	**28.6**	**48.6**
	STA	643	554	28.3	46.6
Ti-0.5C	A	622	544	27.3	44.8
	STA	689	561	25.2	36.9
Ti Grade 1*	A	240	170	25.0	35.0
Ti Grade 4*	**A**	**550**	**485**	**15.0**	**30.0**

Effect of carbon on the mechanical properties of titanium alloys





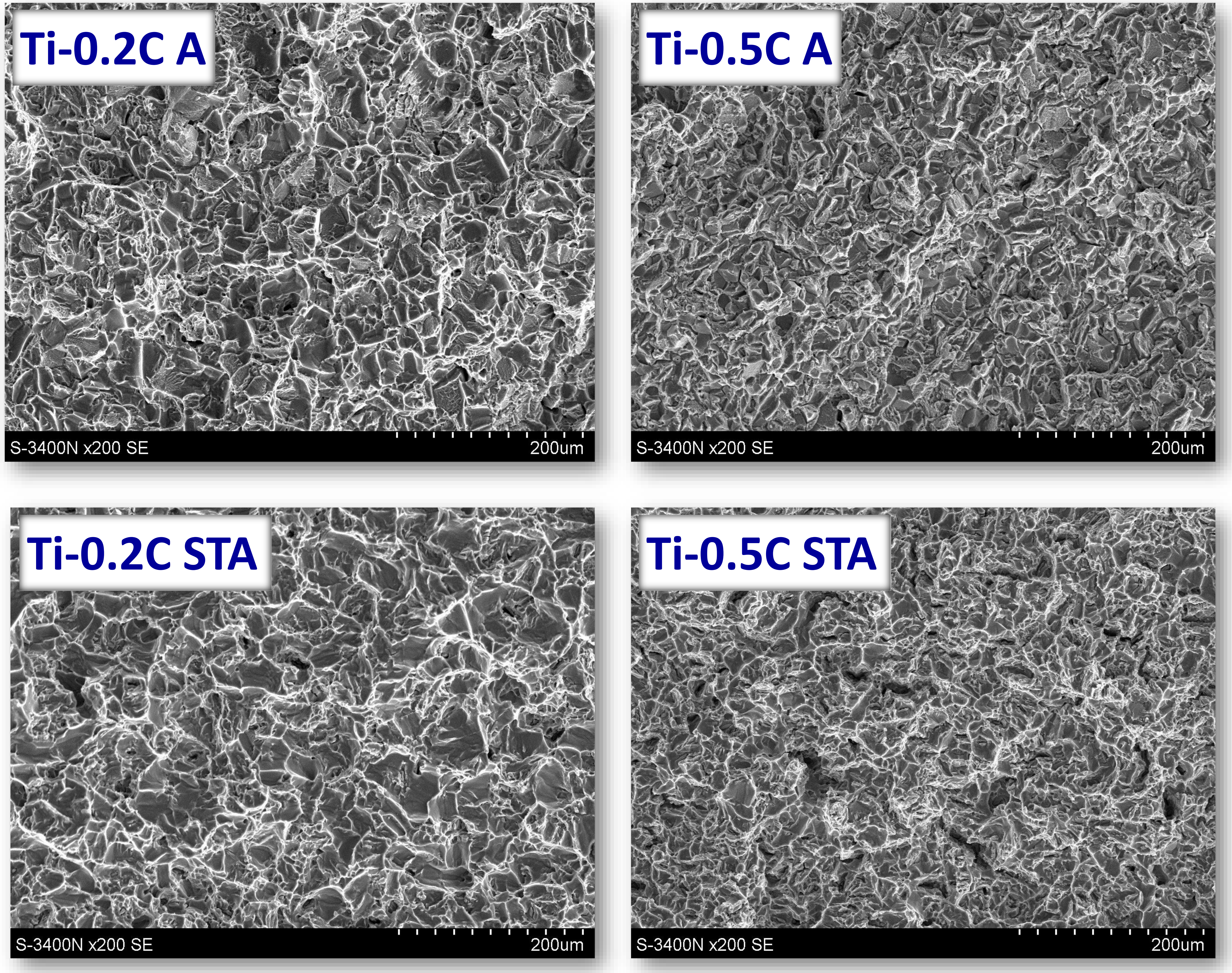


Carbide as „oxygen scavenger "

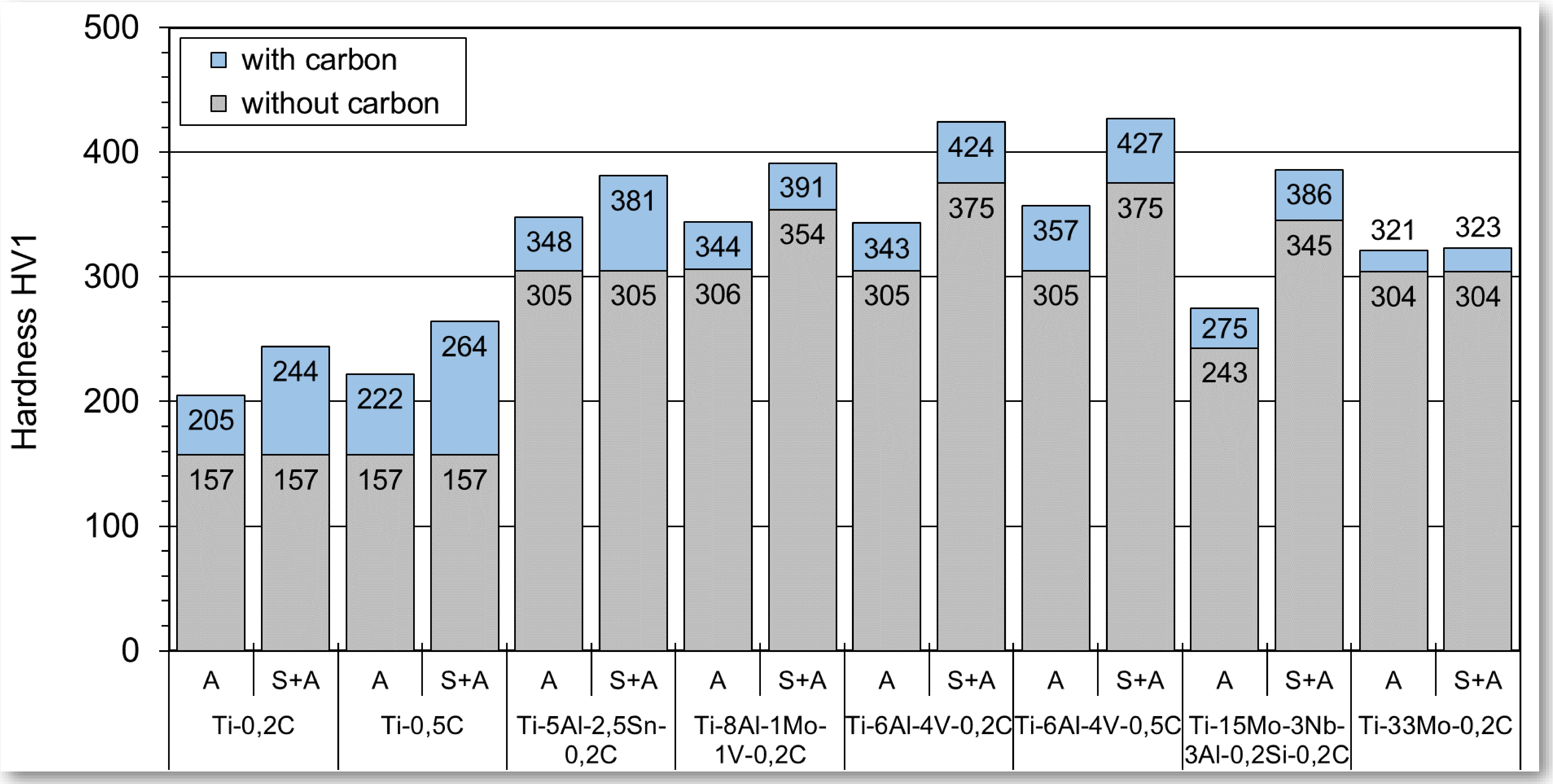
- traps oxygen atoms in place of the vacant lattice point in the carbon sublattice
- Decrease the oxygen content in the matrix

Effect of carbon on the impact energy of titanium alloys

Alloy	State	KV. J
Ti	A	84.5
Ti-0.2C	A	67.0
	STA	54.5
Ti-0.5C	A	28.5
	STA	18.0
Ti Grade 1*	A	50.0
Ti Grade 4*	A	20.0



Effect of carbon on the hardness of titanium alloys



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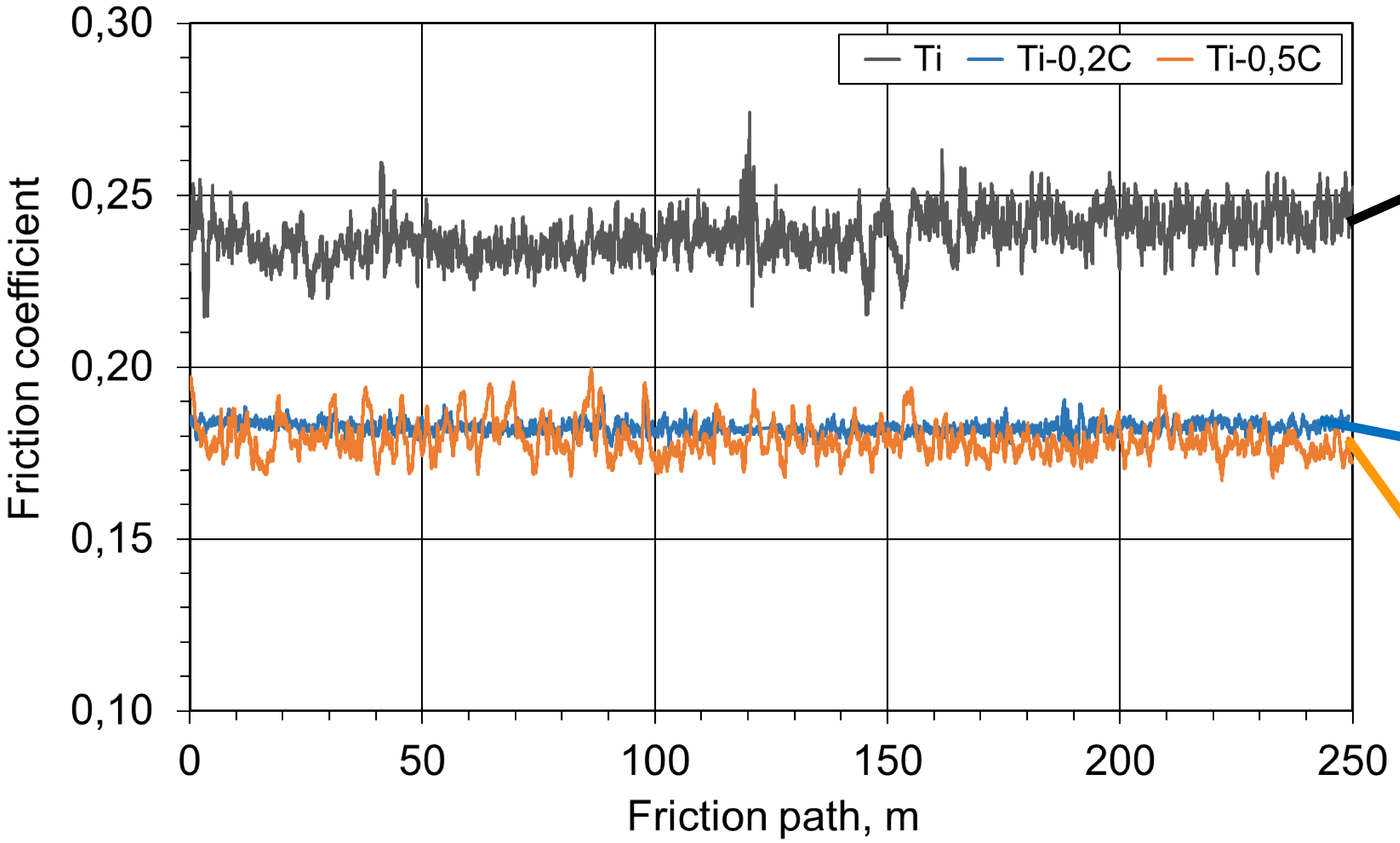
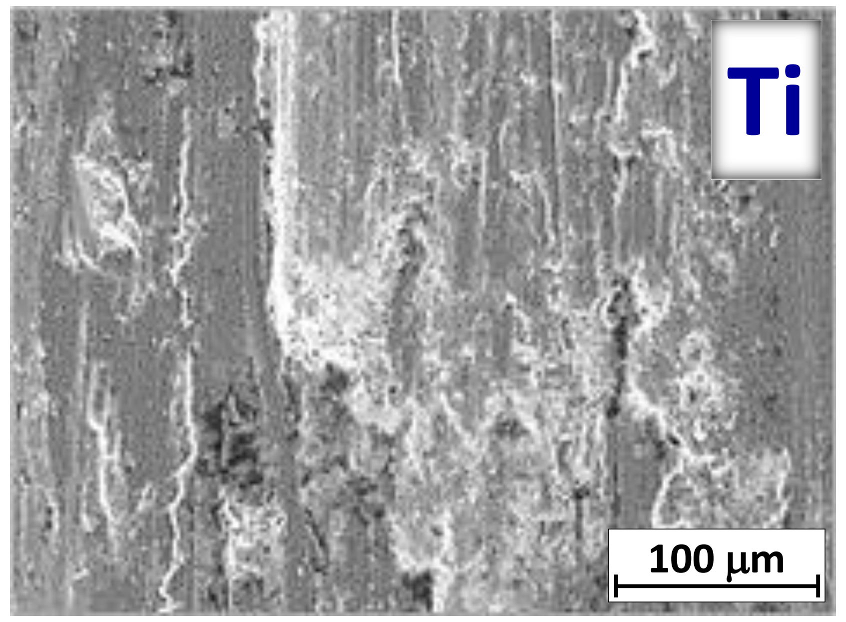
Effect of carbon on the wear resistance of titanium alloys



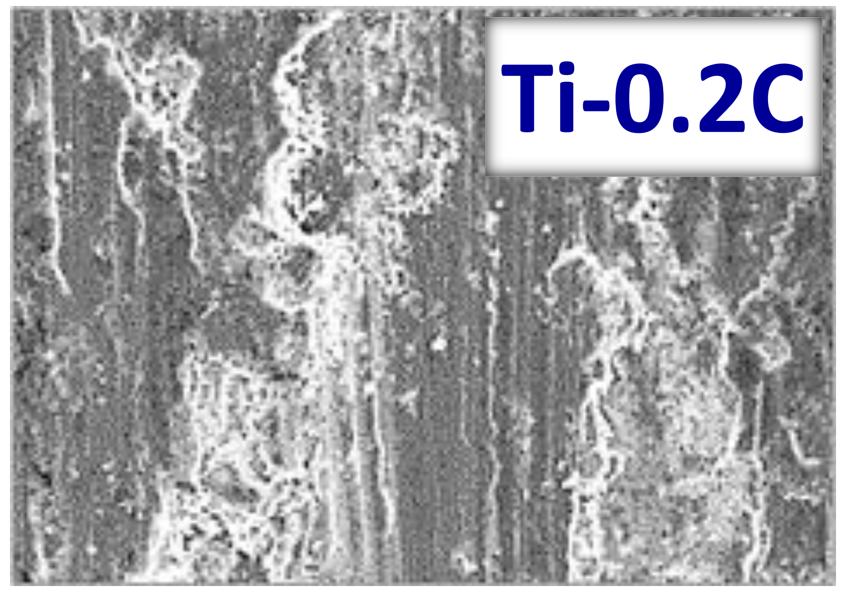
0.252±0.006

Ra=6.09



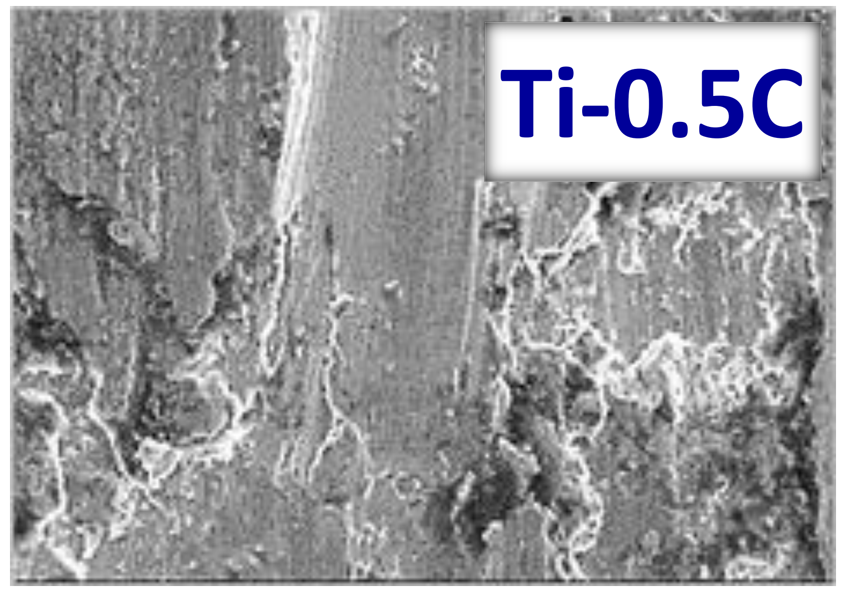
0.18±0.002

Ra=4.78



0.17±0.004

Ra=3.61



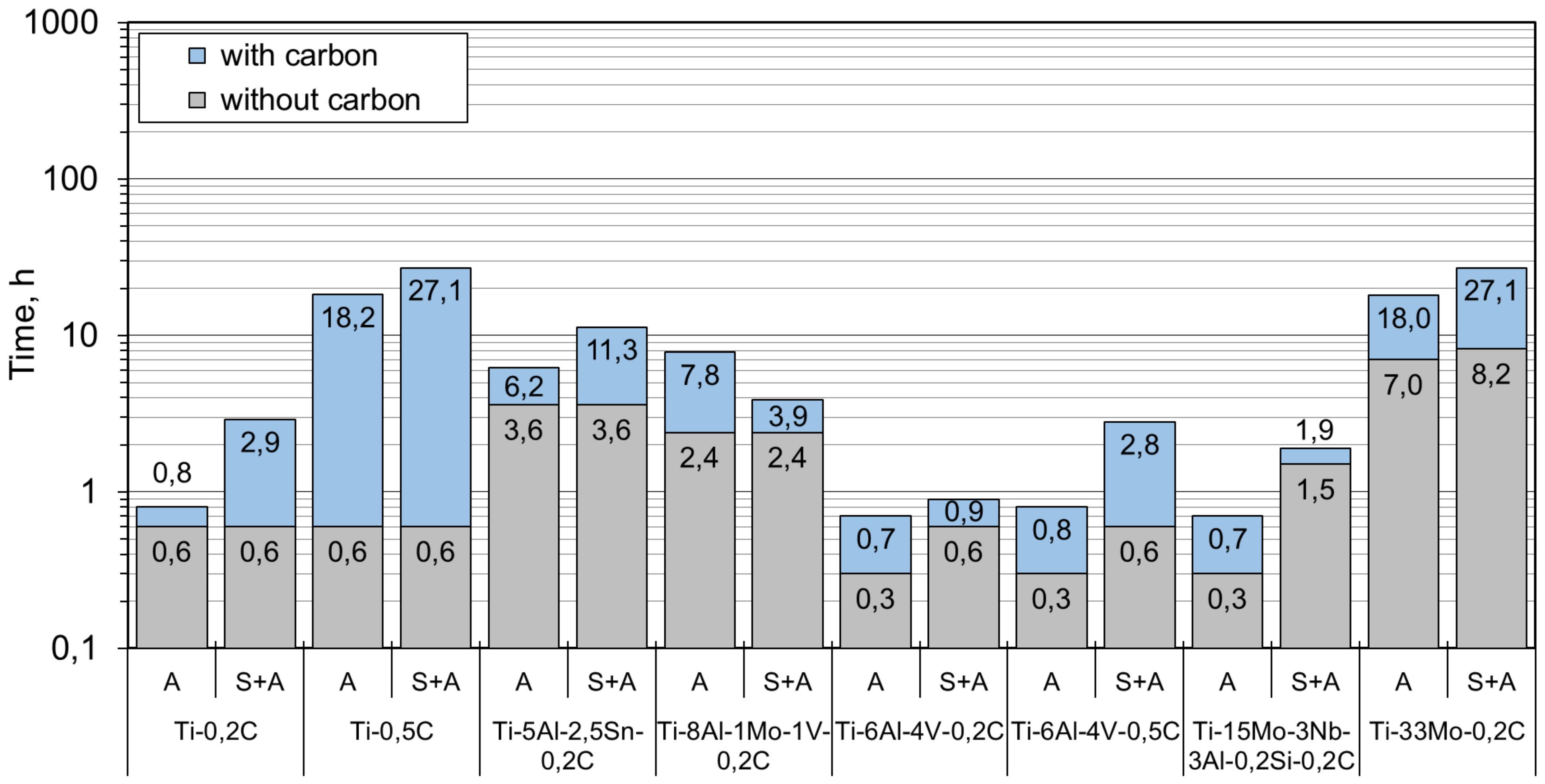
TEST PARAMETERS:

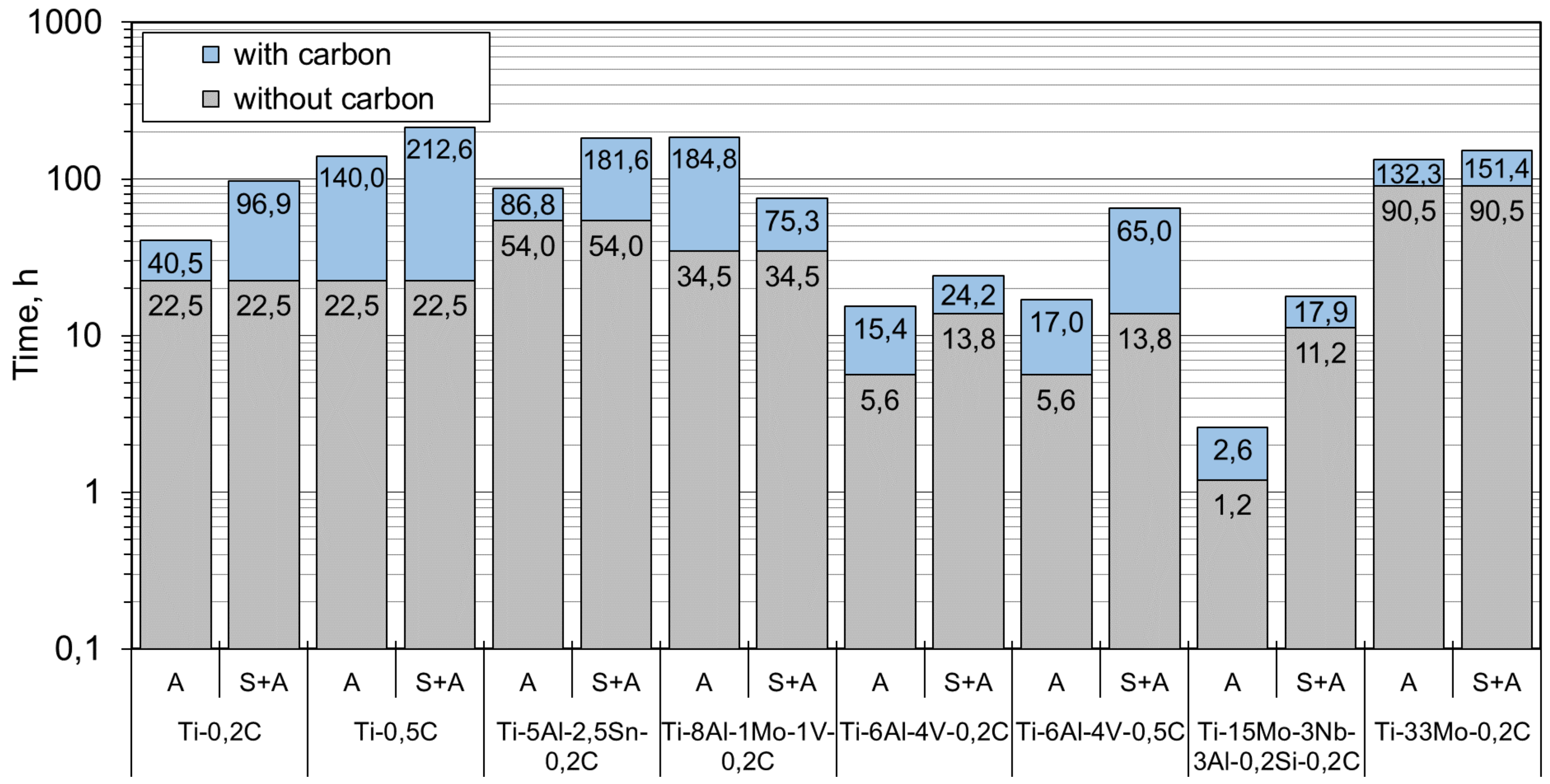
Dry friction. 0.5 m/s; 10N; to 500 m

Sample dimensions: 35x10x5 mm

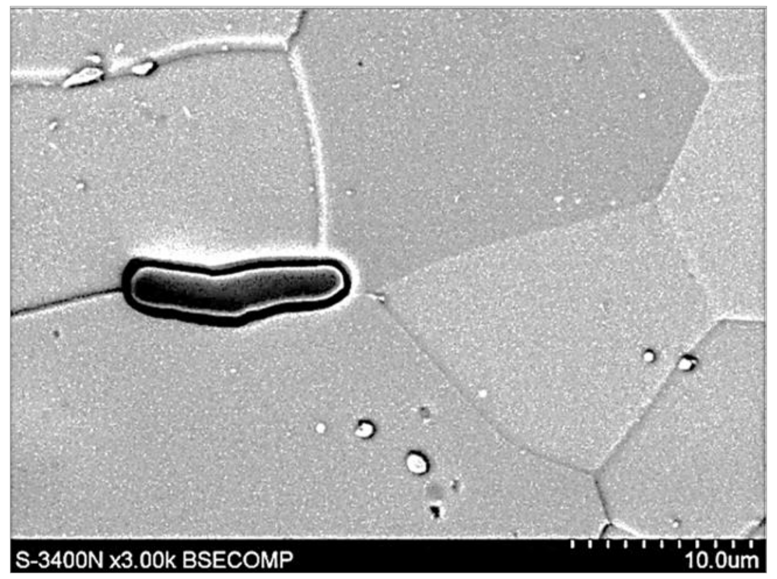
Counter-sample material: technically pure titanium

Effect of carbon on the creep resistance of titanium alloys

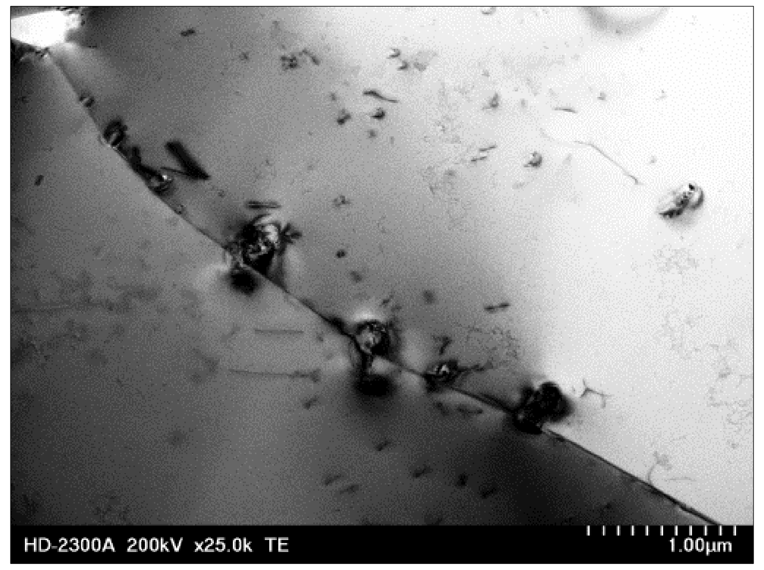


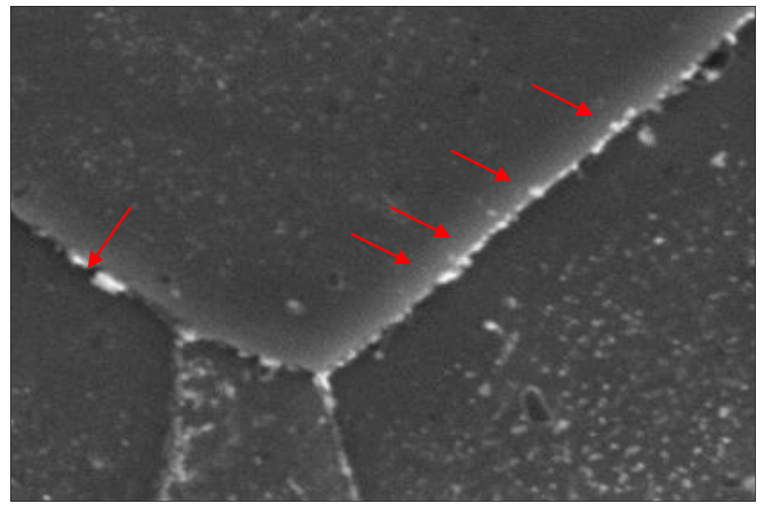


Primary carbides



Secondary carbides

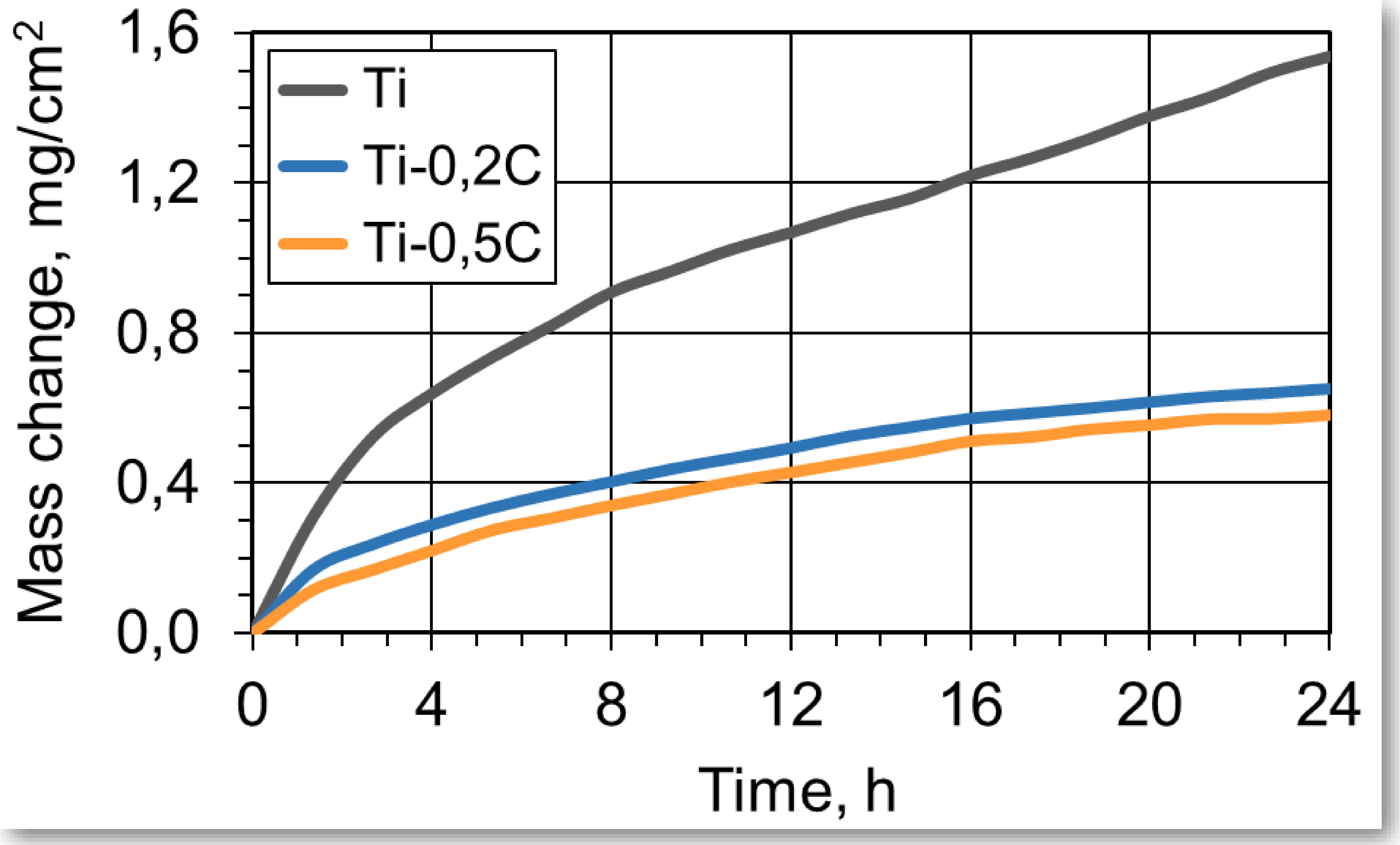




Alloy	State	Temperature ºC	Strain MPa	Creep time to stress. h						Steady state creep rate, s^{-1}
				0.1%	0.2%	0.5%	1.0%	2.0%	5.0%	
Ti (Grade 1)	A	400	170	0.1	0.6	8.4	22.5	45.8	73.4	0.000355
Ti-0.2C	A	400	170	0.1	0.8	13.2	40.5	85.0	193.0	0.000171
	STA			0.1	2.9	48.3	96.9	175.4	-	0.000067
Ti-0.5C	A	400	170	4.1	18.2	69.5	140.0	-	-	0.000058
	STA			5.9	27.1	97.4	212.6	-	-	0.000043

Effect of carbon on the oxidation resistance of titanium alloys

650^{o}C

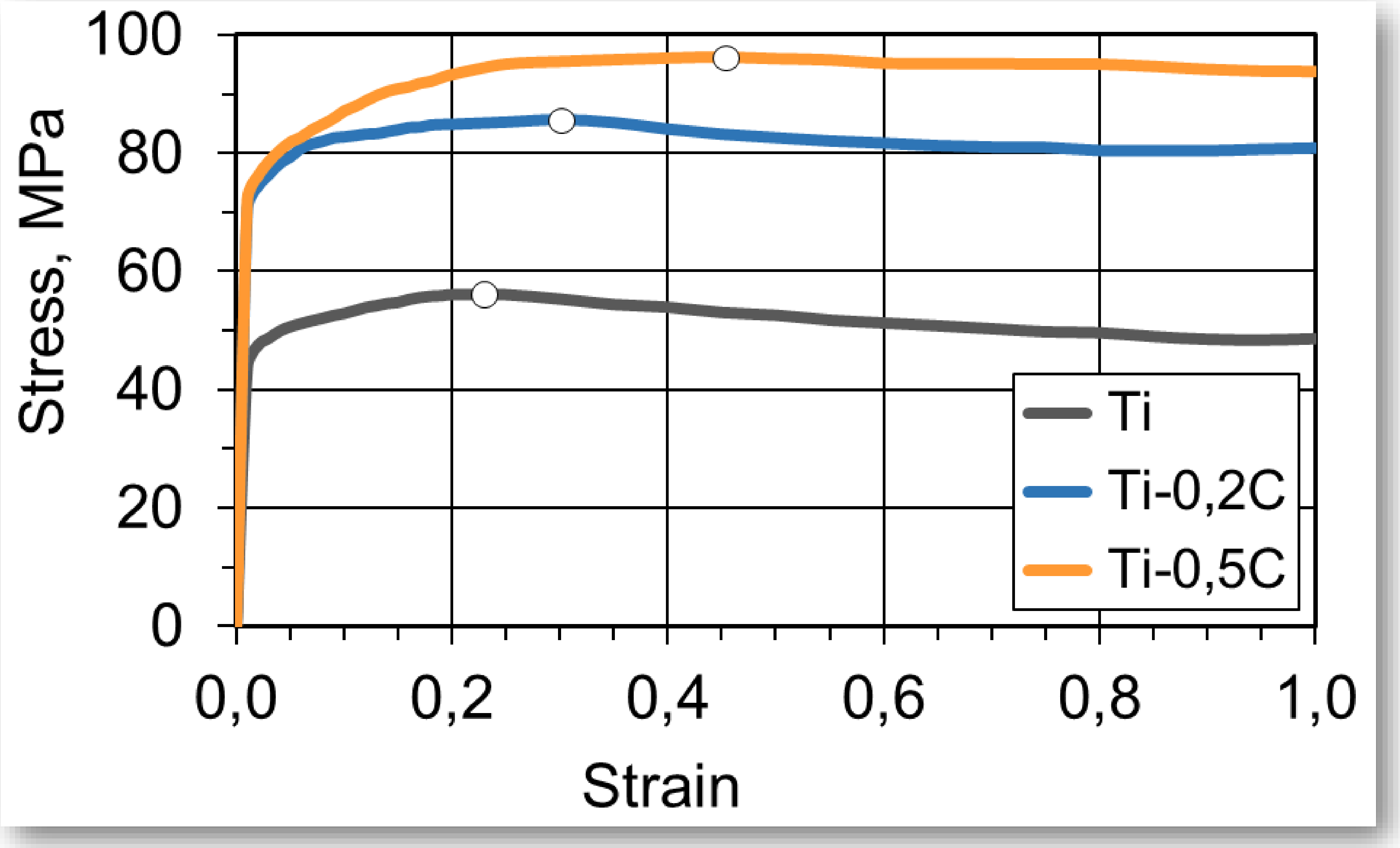


Reasons:

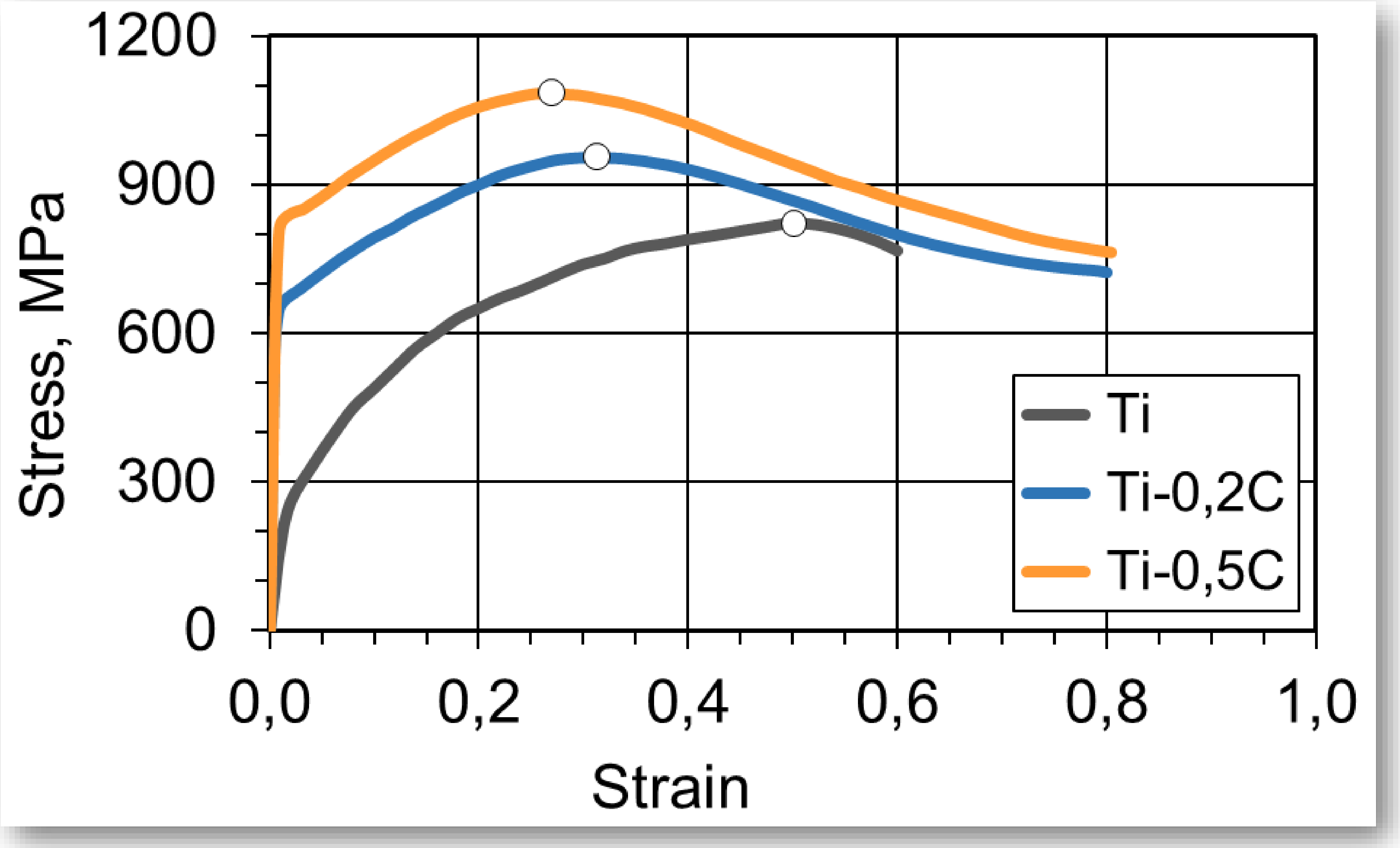
- decrease of oxygen diffusion activity by limiting its solubility in the interstitial spaces of the phases and occupied by carbon atoms
- decrease of oxygen content in the alloy matrix caused by the transfer of oxygen atoms from the matrix to the vacance in the carbon sublattice of non-stoichiometric TiCx carbides.

Effect of carbon on the deformability of titanium alloys

T = 890°C



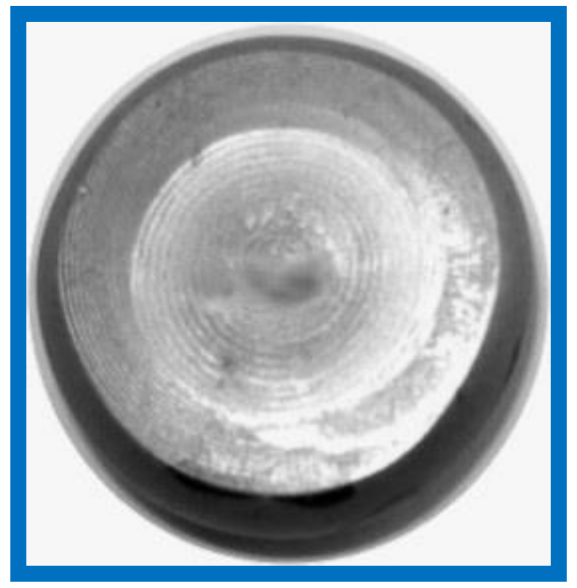
T = RT



Ti-0.2C

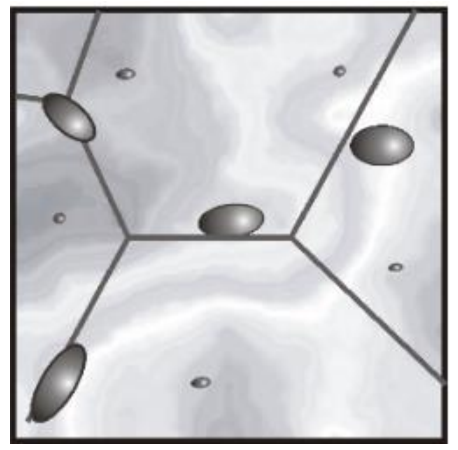
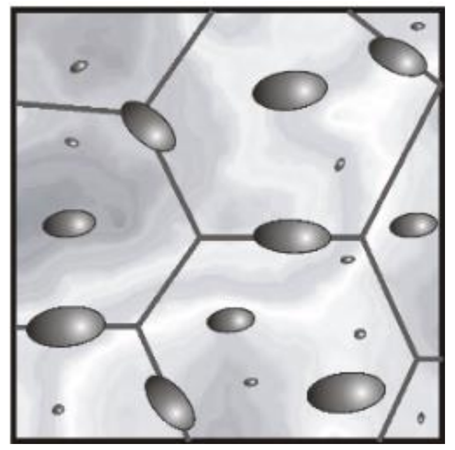
Ti-0.5C

Ti-0.2C



Ti-0.5C

Effect of carbon on the properties of titanium alloys – SUMMARY

<0.08%C	0.2%C	0.5%C
		
Tensile strength	++	+/–
Elongation	+/–	–
Young's modulus	+	+
Hardness	++	+
Impact Energy	–	– –
Creep resistance	+	++
Oxidation resistance	+	++
Corrosion resistance	+/–	–
Wear resistance	+	+
Hot formability	+/–	–
Cold formability	–	– –
Hardenability by heat treatment	+	+
Microstructure stability	+	+
Susceptibility to grain growth	+	++

Effect of 0.2% C on the properties of titanium alloys

Parameter	Effect of 0.2 mas. % C in titanium alloys					
	Ti	α	near-α	α+β	near-β	β
Tensile strength	+++	++	++	+	+	+
Yield strength	+++	++	++	+	+	+
Elongation	–/+	–/+	–/+	–/+	+	+
Young's modulus	+	+	+	+	+	+
Hardness	+++	++	++	+	+	+
Impact energy	–	– –	– –	– –	– –	–
Creep resistance	+++	+++	+++	+	+	++
Oxidation resistance	+++	+	+	++	+	+
Corrosion resistance	–/+	–/+	–/+	–/+	–/+	+/–
Hot formabiity	–/+	–	–	–	–	–
Cold formability	–/+	– –	– –	– –	– –	–
Wear resistance	+	+	+	+	+	+
Hardenability in heat treatment	++	++	+	+	+/–	+/–
Microstructure stability	+	+	+	+	+	+
Susceptibility to grain growth	+	+	+	+	++	++
Transformation temperature	+	+	+	+	+	

Carbon in titanium alloys – problems or benefits

It depends from:

- group of titanium alloys
- level of carbon content
- content of alloing elements (phase composition of alloy)

within the controlled content of up to approx. 0.2 wt.%. carbon in titanium alloys is not an impurity, but a component that may have many useful functions which are different for different groups of alloys

The results achieved to date perhaps bring closer the time when some small addition of carbon to any titanium alloy will become a mandatory standard???

Research Team

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Prof. dr hab. inż. Lucjan Swadźba
Prof. dr hab. inż. Janusz Szala
Dr hab. inż. Agnieszka Szkliniarz, prof. PŚ,
Dr hab. inż. Tomasz Rzychoń, prof. PŚ,
Dr hab. inż. Grzegorz Moskal, prof. PŚ,
Dr inż. Roman Przeliorz
Dr inż. Bartosz Chmiela,
Dr hab. inż. Kinga Rodak, prof. PŚ,
Dr inż. Tomasz Mikuszewski
Dr inż. Tomasz Pawlik
Dr inż. Rafał Michalik
Dr inż. Jacek Chrapoński
Dr inż. Barbara Juszczyk
Dr inż. Georg Jarczyk, ALD Vacuum Technologies, Hanau
Prof. Ivo Schindler, VSB Ostrava
Prof. Rudolf Kawalla, TU Bergakademie Freiberg

Technology Hall
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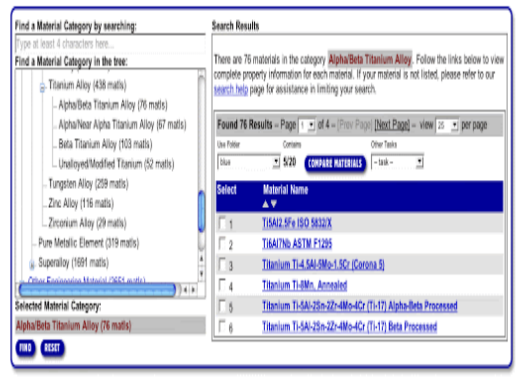
UCZELNIANA STREFA INNOWACJI MATERIAŁOWYCH

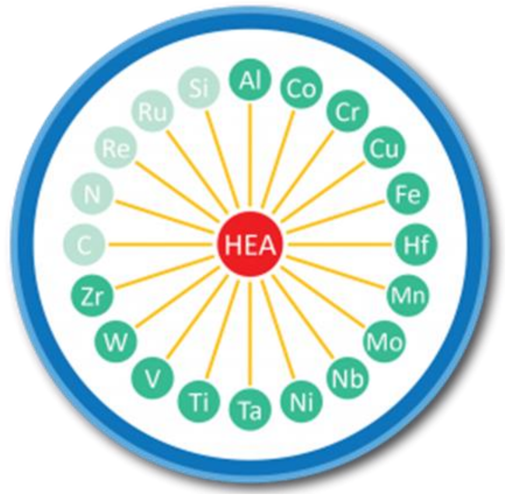
University Zone of Material Innovations (USTINMAT)

Alloy design → Production → Quality control → Processing → Heat and Surface treatment → Characterization → Degradation → Regeneration/ Recycling/Utylization







Wydział Inżynierii Materiałowej Politechnika Śląska

Thermo-Calc Software







Areas of research: **TiAl based alloys,**
Low-cost titanium alloys,
Lightweight high entropy alloys,
New titanium alloys for medicine,
Hydrogen storage materials.

Silesian University of Technology

We invite You to cooperation

Forum Inżynierii Materiałowej PAN – Materials Engineering Forum

Thank You for attention