CORRECT HEAT TREATMENT FOR THE PRODUCTION OF CASTINGS OF THE ALLOY ASTM A494 42Ni-21.5Cr-3Mo-2.3Cu

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Material

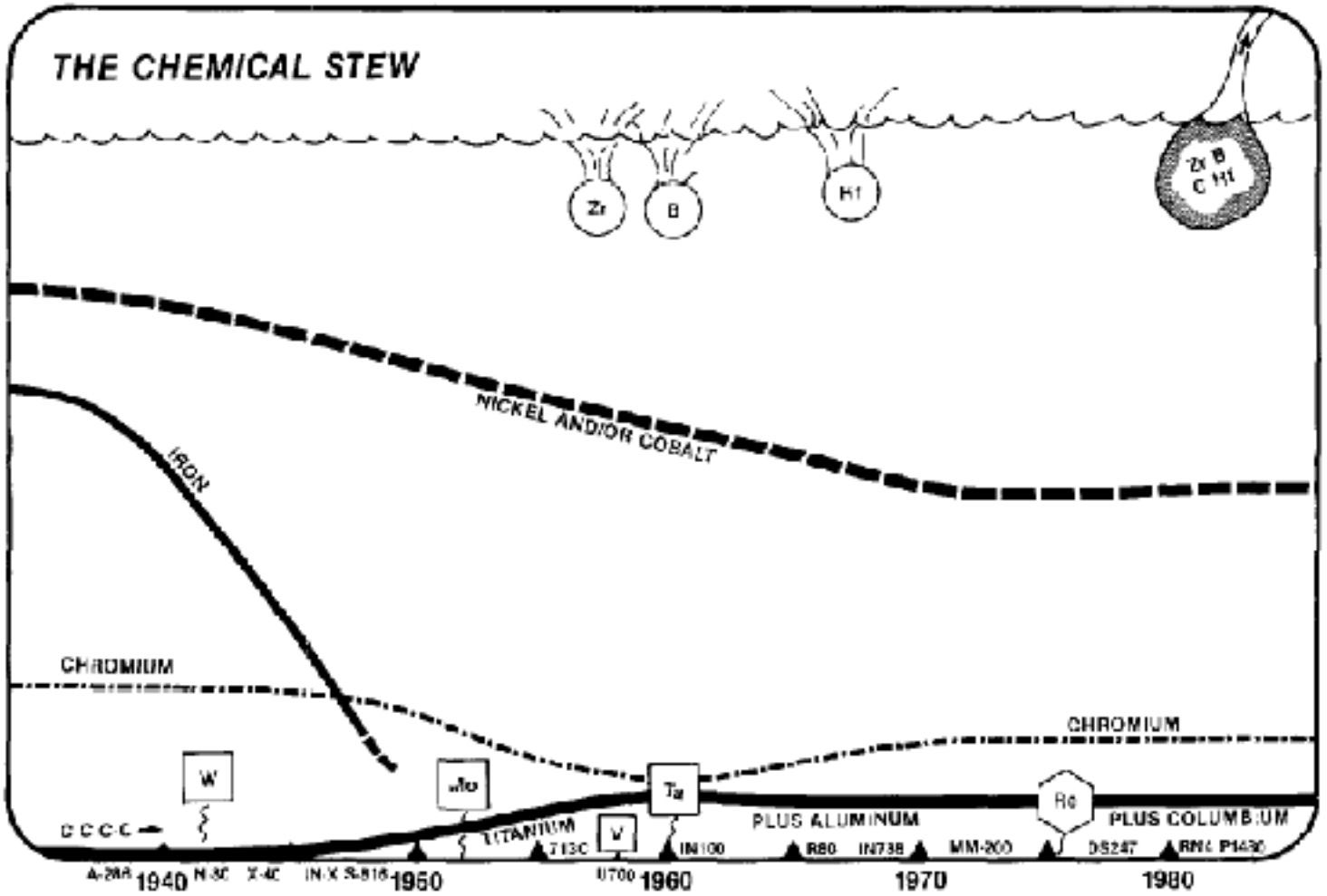
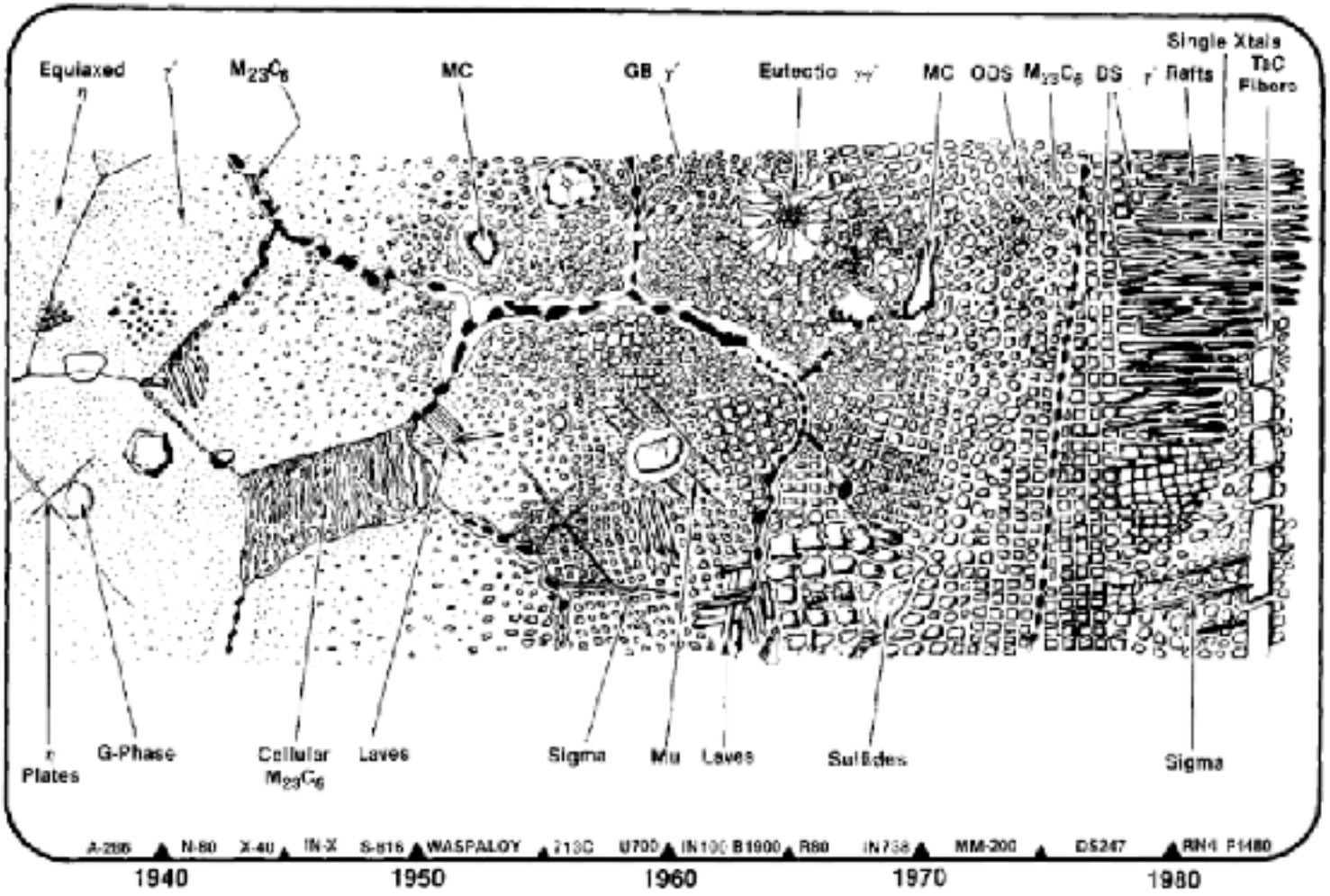


Figure 4. A qualitatively comparative view of trends in superalloy composition for representative superalloys.

Microstructural evolution



Material & technological process

The super-alloys can be classified in four main groups

1 – solubilized for the chromium carbide precipitation
2 – γ' hardened by the precipitation of the intermetallic [Ni_3.(Al.Ti)]
3 – γ'' hardened by the precipitation of the intermetallic Ni_3.Nb
4– strengthened by the dispersion of the oxide particles

All the super-alloys have to undergone a solubilization process

INCOLOY 825

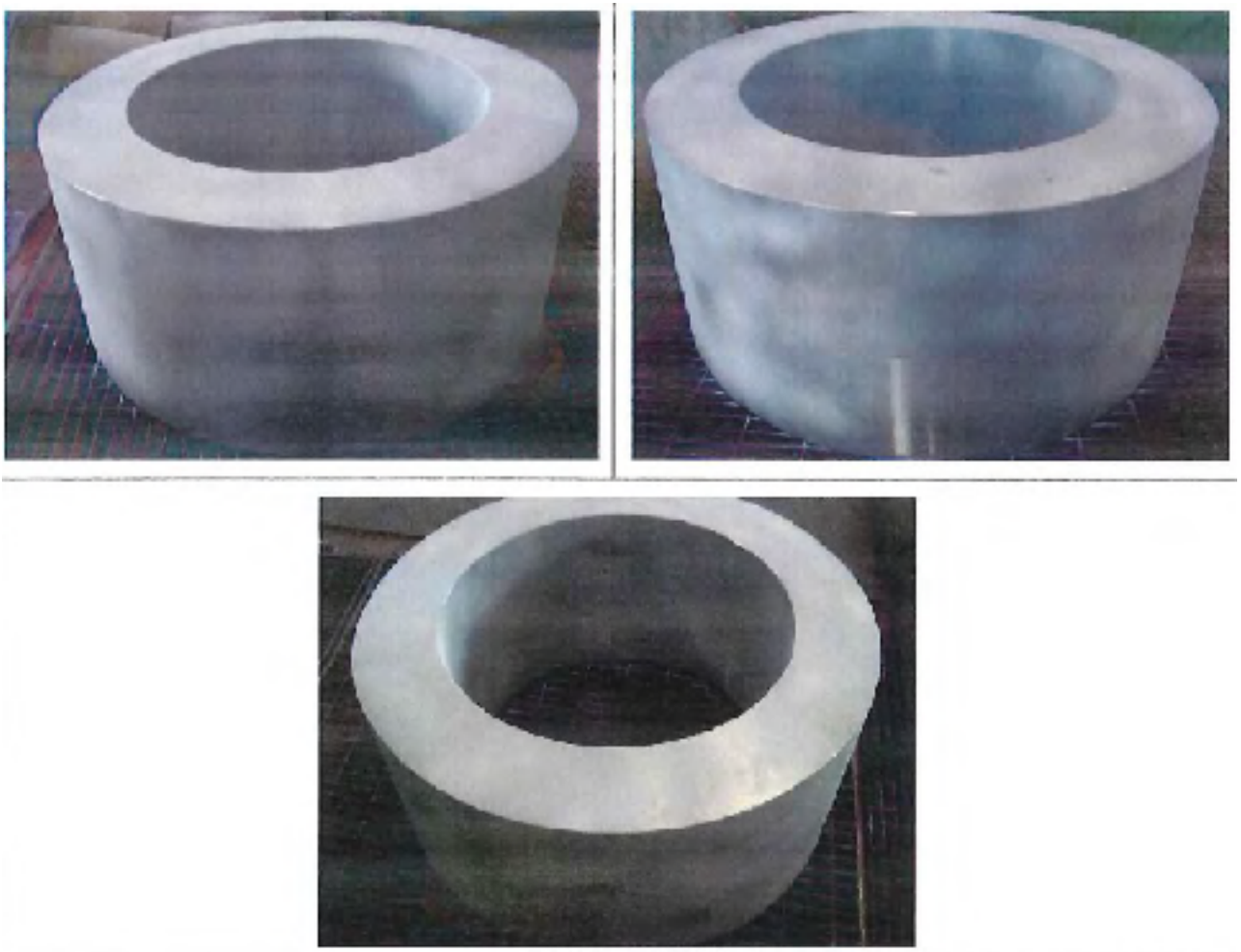
Rolled and Forged Products

Nickel	38.0-46.0
Iron	22.0 min.
Chromium	19.5-23.5
Molybdenum	2.5-3.5
Copper	1.5-3.0
Titanium	0.6-1.2
Carbon	0.05 max.
Manganese	1.0 max.
Sulfur	0.03 max.
Silicon	0.5 max.
Aluminum	0.2 max.

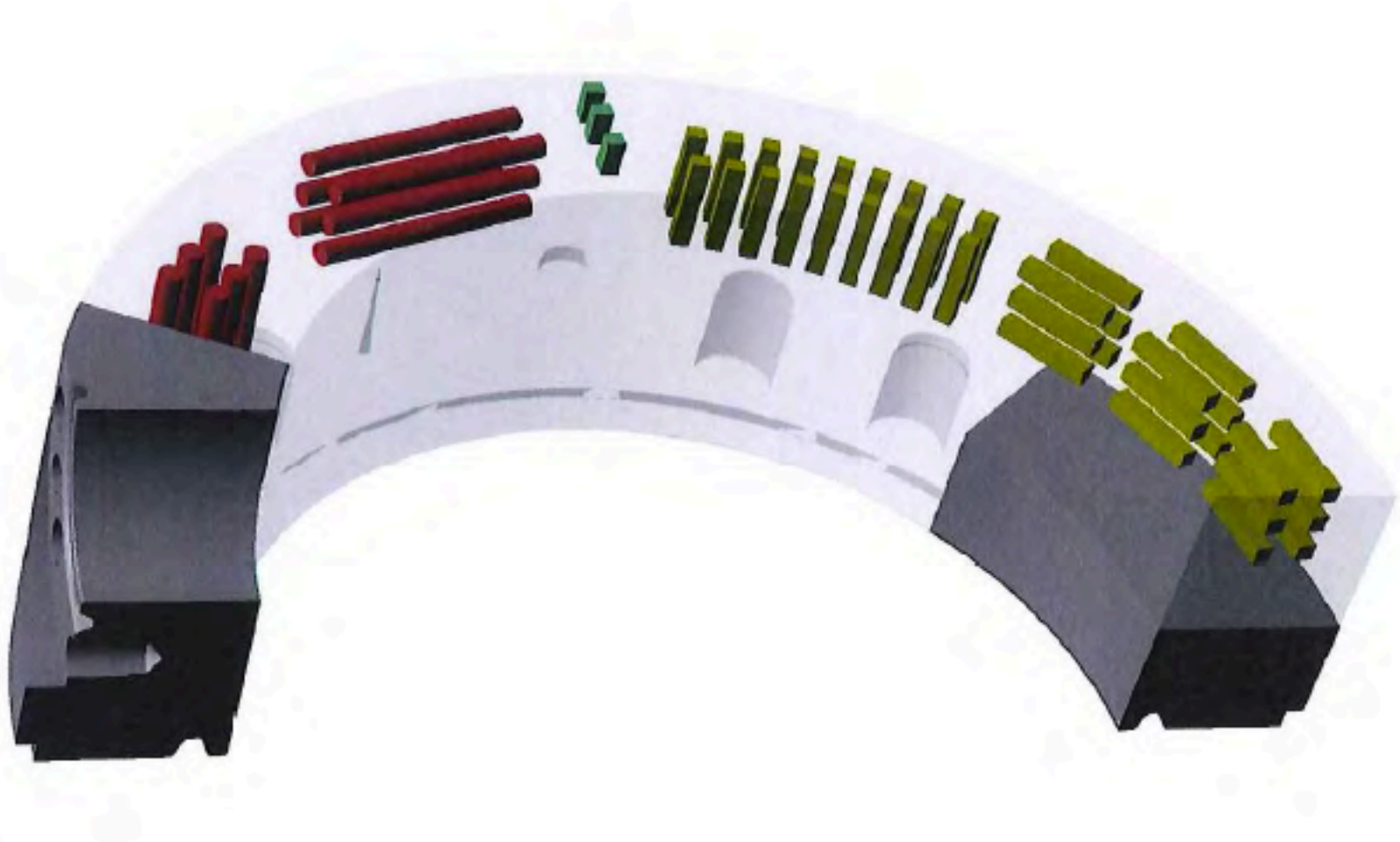
Cast Products

Niobium	1.2 max.

Material & technological process



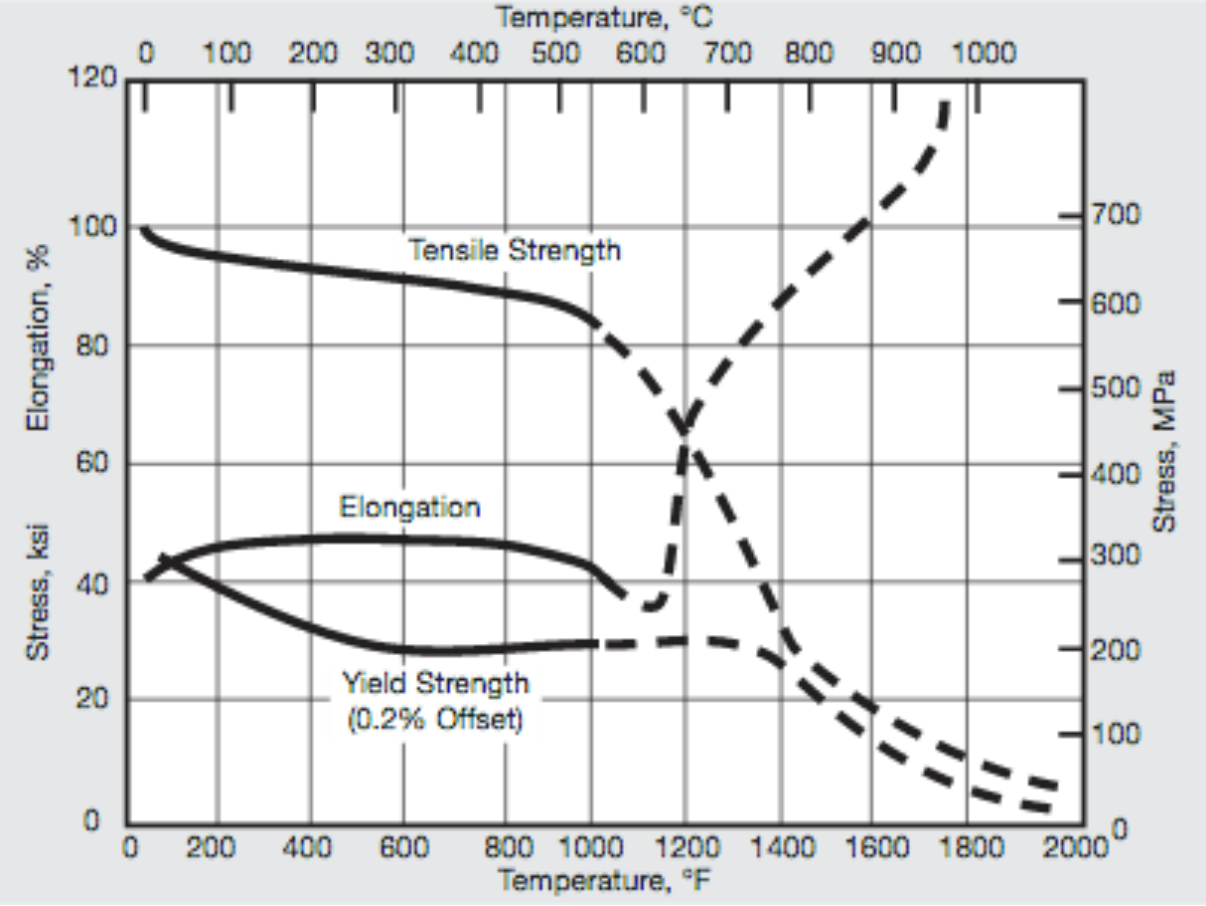
Sampling of the specimens



Mechanical properties typical of the rolled or forged products

Form	Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation
	ksi	MPa	ksi	MPa	%
Plate Annealed	49	338	96	662	45
Sheet Annealed	61	421	110	758	39
Rod and Bar Annealed	47	324	100	690	45
Tubing Cold Drawn	129	889	145	1000	15
Tubing Annealed	64	441	112	772	36

Mechanical Properties



Corrosion resistance

Test Environment		Temperature		Length of Test	Corrosion Rate	
Name	Test conditions	°F	°C	Days	mpy	mm/y
Sulfuric Acid	40 % Sulfuric Acid	122	50	7	0.5	0.013
Sulfuric Acid	40 % Sulfuric Acid	212	100	7	14	0.36
Sulfuric Acid	60 % Sulfuric Acid	122	50	7	4	0.1
Sulfuric Acid	60 % Sulfuric Acid	212	100	7	20	0.51
Sulfuric Acid	80 % Sulfuric Acid	122	50	7	5	0.13
Sulfuric Acid	80 % H_2SO_4	212	100	7	20	0.51
Sulfuric Acid	Aqueous solution containing 0.05 % Sulfuric Acid	210	99	45	2	0.051
Sulfuric Acid	12 % Sulfuric Acid pickling solution containing copper sulfate up to 11.2 %. Immersed inside pickling tank.	180	82	26	0.2	0.005
Sulfuric Acid	50 % Sulfuric Acid, 22 % Nitric Acid & 19 % Water	150	66	6	0.5	0.013
Sulfuric Acid	50 % Sulfuric Acid, 22 % Nitric Acid & 19 % Water	182	83	5	4.3	0.105
Phosphoric Acid	45 % Phosphoric Acid	145–155	63–68	30	0.5	0.015
Phosphoric Acid	75 % Phosphoric Acid	172	78	30	0.2	0.005
Phosphoric Acid	75 % Phosphoric Acid	221	105	30	1.3	0.033
Phosphoric Acid	75 % Phosphoric Acid	240–260	115–127	30	3.9	0.005
Phosphoric Acid	20 % H_3PO_4, 2 % H_2SO_4, 1 % HF, 40 % H_2O plus $CaSO_4$	170–200	77–93	117	0.7	0.018
Phosphoric Acid	75–80 % H_3PO_4, 1 % H_2SO_4 with some HF. Violent Agitation	250–315	121–157	8	120	3.05

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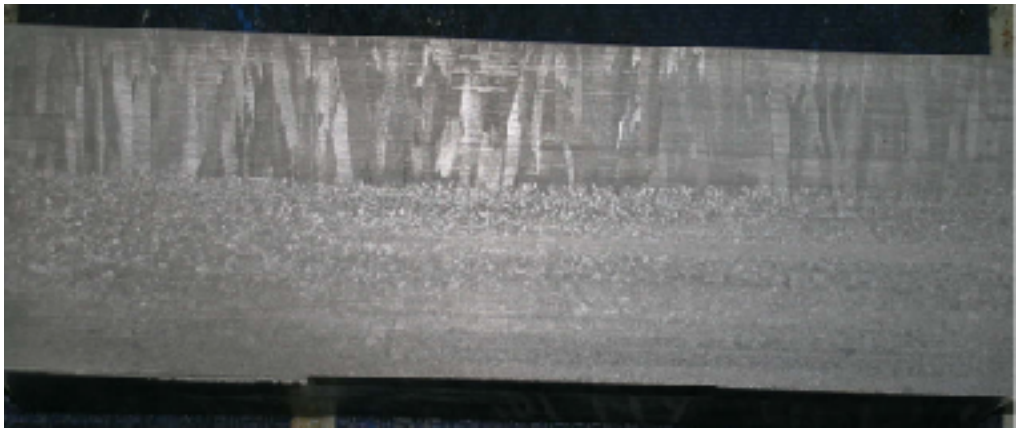
Test Environment		Temperature		Length of Test	Corrosion Rate	
Name	Test conditions	°F	°C	Days	mpy	mm/y
Nitric Acid	White fuming Nitric Acid	room	room	30	0.5	0.013
Nitric Acid	White fuming Nitric Acid	160	71	7	43	1.09
Nitric Acid	Inhibited white fuming Nitric Acid	room	room	30	0.2	0.005
Nitric Acid	Inhibited white fuming Nitric Acid	160	71	7	6.7	0.17
Nitric Acid	Inhibited red fuming Nitric Acid	room	room	30	0.6	0.015
Nitric Acid	Inhibited red fuming Nitric Acid	160	71	7	6.4	0.163
Hydrochloric Acid	5 % Hydrochloric Acid	room	room	–	4.9	0.124
Hydrochloric Acid	5 % Hydrochloric Acid	104	40	–	17.6	0.124
Hydrochloric Acid	5 % Hydrochloric Acid	150	66	–	79	2.007
Hydrochloric Acid	10 % Hydrochloric Acid	room	room	–	7.2	0.183
Hydrochloric Acid	10 % Hydrochloric Acid	104	40	–	18.6	0.472
Hydrochloric Acid	10 % Hydrochloric Acid	150	66	–	102	2.591
Hydrochloric Acid	20 % Hydrochloric Acid	room	room	–	7.3	0.185
Hydrochloric Acid	20 % Hydrochloric Acid	104	40	–	17.2	0.437
Hydrochloric Acid	20 % Hydrochloric Acid	150	66	–	60	1.524
Hydrochloric Acid	Concentrated Hydrochloric Acid	104	40	–	480	12.2
Hydrochloric Acid	Concentrated Hydrochloric Acid	150	66	–	1130	28.7
Acetic Acid	10 % Acetic Acid	boiling	boiling	5	<0.1	<0.003
Formic	10 % Formic Acid	boiling	boiling	5	2.5	0.064
Lactic	10 % Lactic Acid	boiling	boiling	5	0.3	0.008
Maleic	10 % Maleic Acid	boiling	boiling	5	0.1	0.003
Phtalic	10 % Phtalicic Acid	boiling	boiling	5	<0.1	<0.003
Oxalic	10 % Oxalic Acid	boiling	boiling	5	20	0.508
Organic Acid Mixture	99 % Acetic Acid, <0.1 % water	225	107	40	0.2	0.005
Organic Acid Mixture	96.5–98 % acetic acid, 1.5 % formic acid, 1–1.5 % water	225	107	262	6	0.152
Organic Acid Mixture	91.5 % acetic acid, 1.5–2 % formic acid, 0.5 % potassium permanganate, balance water	230–290	110–143	56	1.5	0.038
Organic Acid Mixture	40 % acetic acid, 6 % propionic acid, 20 % butane, 5 % pentane, 8 % ethyl acetate, 5 % methyl ethyl ketone, plus other esters and ketones	345	174	217	2	0.051

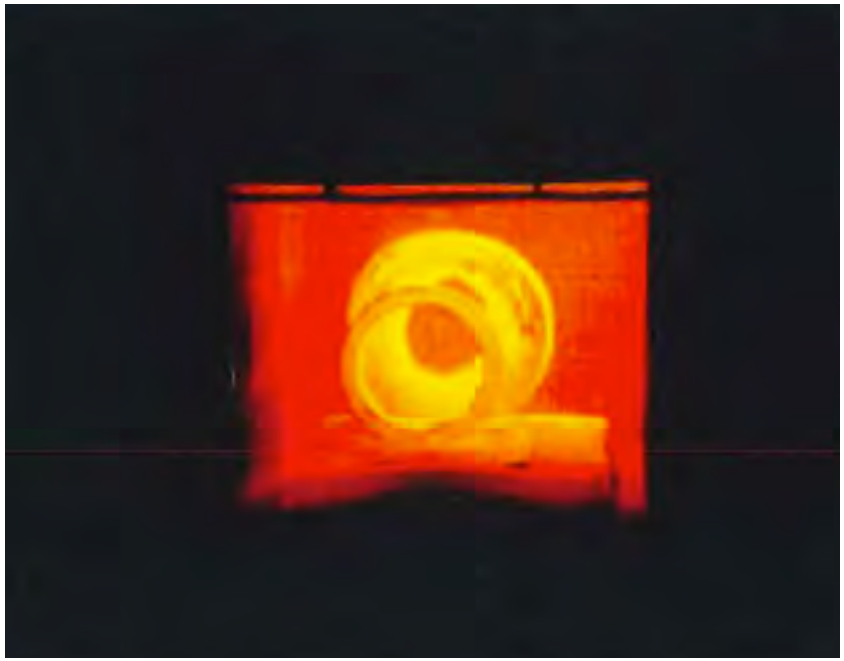
Solidification macrostructure of the cast spheres



Cracks observed after the final test by penetrant liquids

Swirled cast products

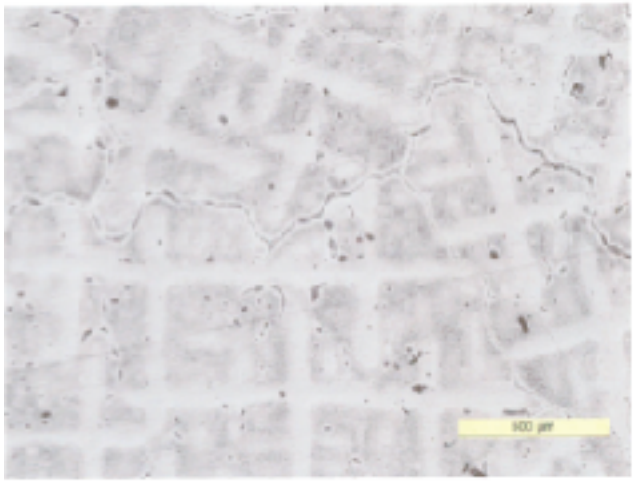
Heat treatment



Solubilization ????°C + Water quenching
Stabilization 950°C + Water quenching

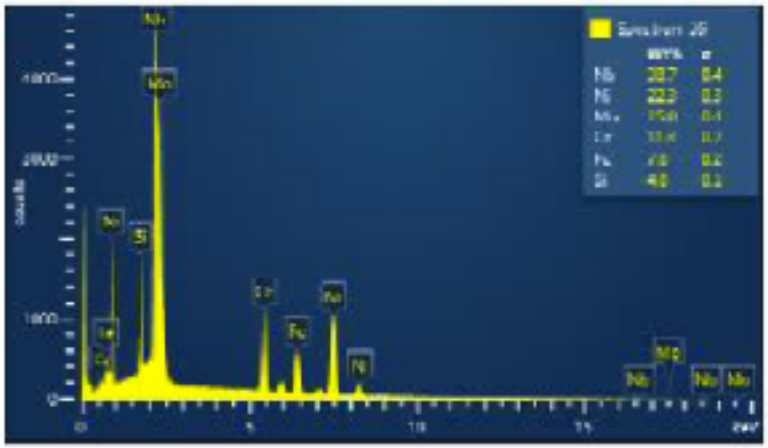
After solubilization at 1150°C

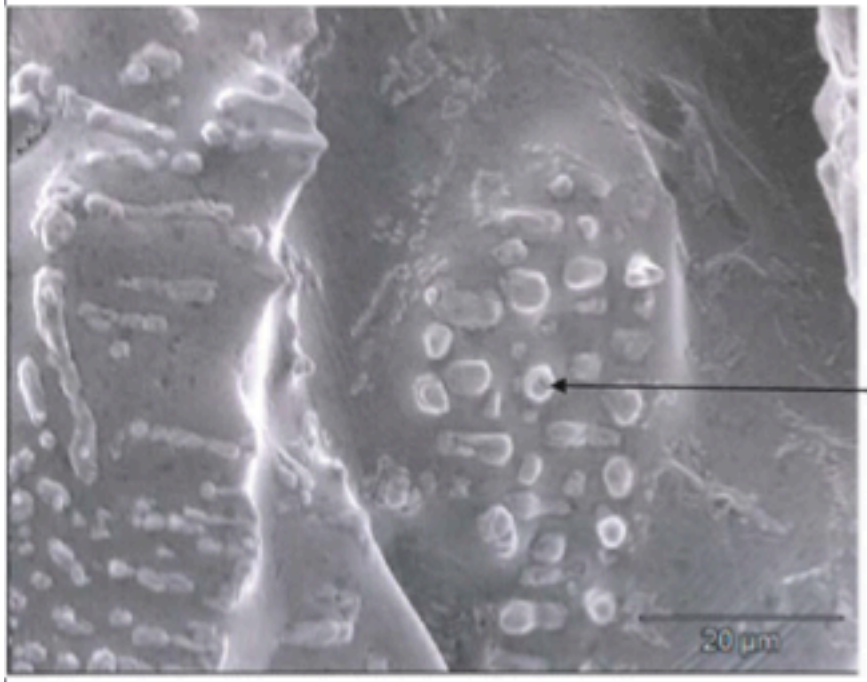
Columnar region

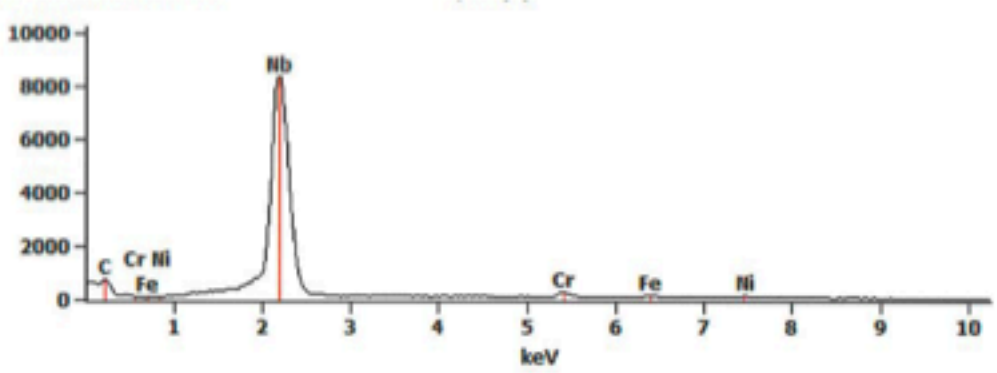


Equiaxic region

Formation of a NbC-Mo_2C network







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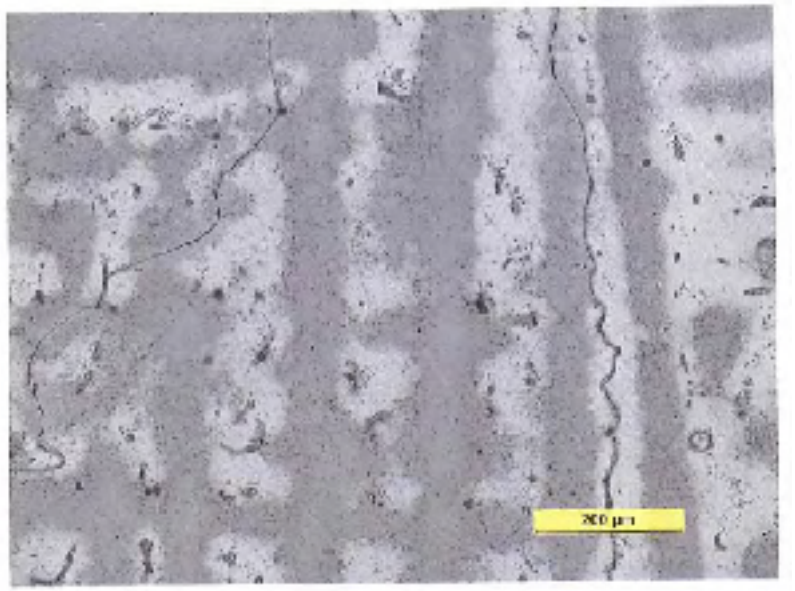
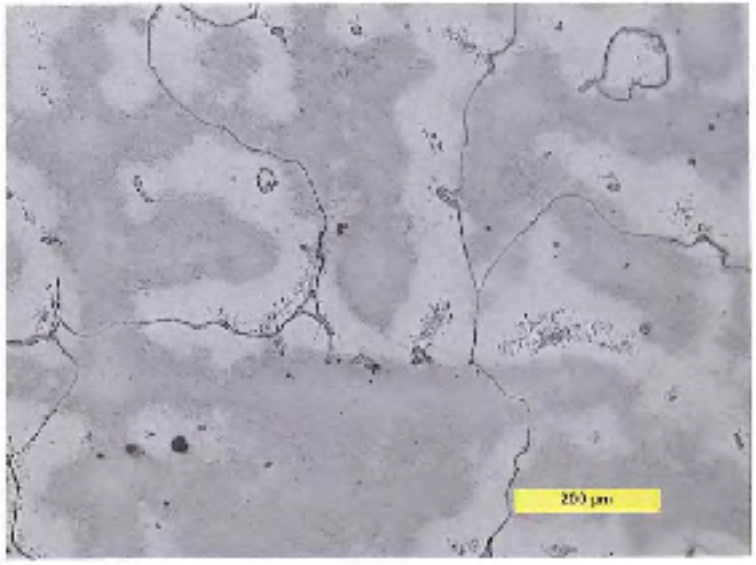
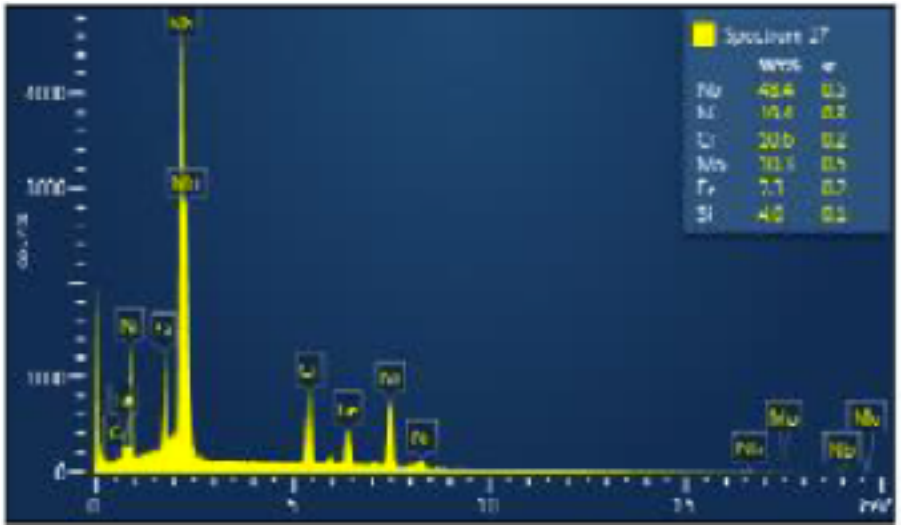
Element	Net Counts	Weight %	Atom %
Cr	3005	2.36	4.03
Fe	1862	2.03	3.22
Ni	1569	2.56	3.86
Nb	196146	93.06	88.89
Total		100.00	100.00

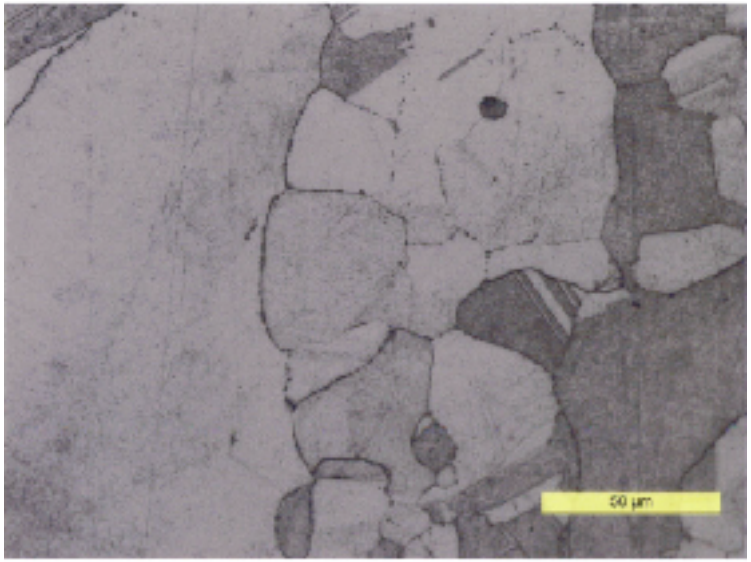
After solubilization at 1190°C

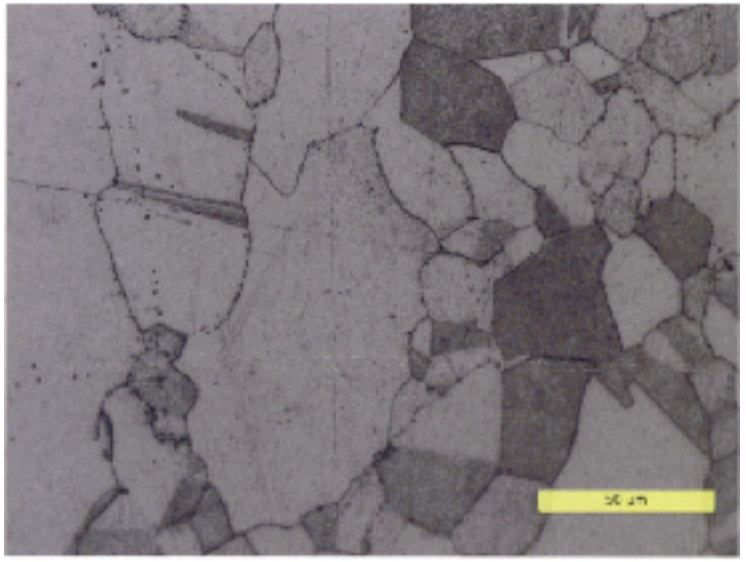






Solubilization at 1115°C of the forged product





Fine precipitation of the carbides at the grain boundaries.

Conclusions

- The observed fractures are caused by the formation of a continuous network of NbC-Mo_2C;

- The INCOLOY 825 alloys for the production of casting are more sensitive to the observed detrimental phenomena because they are featured by a higher concentration of Nb (as a strengthening and stabilizing element) than the alloy used for forging;

- the solubilization of the alloy for te foundry application has to be performed at leat at 1180°C to avoid the formation of an interconneted carbide network that induces brittleness in the castings.