Materials in Cryo Condition

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Background

; Stainless Steel AISI 302 in spring condition become static (Lost its ductility) during load test at temperature -65 to -40℃ after exposing to Cryo temperature between -200 to -165℃ for about 15 Min.

Purpose

1) Understanding the basic theory of spring static phenomena after exposing to Cryo condition.
2) Evaluate a better grade for Cryo Temperature.
3) Possibility to change the spring load test parameters.

Simple Answer

; It is normal for some material, when it expose to a Cryo temperature, the strength increase but in the same time the ductility is drop.

; It is occurred due to the phase transformation from austenite (γ) to martensite (α′).

; Several references also proposed that dislocation is hard to move at a very low temp.

Austenite – martensite (γ-α′) transformation in metastable austenitic STS

☞ Metastable austenitic STS can be transformed to martensite by 2 methods :

① Cold working (Transformation induced plasticity) and,

② Expose to Cryo temperature (Below Ms temperature)

※ It can be both in the same time (Cryo cold working).

※ Ms temp. is defined as the temp. at which α′ transformation begins to take place spontaneously.

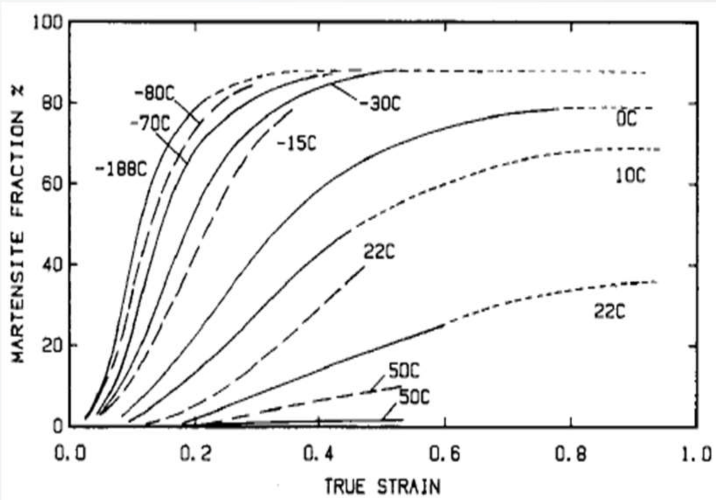

Fig.1 - Graph of 304STS tensile strength exposing at cryo temp.

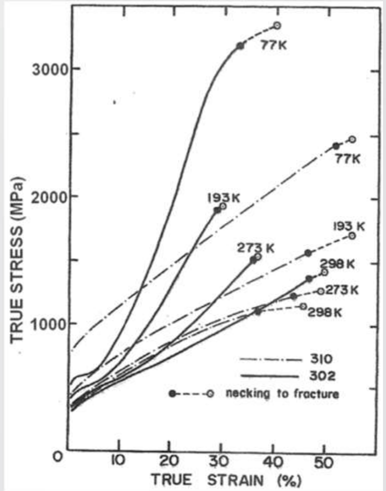

Fig. 2 - True Stress-Strain for AISI 302 and 301 STS from RT to -196℃

☞ In Fig. 1, as test temp. lower, the α′ qty′ increase in the same true strain.
☞ In Fig. 2, as test temp. lower, the true stress increase significantly in the same true strain.

Austenite – martensite (γ-α′) transformation in metastable austenitic STS

Concept :

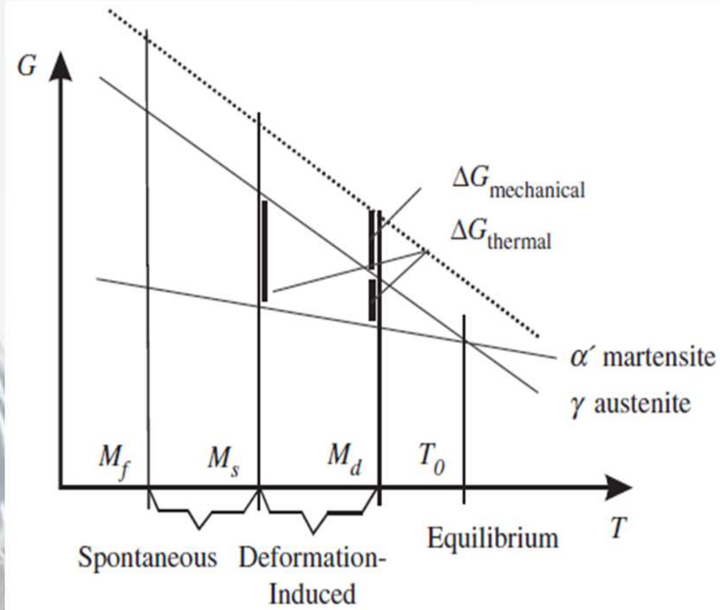

Fig. 3 – Schematic representation of the austenite to martensite transformation depending on the respective Gibbs free energy G versus temperature of Ms, Mf and Md30.

1) When the Gibbs free energy difference ΔG is not sufficient to cause spontaneous transformation of FCC, martensite may be formed by increasing ΔG through a mechanical deformation energy ΔGmech.
2) Cryo condition and mechanical energy during deformation is simply to increase the delta Gibbs free energy (ΔG to initiate and grow the martensite).

Austenite – martensite (γ-α′) transformation in metastable austenitic STS

Example of the Change Martensite (α′) in Cryo Condition (KOS Data) :

Fig. 4 – Comparison of α′ quantity during cold working in Cryo condition and in RT

Conclusions : The change of strength and ductility of wire after or during soaking at cryo condition is due to the phase transformation (γ -> α′).

The trasformation can be accelerated by mechanical.

What is the Solution ?

1) Need to change the material to a grade that more stable in austenite condition (Less difficult to γ – α′ transformation), either by spontaneous transformation or by mechanical.

☞ Several way to indicate that material more ɣ stable (Ex. Ms temp., Md30 temp. or Stacking fault energy).

Ms : The temperature where γ-α′ transform simultaneously.

Md30 : Temperature where the amount of transform α′ is 50% for 30% true strain.

1) Ms was calculated by equation below (Eichelmann) :

Ms Temp. = 1350-1665(C+N)-28(Si)-33(Mn)-42(Cr)-61(Ni)

2) Md30 was calculated by equation below (Nohara) :

Md30 Temp. = 551-462(C+N)-9.2(Si)-8.1(Mn)-13.7(Cr)-29(Cu+Ni)-18.5(Mo)-68(Nb)

Disclaimer :

※ There are several Ms Temp. eq and either of them can be used depend on the needs.

※ There are several Md30 Temp. eq and KOS is using Nohara as the most appropriate.

What is the Solution ? (Cont')

Table – Comparison of Ms and Md temperature of several grade material

Grade	Chemical									Ms Temp, Eichelmann (℃)	Md30, Nohara (℃)
	C	N	Si	Mn	Cr	Ni	Cu	Mo	Nb		
304DST	0.074	0.035	0.419	1.240	18.050	8.445	0.304	0.242	-	-158	-18
304H2P	0.073	0.041	0.440	1.087	18.252	8.331	0.298	0.181	-	-164	-18
302	0.073	0.041	0.480	1.271	18.213	8.021	0.278	0.173	-	-150	-10
316	0.055	0.017	0.402	1.577	16.793	10.564	0.344	2.026	-	-185	-83
2205	0.021	0.175	0.447	0.633	22.157	5.170	0.122	3.024	-	-258	-62
316N	0.067	0.208	0.293	1.296	16.631	10.038	0.365	2.026	-	-472	-157
A286	0.037	-	0.187	1.135	12.210	21.860	-	0.920	-	-601	-295

※The value of Ms and Md can be vary depend on the small difference of alloying and material condition (annealed finished or cold work finished)

☞ Ms and Md expressed the stability of material in Cryo condition and during mechanical working.

☞ The lower the Ms and Md, the more stable.

☞ Material that tested below Ms temp, will become static due to the spontaneous transformation of ɣ -> α'.

Conclusions

1) For AISI 302 STS, Ms Temp. is -150℃. It means, spontaneous γ -> α' might occur that cause spring become static.

2) AISI 316 STS is more stable and can be exposed up to -185 ℃. However, in the same wire size of wire, the wire strength would be lower.

3) AISI 316N STS and Duplex 2205 might be a better option where better strength and can be exposed to a much lower temperature.

4) If the needs is only temperature up to -65℃, exposing material to temperature up to -200℃ is NOT needed. So, if the test can be performed only at -65℃, NO need to change the material.