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Progress Report No. 40
for the period
August 1, through August 31, 1961

on

EVOLUTION OF ULTRA-HIGH STRENGTH STEELS, AND RESEARCH ON MATERIALS AND VARIOUS NOVEL TECHNIQUES OF FABRICATION OF HIGH PERFORMANCE ROCKET MOTOR CASES

Mellon Institute Project No. 381-3

Submitted to:

Bureau of Naval Weapons
Code SP-271
under
Prime Contract: NOrd 18169

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TABLE I

Results of Room Temperature Tensile Tests[a] on Beryllium Wire[b]

Test Number	Threshold[c] Yield Strength ksi	0.2% offset Yield Strength ksi	Tensile Strength ksi
1	144	166	177
2	136	166	179
3	144	168	178

(a) Test conducted in accordance with ASTM specifications.

(b) As-drawn condition.

(c) Corresponds to 0.05% offset.

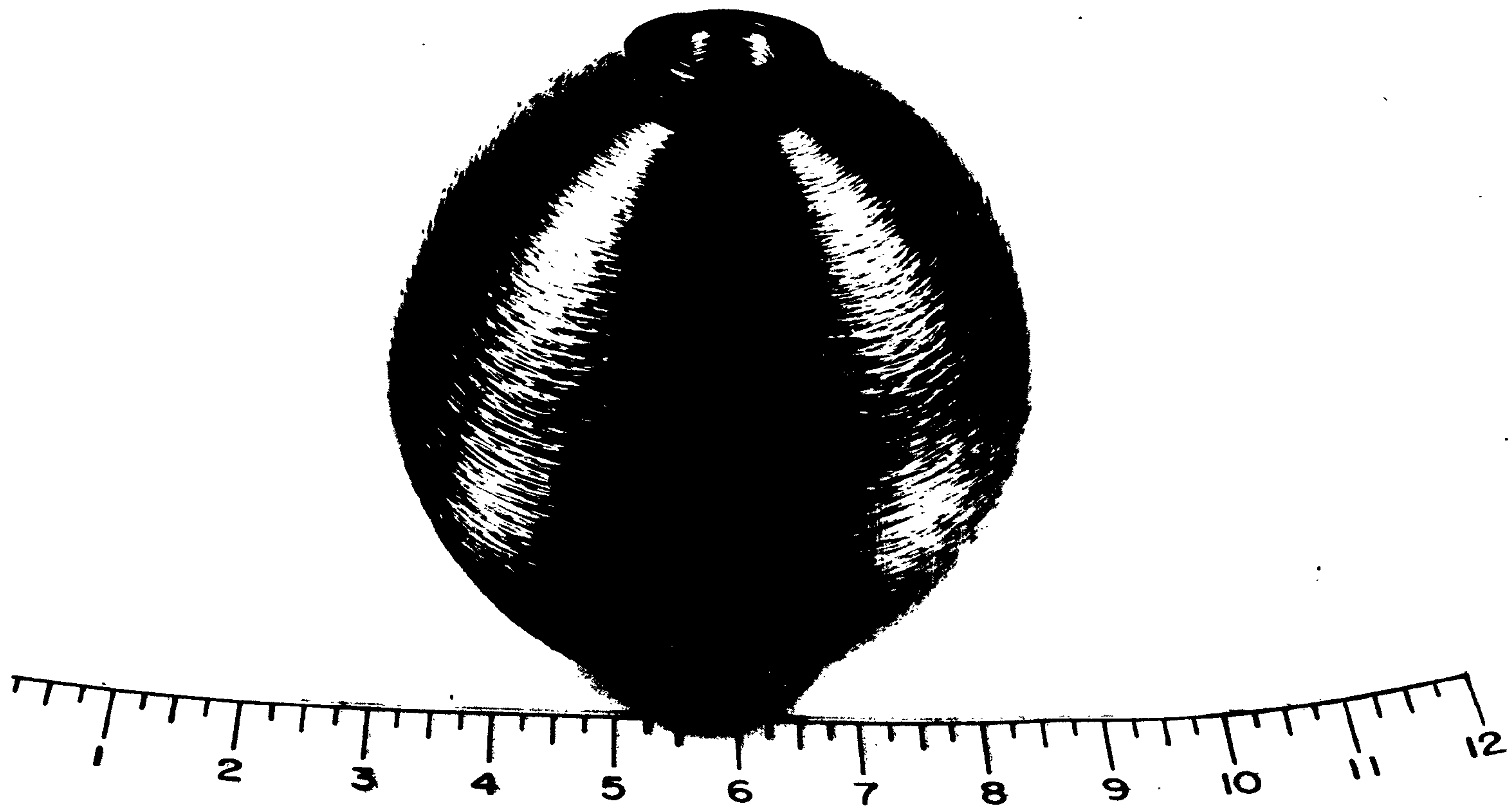


Figure 1 - Aluminum Filament Wound Sphere.

B. There have been a large number of persistent inquiries on Rocoloy 270. Several pressure vessel, missile motor case, aircraft component, and fastner manufacturers had asked for samples or sources for this material in order to initiate various application research programs. Samples sent to Mellon Institute from experimental heats made by Vanadium Alloys Steel Company for one of its customers have been evaluated. This particular composition was modified to achieve Charpy V-notch impact strength minimum of 15 ft. lbs. at 300,000 psi minimum ultimate tensile strength. This requirement has been fulfilled as indicated in Table II.

C. Tensile tests on center notched specimens of MX-2 and Rocoloy 270 have been conducted using several staining media and air to mark slow crack growth. Results shown in Table III and Figure 2 definitely show that there can be significant interaction between the cracked surface and the staining media. Such interaction seem to affect the results and validity of this test when used for comparing slow-crack growth in various engineering materials.

Work on Phases D, E, F and G has been brought to a satisfactory conclusion in view of contract termination.

H. Stress-corrosion evaluation studies on MX-2 and Rocoloy 270 are continuing. No specimen failure has occurred during the current reporting period.

TABLE II

Mechanical Properties[(a)] of Rocoloy 270
(produced by Vanadium Alloy Steel Company)

Test Number	0.2% offset Yield Strength ksi	Ultimate Tensile Strength ksi	Fracture Strength ksi	Hardness R_C	Elongation Per cent in 1 in.
1	257	302	367	53.0	12.0
2	254	304	356	53.0	10.0
3	254	302	340	53.0	11.0

(a) Austenitized at 1730 F for 25 minutes, quenched in oil and triple tempered at 600 F.

Charpy V-notch room temperature impact strength 15 to 18 ft. lbs. (450 F temper).

TABLE III

Effect of Staining Media and Air
on the Notch[a] Strength of Two Steels

	Average Net Section Stress[b], ksi	
Substance	MX-2	Rocoloy 270
India Ink	100	59.7
India Ink[c] + $Na_2Cr_2O_7 \cdot 2H_2O$	88	45.1
Salt Water[d]	108	43.8
Dye Penetrant[e]	122	74.0
Laboratory Air[f]	114	65.0

(a) Specimens conform to ASTM specification for pin loaded center notch test pieces.

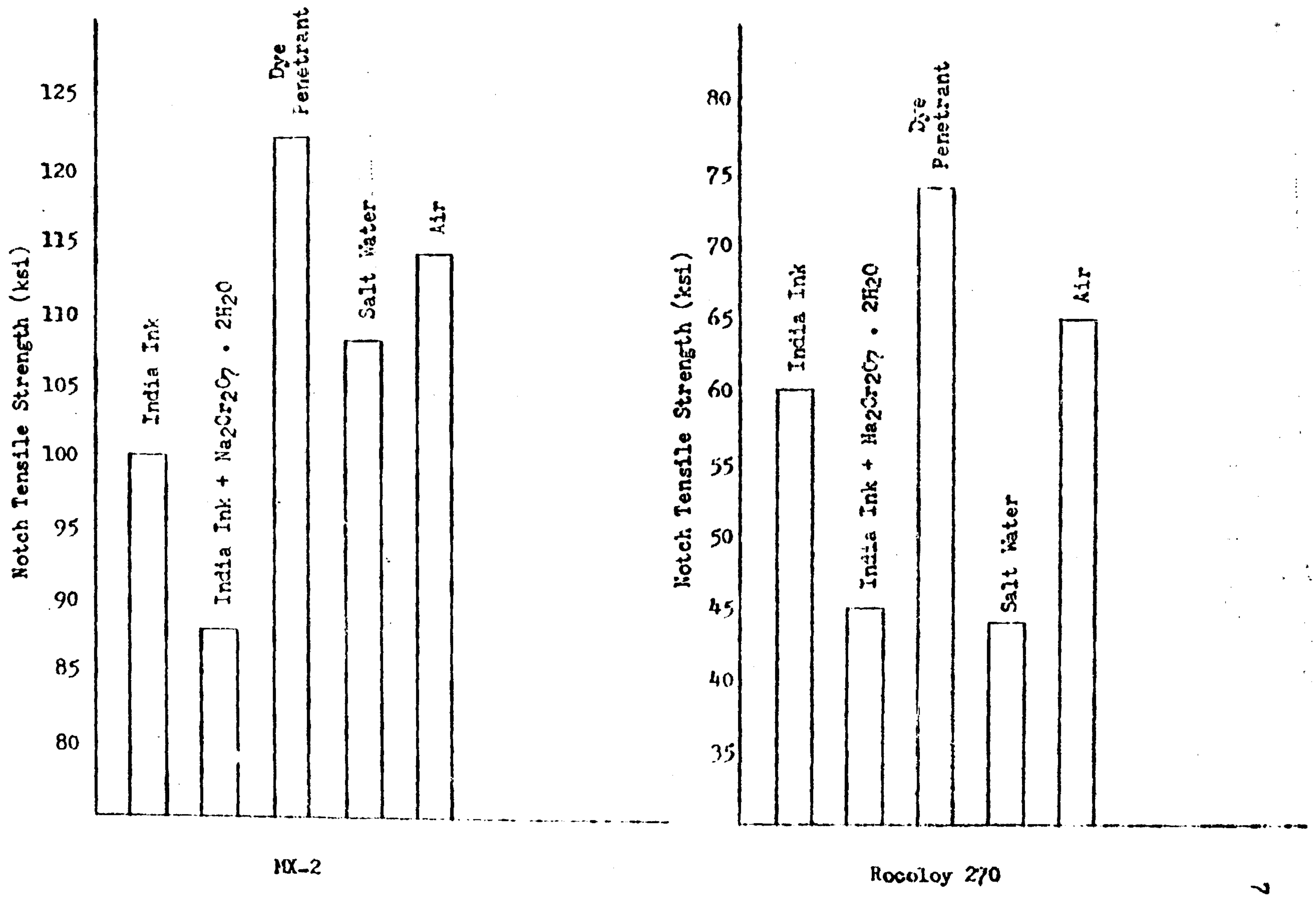
(b) $\sigma_{net} = \frac{\text{load at failure}}{t\ (W - 2a_o)}$ t = thickness; W = width; $2a_o$ = original notch size

(c) 1 gm. $Na_2Cr_2O_7 \cdot 2H_2O$ in 5 ml. India Ink.

(d) 5 per cent by weight.

(e) Tradename SPOTCHECK, made by Magnaflux Corporation.

(f) Temperature ≈ 80 F   R.H. ≈ 80%



<u>Figure 2</u> - Effect of Staining Media and Air on the Notch Properties of MX-2 and Rocoloy 270.

Studies directed toward determining the effect of surface decarburization on several low-alloy ultra-high strength steels loaded to produce various basic stress conditions are nearing completion. Results obtained to date may be summarized as follows:

Uniaxial Tensile Loading - Surface decarburization has been found to reduce the tensile and yield strengths of all steels tested. However, decarburization beyond a certain depth did not produce uniform incremental strength reduction. It is also observed that surface decarburization has little or no effect on ductility of the test specimen. Data of these studies are presented in Table IV.

Impact Loading - Impact tests using Charpy V-notched specimens were conducted to investigate the notch-blunting effect of decarburization. Data of these tests are given in Table V which indicate that the effect of surface carbon reduction up to a certain level is to increase the energy absorbed or increase the effective radius at the root of the notch. Beyond this level of decarburization the energy absorbed seems to decrease.

Plastic Deformation without Fracture - These studies were conducted by bending strips (4" x 3/8" x 0.050") into a U-shape and then removing them from the bending press to observe the extent of spring-back. Significance of these tests to the metal forming industry hardly needs any explanation.

TABLE IV

The Effect of Surface Decarburization[a] on the Tensile Mechanical Properties[b] of Several Low Alloy Steels

Material Designation and Decarb Depth	0.2% offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation Per cent in 1 in.	Elongation Per cent in 2 in.	Per cent Reduction in Area
R-270 (No Decarb)	270	323	11.0	5.5	21.0
R-270 (.012" Decarb)	250	303	10.6	6.0	20.7
R-270 (.018" Decarb)	248	297	10.3	5.0	20.0
300-M (No Decarb)	250	296	12.0	6.0	21.7
300-M (.012" Decarb)	234	281	12.3	6.2	21.7
300-M (.018" Decarb)	237	283	11.6	5.3	20.0

Continued...

TABLE IV Continued

Material Designation and Decarb Depth	0.2% offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation Per cent in 1 in.	Elongation Per cent in 2 in.	Per cent Reduction in Area
AISI 4340 (No Decarb)	193	197	13.0	6.0	23.6
AISI 4340 (.012" Decarb)	187	192	10.7	6.1	28.9
AISI 4340 (.018" Decarb)	185	194	12.0	5.2	21.0

(a) Surface decarburization depth determined by microscopic examination and microhardness.

(b) Materials heat treated as follows:

Rocoloy 270 - Austenitized at 1730 F for 25 minutes at temperature, oil quenched and triple temper at 600 F.

300-M - Austenitized at 1700 F for 25 minutes at temperature, oil quenched and double temper at 600 F.

AISI 4340 - Austenitized at 1650 F for 45 minutes at temperature, oil quenched and double temper at 800 F.

TABLE V

The Effect of Surface Decarburization on Charpy Impact Energy

Material[(a)]	Decarb. Depth[(b)] in.	Energy Absorbed ft. lbs.
300-M	0.000	11.0
	0.012	15.5
	0.018	12.3
R-270	0.000	12.0
	0.012	14.3
	0.018	13.3

(a) Heat treated according to the program given with Table IV.

(b) Depth determined from control samples.

As shown in Figure 3, increased amount of decarburization reduces the spring-back. Decarburization did not seem to produce any undesirable surface conditions such as orange-peel, strain lines on the bent specimen surface.

Stress-Corrosion - The effect of surface decarburization on stress-corrosion is being studied on three ultra-high strength steels heat treated to various strength levels. U-bend specimens were prepared and exposed in a one molar solution of sodium chloride. Specimen failure data indicate that surface decarburization tends to prevent stress-corrosion attack. Specimens of all three steels without any decarburization have failed.

Tensile Loading of Center Notched Specimens - Center notch 3 in. wide sheet specimens were prepared, heat treated in a manner to prevent any decarburization in the notch root, and were tested at three levels of surface decarburization. Results given in Table VI show a definite improvement in fracture toughness and per cent shear fracture commensurate with increased depth of decarburization.

The effects of decarburization on fatigue and biaxial strength of these steels are also being investigated.

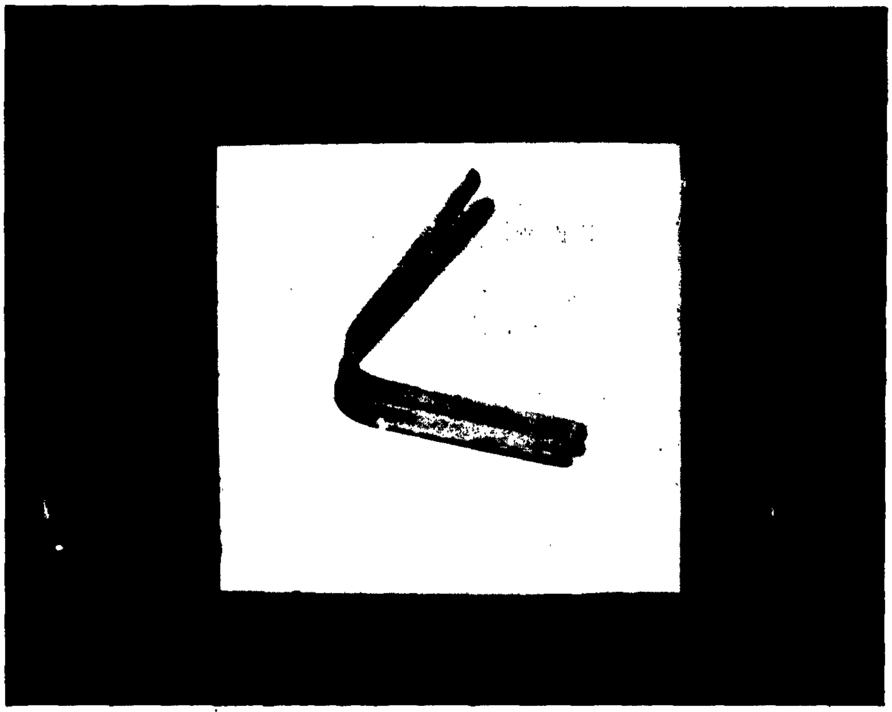


Figure 3

Photograph of samples of 300-M showing the effect of surface decarburization on spring-back after deformation. The front sample has 0.012 in. surface decarburization and the rear sample has no surface decarburization. Both samples have the same core hardness of 54 R_C. The surface decarburized sample has a surface hardness of 51 R_C.

TABLE VI

Effect of Surface Decarburization[a] on the Fracture Toughness[b] and Fracture Appearance of Low Alloy Steels

Material	Decarb Depth in.	G_c ipsi	σ_{net} ksi	Per cent Shear
Rocoloy 270	0.000	127	67.5	14
	0.012	197	87.2	22
	0.018	476	135.0	30
300-M	0.000	233	96.0	30
	0.012	539	144.0	65
	0.018	808	176.0	65
AISI 4340	0.000	682	173.0	100
	0.012	816	191.0	100
	0.018	773	183.0	100

(a) Surface decarburization depth determined using metallographic and microhardness tester.

(b) Visual examination revealed no decarburization at the root of the notch.

This program comes to a conclusion on September 30. Hence, no further experimental work has been planned for the next reporting period. A final report will be issued in October.

Respectfully submitted,

GKBhat

G. K. Bhat
Project Leader

Approved:

H. L. Anthony

H. L. Anthony III
Director of Research

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