UNCLASSIFIED

AD NUMBER

AD467249

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 25 MAY 1965. Other requests shall be referred to Foreign Technology Div., AFSC, Wright-Patterson AFB, OH 45433.

AUTHORITY

FTD ltr, 24 Oct 1967

THIS PAGE IS UNCLASSIFIED

FTD-TT- 65-125

TRANSLATION

EFFECT OF NEUTRON RADIATION OF CERTAIN MECHANICAL AND STRUCTURAL PROPERTIES OF AUSTENITIC CHROME NICKEL STEEL

By

Jiri Cervasek and Jan Kutka

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE
OHIO

FTD-TT- 65-125/1+2

UNEDITED ROUGH DRAFT TRANSLATION

EFFECT OF NEUTRON RADIATION ON CERTAIN MECHANICAL AND STRUCTURAL PROPERTIES OF AUSTENITIC CHROME NICKEL STEEL

BY: Jiri Cervasek and Jan Kutka

English pages: 11

SOURCE: Jaderna Energie. (Czechoslovakian), Vol. 9, No. 11, 1963, pp. 342-346.

Z/0038-063-009-011 TP5000280

	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

FTD-TT- 65-125/1+2 Date 25 May 19 65

B

EFFECT OF NEUTRON RADIATION ON CERTAIN MECHANICAL AND STRUCTURAL PROPERTIES OF AUSTENITIC CHROME NICKEL STEEL

Jiri Cervasek - Jan Kutka

Summary

The change of mechanical and structural properties of 13 kinds of anticorrosive steels of Cr-Ni-type exposed to integral dose of $1,6.10^{19}$ n/cm^2 (E $>$ 1 MeV) was investigated. The dose was held at a constant value and the chemical composition varied namely in the Cr and Ni content. The strengthening was observed, i.e. yield point, strength and hardness increased and plasticity decreased at the same time. Primary the rate of strengthening is independent on chemical composition, namely on chrome and nickel content, however is depends on the physical condition of steel before the radiation. As far as the alloying elements do not influence the properties in initial condition of steel, they exercise no influence also on the radiation stability. Ferromagnetic induction measurement indicated the decrease of corrosion resistance of austenitic steels by radiation to be negligible. Transient austenitic-ferritic structure steels only show a 0.43-0.72% increase of magnetic phase caused by $\gamma \rightarrow \alpha$ decay.

In this report is investigated the effect of chemical composition on the reinforcement of stainless steel under the effect of neutron radiation. Given is an analysis of the investigated steel, experimental conditions and values of measured changes are compiled in table. Relative changes in slide boundaries and the ratio of slide boundaries to strength boundary are expressed by graphic relations. Investigated are factors, which have a primary effect on radiation stability and on corrosion stability by the effect of radiation.

Introduction

Stainless austenitic type steel is a widely used structural material in the construction of nuclear installations. Their selection is most frequently motivated by the corrosion resistance against effective media, e.g. primary radius of the reactor, or against decontaminating droplets with which contact is ordinarily made during temporary stoppage of the installation. It has also other important qualities, such as ductility, which is retained even at extremely low temperatures. That is why its radiation stability, resp. the effect of neutron radiation on the changes of its mechanical properties, is a constant research subject of various laboratories [1, 2, 3, 5, 6, 7, 8, 9].

Since a complex solution of this problem is very challenging, a majority of hither to conducted investigations is limited to the investigation of radiation stability of steel of a definite type, which was chosen for concrete utilization. Ordinarily the unfamiliarity of the radiation effect leads to the use of most costly steel with high content of alloying elements. Its deficiency-especially in our measurements, calls for a reexamination to determine to what measure high alloying is justified. This was the motive of this report, which is a contribution to solving this problem.

Technique of Experimentation

The stability of 13 kinds of steel with various content of nickel and chromium as basic alloying components, was investigated. A listing of the composition of the steel together with a control analysis are given in table 1. The first four kinds of steel are of standard types corresponding to trade names AKVN, AKVS, AKV extra and AKV extra S. Steels 5 through 8 were prepared intentionally and have at a roughly constant composition of chromium graduated nickel. Steel 9 through 13 are auxiliary variants similar already to ferrite-austenitic steel (steel No. 13). They were all examined in austenitic annealed state.

Samples were exposed to radiation in the VVRS reactor where they were exposed to a neutron dosage of 4.10^{19} n/cm^2. The neutron dosage with an energy E > 1 mev, was calculated in accordance with the energy spectrum, corresponding to $1.6.10^{19}$ n/cm^2. The samples were irradiated in water-proof aluminum receptacles. It was assumed that the heat of radiation corresponds to the temperature of reactor cooling water, i.e. 40°C. To fix the effect of self-heating of the sample and to maintain definite temperatures the samples were arranged with spacings in the interior of the circumference of the irradiation receptacles so, that intensive tapping of heat could be realized (fig. 1).

Table 1. Control analyses of main element of investigated steel*)

Steel No.	Designation	Cr [%]	Ni [%]	C [%]	Mn [%]	Si [%]	P [%]	S [%]
1	ČSN 17241	18,54	9,28	0,08	0,44	0,70	0,015	0,012
2	ČSN 17246	18,27	10,16	0,15	0,30	0,69	0,041	0,038
3	ČSN 17345	18,06	10,35	0,15	0,30	0,66	0,039	0,032
4	ČSN 17347	18,25	10,53	0,12	0,59	0,58	0,010	0,026
5	VÚHZ	19,35	11,27	0,04	0,52	0,25	0,022	0,013
6	VÚHZ	19,74	10,80	0,07	0,50	0,28	0,019	0,012
7	VÚHZ	19,20	8,14	0,07	0,45	0,35	0,017	0,014
8	VÚHZ	20,30	9,37	0,06	0,48	0,26	0,023	0,022
9	FIS	11,95	12,36	0,02	0,13	stopy	0,012	0,017
10	FIS	17,25	10,86	0,04	0,13	0,20	0,013	0,010
11	FIS	15,28	10,99	0,05	0,21	0,28	0,011	0,008
12	FIS	11,99	14,59	0,02	0,17	0,22	0,012	0,007
13	FIS	11,27	11,17	0,03	0,09	0,18	0,011	0,005

* Data in weight %.

After the irradiation were determined changes in hardness, limits of sliding, strength, notch toughness and content of ferrite originated by the transition of $\gamma \rightarrow \alpha$ in the process of irradiation. Forms and dimensions of test samples are shown in fig. 2. After test were made on the Chevenard MI 34 installations, impact tests with the MK 05 type hammer. Both installations were adjusted for remote control. The ferrite content was determined by magnetic scales of our own construction [11].

Measured Values

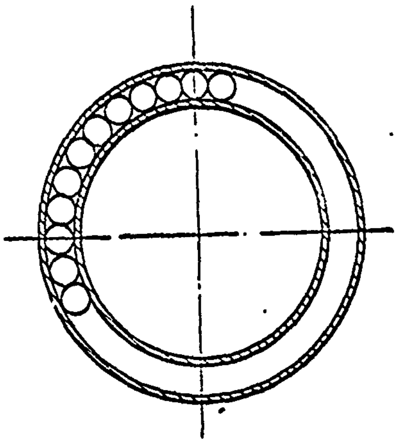

Fig. 1. Distancing of samples in radiation receptacle.

Changes in hardness, slide limit, strength, ductility and notch toughness are evident from tables 2, 3, 4. For total ductility values $\delta 5$ table 4 shows a so called uniform ductility δ_r, calculated from the elongation, which the test rod has shown up to sudden intensive reduction in cross section. Change in ductility is better characterized by this value than the ductilities expressed by total elongation. Table 4 also contains an important structural value, ratio $\frac{\sigma_{k\,0.2}}{\sigma_p}$ and percentage changes in properties, included in initial state.

Measurement of magnetic phase capacity α showed, that irradiation led only to a slight change in $\gamma \rightarrow \alpha$, of the order of perhaps 10^{-20} % [11]. Only in cases when the sample showed prior to irradiation a greater ferromagnetic induction, originated a change of from 0.43 to 0.72%.

Magnetic phase α, which originated by the decomposition of $\gamma \rightarrow \alpha$ during irradiation could not be reproduced neither by the optical nor by the electron microscope.

Discussion of Results

The criterion for the radiation stability of the investigated steel samples can be a certain investigated quality, which changes under radiation. The acceptable criteria however are the ones, which are sensitive to radiation, less fitted are qualities with lower sensitivity, e.g. hardness, and in the least are such which offer great discrepancies during the measurement, originating already from the basis of the method, e.g. notch toughness. Such values have to be evaluated statistically.

To sensitive criteria of steel belongs slide limit. Point disruption in crystallographic lattice - caused by radiation - lead to the formation of impoverished zones (depleted zones), which act as preventives against movements of dislocations [4].

Table 2. Results of hardness tests by Vickers (HV 30)

Steel No.	Nonirradiated State		Irradiated State		Change %
	No. of measurements	Mean value HV	No. of measurements	Mean value HV	
1	5	155	10	245	+58,0
2	4	192	10	266	+38,5
3	4	193	10	292	+51,3
4	4	161	10	285	+77,0
5	4	134	11	242	+80,6
6	5	140	10	226	+61,4
7	5	148	10	231	+56,1
8	5	130	9	242	+86,1
9	5	133	16	233	+75,2
10	5	99,3	13	167	+68,2
11	4	105	5	183	+74,3
12	4	93	12	161	+73,1
13	4	252	14	276	+ 9,5

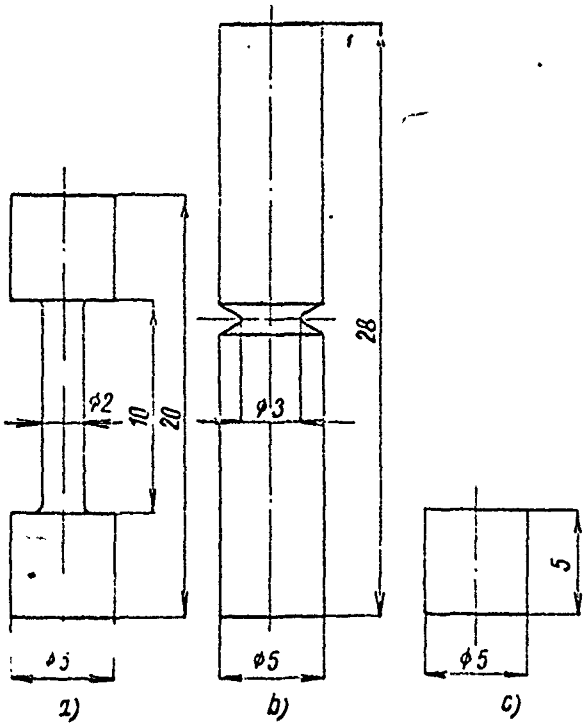

Fig. 2. Forms and dimensions of test samples. a) tensile tests; b) notch toughness tests; c) hardness tests and phase volume

If we compare the changes in slide (slip) limits with chemical composition of the steel, it is possible to better evaluate the effect of individual elements as such:

Steel 1 and 2 show after exposure almost identical changes. A similar conclusion will be derived by comparing steels 3 and 4. In both instances does the steel mutually differ in small admixture of Ti as carbide stabilizer. It is evident that Ti as an admixture element is in no way suitable in reinforcing

Table 3. Results of notch toughness tests Rm kgcm/mm²

Steel No.	Nonirradiated state	Irradiated State
1	10,62; 10,06; 10,62; 10,43; 9,80; 10,66	8,73; 7,96; 8,04; 8,04; 7,96; 8,20; 8,16; 8,29; 7,96; 7,96; 8.04
2	5,77; 5,93; 5,89; 6,00; 6,77; 6,18; 5,81	5,29; 5,29; 5,11; 5,11; 5,07; 5,29; 5,4; 5,26; 5,30
3	5,88; 6,07; 5,66; 5,51; 5,78; 5,88; 5.99	5,84; 5,7; 5,34; 5,48; 5,48; 5,3; 5,9; 5,48; 5,12
4	6,43; 6,97; 6,79; 7,01; 6,58; 6,21; 6,94; 6,32	6,5; 5,9; 6,72; 6,6; 6,27
5	9,24; 7,32; 7,32; 7,00; 7,90	6,0; 5,82 5,69; 5,82; 5,65
6	9,53; 8,47; 9,36; 8,18	5,86; 5,15; 5,15; 5,33; 5,21
7	6,75; 8,03; 7,21; 7,17; 6,12	5,86; 5,15; 5,15; 5,33; 5,21
8	5,29; 5,75; 6,12; 5,80; 6,23	4,34; 4,03; 4,34; 4,56; 4,85
9	6,14; 6,34; 6,34; 6,52	4,96; 5,03; 4,85; 4,69
10	*) —	7,39; 7,19; 7,12; 7,04
11	*) —	8,04; 7,64; 7,57; 7,71
12	*) —	7,73; 7,98
13	6,49; 5,35; 5,73; 6,07	4,61; 3,71; 3,05; 3,98

*) Samples could not be broken with the aid of used installation.

process during exposure to radiation.

The effect of Mo in steels 3 and 4 could be evaluated partly by comparing steel 1 and 3, partly 2 and 4. The small differences in changes in slide limit and in strength and finally in individual pairs of opposite sense indicates, that in reinforcing against radiation not even molybdenum is of any validity.

The effect of Ni can be investigated on steels 5 to 8, where at approximately 19.5% Cr Ni was graduated by approximately

Table 4. Results of tensile tests

Steel No.	Nonirradiated State						Irradiated State						Change %				
	počet zkouš. vzorků (a)	σ_p [kg . mm^{-2}]	$\sigma_{k0,2}$ [kg . mm^{-2}]	$\frac{\sigma_{k0,2}}{\sigma_p}$	δ_5 [%]	δ_r [%]	počet zkouš. vzorků (a)	σ_p [kg . mm^{-2}]	$\sigma_{k0,2}$ [kg . mm^{-2}]	$\frac{\sigma_{k0,2}}{\sigma_p}$	δ_5 [%]	δ_r [%]	σ_p	$\sigma_{k0,2}$	$\frac{\sigma_{k0,2}}{\sigma_p}$	δ_5	δ_r
1	4	69,8	42,3	0,606	52,5	43,0	4	78,8	59,3	0,753	39,6	33,8	+12,9	+40,2	24,25	—21,7	—21,4
2	5	74,1	45,9	0,62	52,5	46,1	6	81,8	64,9	0,795	38,1	31,3	+10,4	+41,4	28,25	—27,4	—32,1
3	5	77,3	49,0	0,635	48,1	43,8	6	86,6	66,4	0,767	32,9	22,6	+12,0	+35,6	20,80	—31,6	—48,1
4	5	73,6	51,5	0,7	40,6	32,8	6	83,7	67,4	0,805	25,6	17,5	+13,7	+30,9	15,00	—36,9	—16,6
5	2	60,5	31,5	0,508	57,8	50,15	2	70,0	50,0	0,715	32,9	26,9	+15,7	+58,7	40,10	—43,1	—16,4
6	3	60,1	35,3	0,586	47,0	42,1	3	71,1	53,3	0,716	39,3	32,1	+23,3	+56,7	22,30	—16,4	—23,8
7	3	68,3	35,8	0,525	60,7	55,2	2	78,6	55,2	0,702	48,8	39,8	+15,1	+51,2	33,70	—19,6	—27,9
8	3	67,4	34,2	0,508	59,3	51,6	3	70,0	51,3	0,734	40,6	33,1	+ 3,8	+50,0	11,50	—31,5	—35,8
9	3	66,4	36,1	0,541	36,2	25,0	2	70,9	57,3	0,808	25,4	15,7	+ 6,8	+58,7	48,50	—29,8	37,2
10	3	58,3	22,6	0,388	64,1	54,6	3	66,0	42,8	0,619	46,0	37,3	+13,7	+89,1	67,30	—28,2	—31,7
11	3	57,3	22,2	0,387	59,9	56.7	3	65,1	44,0	0,676	47,8	37,3	+13,6	+98,2	71,60	—20,2	—31,2
12	3	51.1	22,7	0,445	59,0	50,6	3	59,1	39,2	0,660	35,7	25,7	+16,2	+72,7	50,50	—39,5	—19,2
13	2	80,2	80,9	0,938	14,3	2.28	2	94,5	88,7	0,938	10 4	1,6	+ 9,6	+ 9,6	0	—27,3	—20,8

a) Number of test samples

8, 9, 10 and 11% and then in groups 9, 10 and 13, where at 12% Cr Ni was graduated by perhaps 11, 13 and 15%. In first group the increment in slide limit varies within limits of 50 to 58.7% of initial value prior to irradiation. Changes in volume of 8.7% do not correspond to the graduated content of Ni. Basic differences in slide limit and in strength after irradiation appear also in other groups. Steel No. 13 with 11% Ni is beyond basic comparison with preceding steels for its mixed ferrite-austenitic structure, which leads at the application of heat treatment to extremely high values already in initial state prior to irradiation. Basic increase in slide limit of steel No. 12 as compared with steel No 9 (14%) corresponds to an Ni increase of 2.25%. Cut off steel according to the increasing content of Ni gives a roughly rising increase in slide limit and strength after irradiation. This would indicate that nickel is suitable for radiation reinforcement. Further conclusions do indicate, that the effect of Ni last until it affects the slide limit of initial state of the steel.

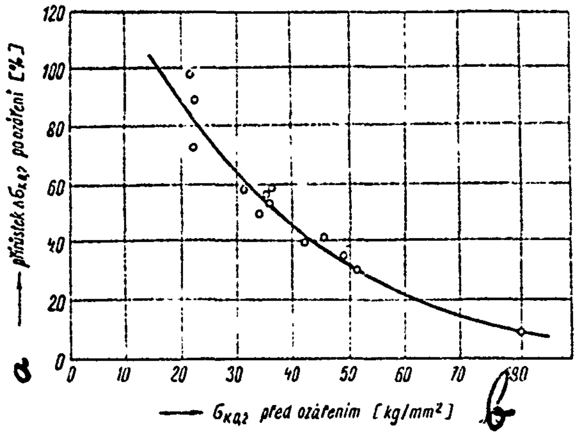

Fig. 3. Magnitude of percentage changes in slide limit after irradiation in dependence upon initial state of the steel.
a) increase Δ ......after exposure
b) before exposure

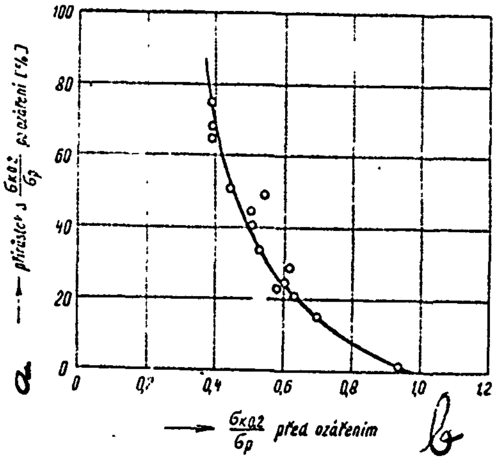

Fig. 4. Magnitude of percentage changes in ratio between slide limit and strength after exposure in dependence upon initial state. a & b as in fig. 3.

Chromium in the investigated series of steel was contained in quite broad degree namely, about 11, 15, 17, 18, 19 and 20%. For the great variability of the latter admixtures, particularly Ni, it is impossible to evaluate its effect. It will be therefore no surprise if there are considerable differences in property changes and a nonsystematism in these changes with respect to the Cr content, which will not allow to make a conclusion.

Let us take a look to the extreme changes in slide limit shown in table 4, indicating that to the extraordinarily high increase (98.2%) came also in case of steel 11 with very low slide limit (22.2 kg/mm^2) before irradiation. On the other hand a lesser increase (9.6%) was found in steel 13 with much higher slide limit before irradiation. By measuring the percentage changes in slide limit after exposure, in dependence upon the slide limit value before exposure, we derive a polytropic dependence, which is evident from diagram fig. 3.

A similar nature is displayed by the dependence of increment in ratio of slide limit and strength limit after irradiation and the absolute value of this ratio before irradiation, as is indicated by diagram in fig. 4.

Both ratios indicate, that the reinforcement is relatively faster in steels of lower strength and that the relative increases in reinforcement depend first of all on the condition before irradiation. The dependence on chemical composition is secondary. Single elements affect radiation stability in same measure and in same sense as is the effect of the initial state of the steel.

Absolute changes in reinforcement are well characterized by stress and elongation diagrams. Fig. 5. contains diagrams of 3 typical variants, with lowest (steel 12), medium (steel 4) and maximum (steel 1) strength. The diagrams indicate, that magnitude of absolute reinforcement will be in all steels perhaps the same and will correspond to the constant dosage of neutrons. At the same time there is a loss in plastic properties, which is manifested by a substantial reduction in elongation.

As already stated, a majority of quoted literature reports intended to

It is necessary to make allowances for that the ratio of slide limit and strength in such steel is already prior to exposure close to unity.

The problem of alloying will then lie mostly in the corrosion stability dependence of the steel, respectively in the technological condition. Measurement of ferromagnetic induction showed, that a reduction in radiation corrosion resistance is insignificant in austenitic steels. Only steel with transient austenitic-ferritic structure shows a rise in magnetic phase by from 0.43 to 0.72%, which originated by decomposition of $\gamma \rightarrow \alpha$.

Literature

1. Coffin, I. F.: Radiation Effects on Creep of Stainless Steel."Radiation Damage Conference", March 1953, CF-53-3-276.

2. Wilson, J. C.; Zukas, J. C.; Davis, W. W.: Creep of inconel and Stainless Steel Under Irradiation. "Radiation Damage Conference", March 1953.

3. Murphy, W. F.; Paine, S. H.: Fast Neutron on Tensile and Hardness Properities of Type 347 Stainless Steel. Special. techn. publ. No. 208, ASTM. Philadelphia, 1957.

4. Seeger, A.: Report P. 6 (1953) Second International Conference on Peaceful Utilization of Atomic Energy.

5. Joseph, J. W.: Stress Relaxation in Stainless Steel During Irradiation. Savannah River Lab. DP-369, Jun. 1959.

6. Berggren, R. G.; Brundage, W. E.; Davis, W. W.; Hinkle, N. E.; Zukas, J. C.: Tensile Steels Rupture Properties of Irradiated Stainless Steels and Inconel. USAEC Conference on the Status of Radiation Effects Research on Structural Materials and the Implications to Reactor Design, Chicago, Ill., October 15.—16., 1959.

7. Paine, S. H.; Murphy, W. F.; Hachett, D. W.: A Study of Irradiation Effects in Type "A" Nickel and Type 347 Stainless Steel Tensile Specimens. NMI-6102, Jul. 1960.

8. Weiss-Hollenwoeger B.: Effect of Neutron Irradiation on Phase Changes in Cr-Steel. Radex Review 6, (1960).

9. Pravdjuk, N. F. af.: The Effect of Neutron Irradiation on the Properties of Structural Materials. International Conference at Berkeley, 1961.

10. Jaegersberger; Highly alloyed steel in nuclear energy installations. Atomwirtschaft 6 (1961).

11. Kutka J.: Effect of neutron radiation on structural changes of certain steels. Transactions of UJV No. 463 and 602 (1961 and 1962).