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PREDICTING AND MONITORING EUTECTIC CARBIDES PROPORTION IN CAST AUSTENITIC Cr-Ni STAINLESS STEELS

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The correlation between the structure of austenitic stainless steels Cr-Ni and the variation of their chemical composition are experimentally established. The obtained experimental data are used to perform a statistical processing, resulting in a regression equation, useful for predicting and monitoring the proportion of eutectic carbides in cast alloy austenitic Cr-Ni steels.

Keywords: carbides, austenitic stainless steels, chemical composition

1. Introduction

The proportion of eutectic carbides present in the solidification structure is an important factor in assessing the operating behavior of cast austenitic Cr-Ni steels as it directly influences both heat shock resistance and corrosion resistance. Even small variations in the content of certain elements such as C and Cr can cause significant changes in the mechanical properties of these steels by increasing or decreasing the proportion of carbides with affecting their durability in service [1]. The authors have proposed to establish a correlation between the structure of austenitic stainless-steel Cr-Ni and the variation of their chemical compositions, useful in identifying possible non-conformities and ways to solve them, from the steels production stage [2].

2. Experimental work

To establish the correlation between the structure of Cr-Ni austenitic stainless steels and the variation of their chemical compositions, 13 batches of steels with different chemical compositions were melted in an induction furnace of 250 kg capacity and austenitic Cr-Ni steels were cast in sand moulds banded with sodium silicate and hardened with CO_2.

Starting from the standardized composition of W1.4855, C, Ni and Cr percentages were varied, keeping the other relative ones constant. The chemical composition investigations were performed using an optical emission spectrometer (OES), ARL QUANTRIS, based on the latest high-end CCD

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(Charge Coupled Device) technology. Sample preparation was done both by electrolytical and mechanical polishing, in order to accomplish the surface preparation. The structural analysis was made with an Olympus microscope, according to the ASTM B487 standard, by using Scentis Software version 1.2 for Windows for data interpreting. For a quantification of the structural effect, the percentage of eutectic carbides was used. Its selection was based on the fact that, in the case of Cr-Ni steels, the structure consists of austenite and eutectic carbides, carbides being the phase that will be predominantly affected by variations of the chemical composition [3].

The alloys are divided into three groups:

- First group having different percentages of nickel (see table 1)
-Second group having different percentages of chromium (see table 2)
-Third group having different percentages of carbon (see table 3)

Table 1

The chemical composition for the group having variable Nickel content

Chemical composition	Sample No.					
	1	**2**	**3**	**4**	**5**	**6**
C	0.12757	0.14342	0.29461	0.25094	0.26477	0.26901
Mn	0.91038	0.95495	0.92932	0.79451	0.72935	0.67604
Si	1.29232	1.35283	1.41138	1.29625	1.22478	1.29053
P	0.03280	0.03386	0.01872	0.03064	0.13168	0.03220
S	0.02777	0.02343	0.02157	0.01938	0.02006	0.01674
Ni	14.64553	18.99652	23.26603	25.95366	29.83821	32.46532
Cr	18.63778	18.57430	18.29848	18.69270	18.36277	18.35101
Cu	0.25389	0.25082	0.33590	0.20028	0.17263	0.15865
Mo	0.17975	0.16003	0.14993	0.14379	0.14390	0.12816
V	0.07743	0.07076	0.08253	0.06867	0.06309	0.06185
Ti	0.00050	0.00050	0.00050	0.00050	0.00050	0.00050
Al	0.07997	0.15557	0.16409	0.07121	0.15631	0.02845
Nb	0.02329	0.04561	0.03551	0.03066	0.01456	0.02049
W	0.01300	0.01300	0.01300	0.01300	0.01300	0.01300
Sn	0.00755	0.00670	0.00927	0.00511	0.00388	0.00322
Co	0.18966	0.19269	0.24905	0.16524	0.14067	0.13358
B	0.00146	0.00127	0.00141	0.00122	0.00133	0.00108
Ca	0.00070	0.00052	0.00114	0.00095	0.00041	0.00037
FE %	63.4643	58.9890	54.7734	52.2283	48.7855	46.3168

Table 2

The chemical composition for the group having variable Chromium content

Chemical composition	Sample no.			
	7	**8**	**9**	**10**
C	0.09806	0.09770	0.11379	0.10894

Mn	0.83391	0.74519	0.83559	0.76099
Si	1.22878	1.11164	1.21366	1.03863
P	0.02827	0.03276	0.03663	0.03976
S	0.02480	0.02437	0.02437	0.02264
Ni	25.55711	25.04426	24.26328	24.10008
Cr	14.51733	18.06486	21.92676	25.58822
Cu	0.18828	0.17620	0.16148	0.14994
Mo	0.13554	0.12304	0.11821	0.10307
V	0.04953	0.05119	0.05397	0.05465
Ti	0.00050	0.00050	0.0050	0.00050
Al	0.18508	0.07232	0.04872	0.01963
Nb	0.00200	0.00200	0.00200	0.00200
W	0.01300	0.01300	0.01300	0.01300
Sn	0.00534	0.00466	0.00393	0.00315
Co	0.15758	0.15173	0.14567	0.14160
B	0.00071	0.00082	0.00097	0.00105
Ca	0.00071	0.00048	0.00057	0.00048
FE %	56.9393	54.2489	51.0025	47.8173

Table 3

The chemical composition for the group having variable Carbon content

Chemical composition	Sample no.			
	10	11	12	13
C	0.10894	0.29032	0.49064	0.68294
Mn	0.76099	0.75832	0.74687	0.70750
Si	1.03863	1.06435	1.09160	1.10572
P	0.03976	0.03397	0.03652	0.03749
S	0.02264	0.01956	0.02263	0.02349
Ni	24.10008	24.29665	24.36708	24.56381
Cr	25.58822	25.18587	24.82062	24.69321
Cu	0.14994	0.16418	0.13577	0.13577
Mo	0.10307	0.10554	0.11070	0.11070
V	0.05465	0.05743	0.04933	0.04933
Ti	0.00050	0.00050	0.00050	0.00050
Al	0.01963	0.09040	0.15017	0.05108
Nb	0.00200	0.00200	0.00200	0.00200
W	0.01300	0.01300	0.01300	0.01300
Sn	0.00315	0.00359	0.00317	0.00282
Co	0.14160	0.15711	0.12845	0.11056
B	0.00105	0.00108	0.00105	0.00104

Ca	0.00048	0.00037	0.00028	
FE %	47.8173	47.7781	47.6758	

3. Experimental results

The carbide content of the cast samples with variable chemical composition are presented in table 4

Table 4

The carbide content of cast samples with variable chemical composition

Variable content of	Sample no.	%C	%Ni	%Cr	% Carbide
Nickel	1	0.12757	**14.64553**	18.63778	3.8
	2	0.14342	**18.99652**	18.57430	4.1
	3	0.29461	**23.26603**	18.29848	9.8
	4	0.25094	**25.95366**	18.69270	9.2
	5	0.26477	**29.83821**	18.36277	10.1
	6	0.09806	**32.46532**	18.35101	10.4
Chromium	7	0.09770	25.55711	**14.51733**	3.4
	8	0.11379	25.04426	**18.06484**	3.9
	9	0.10894	24.26328	**21.92676**	4.8
	10	**0.10894**	24.10008	**25.58822**	4.7
Carbon	11	**0.29032**	24.29665	25.18587	12.52
	12	**0.49064**	24.36708	24.82062	16.92
	13	**0.68294**	24.56381	24.69321	17.33

4. Establishing the correlation equation between the chemical composition and the eutectic carbide content of the analyzed materials

Starting from the effective chemical composition of Cr-Ni austenitic stainless steel, our purpose was processing the statistical data related to it. A regression equation was determined in order to predict and monitor the percentage of carbides in cast steels [4].

The elaboration of an algorithm for explaining the connection between the independent variables x_1, x_2, x_3 ...... x_n related to the proportion of the different elements that in the steel composition and the dependent variable[5], respectively, corresponding to the proportion of the eutectic carbides, involved the following steps:

- Completing the chemical compositions database of the 13 series of Cr-Ni austenitic stainless steels, with the data needed to calculate the partial correlation coefficients τ_{yx} and internal $\tau_{xi\,xj}$ (see table 5).

Table 5

The database of chemical compositions of the 13 series of Cr-Ni austenitic stainless steel, with the data needed to calculate the partial correlation coefficients

Alloy no	**Carbide % Y**	**C % X_1**	**Cr % X_2**	**Mn % X_3**	**Fe % X_4**	**Si % X_5**
1	3.8	0.12757	18.63778	0.91038	63.4643	1.29232
2	4.1	0.14342	18.5743	0.95495	58.989	1.35283
3	9.8	0.29461	18.2948	0.92932	54.7734	1.41138
4	9.2	0.25094	18.6927	0.79451	52.2283	1.29625
5	10.1	0.26477	18.36277	0.72935	48.7855	1.22478
6	10.4	0.26901	18.35101	0.67604	46.3168	1.29053
7	3.4	0.09806	14.51733	0.83391	56.9393	1.22878
8	3.9	0.09770	18.0648	0.74519	54.2489	1.11164
9	4.8	0.11379	21.9267	0.83559	51.0025	1.21366
10	4.7	0.10894	25.5882	0.76099	47.8173	1.03863
11	12.52	0.29032	25.1857	0.75832	47.7226	1.06435
12	16.99	0.19064	24.8206	0.74687	47.7781	1.0916
13	17.33	0.68294	24.6931	0.7075	47.6758	1.10572
Z	110.97	3.23270	265.7139	10.3829	677.742	15.7224
Average	8.56	0.24867	20.4395	0.79868	52.134	1.2094

Table 5(continuation)

Alloy no	**Carbide % Y**	**Nb % X_6**	**Mo % X_7**	**B % X_8**	**Ni% X_9**	**V % X_{10}**
1	3.8	0.02329	0.17975	0.00146	14.64553	0.7743
2	4.1	0.04561	0.16003	0.00127	18.99652	0.07076
3	9.8	0.03551	0.14993	0.00141	23.26603	0.08253
4	9.2	0.03066	0.14379	0.00122	25.45366	0.06867
5	10.1	0.01456	0.1439	0.00133	29.83821	0.06309
6	10.4	0.02049	0.12816	0.00108	32.46532	0.06185
7	3.4	0.002	0.13554	0.00071	25.55711	0.04953
8	3.9	0.002	0.12304	0.00082	25.04426	0.05119
9	4.8	0.002	0.11821	0.00097	24.26328	0.05397
10	4.7	0.002	0.10307	0.00105	24.10008	0.05465
11	12.52	0.002	0.10554	0.00108	24.29665	0.05743
12	16.99	0.002	0.1107	0.00105	24.36708	0.04933
13	17.33	0.002	0.1107	0.00104	24.56381	0.04933
Z	110.97	0.1841	1.71236	0.01449	317.357	0.78976
Average	8.56	0.0141	0.1317	0.00111	24.412	0.0607

Table 5(continuation)

Alloy no	**Al % X_{11}**	**Co % X_{12}**	**Ca % X_{13}**	**y^2**	**X_1^2**	**X_2^2**
1	0.07997	0.18966	0.0007	14.44	0.01327	347.3668
2	0.15557	0.19269	0.00052	16.81	0.02057	345.004
3	0.16409	0.24905	0.00114	96.04	0.08679	334.834
4	0.07121	0.16524	0.00095	84.64	0.06297	349.417
5	0.15631	0.14067	0.00041	102.01	0.0701	337.191

6	0.02845	0.12258	0.00037	108.16	0.07236	336.759
7	0.18508	0.015758	0.00071	11.56	0.00961	210.752
8	0.07232	0.151173	0.00048	15.21	0.00954	326.337
9	0.04872	0.14567	0.00057	23.04	0.01294	480.78
10	0.01963	0.1416	0.00048	22.09	0.01186	654.756
11	0.0904	0.15711	0.00057	156.75	0.08428	634.319
12	0.15017	0.12845	0.00037	286.286	0.5407	616.062
13	0.05108	0.11056	0.00028	300.328	0.4664	609.749
Z	1.273	2.055	0.00722	1237.36	1.16439	5583.33
Average	0.0979	0.158	0.00058			

Table 5(continuation)

Alloy no	**X_3^2**	**X_4^2**	**X_5^2**	**X_6^2**	**X_7^2**	**X_8^2**
1	0.8287	4027.72	1.67	0.00054	0.0323	$2.1*10^{-6}$
2	0.9119	3479.7	1.83	0.00208	0.0256	$1.61*10^{-6}$
3	0.8636	3000.12	1.99	0.00126	0.0224	$1.98*10^{-6}$
4	0.6312	2727.79	1.68	0.00094	0.0206	$1.48*10^{-6}$
5	0.5319	2380.02	1.50	0.00021	0.0207	$1.77*10^{-6}$
6	0.457	2145.24	1.665	0.00042	0.0164	$1.16*10^{-6}$
7	0.6954	3242.08	1.51	0.000004	0.01837	$5*10^{-6}$
8	0.5553	2942.94	1.235	0.000004	0.0151	$6.7*10^{-6}$
9	0.6982	2601.25	1.473	0.000004	0.0140	$9.4*10^{-6}$
10	0.5791	2286.49	1.078	0.000004	0.0106	$1.1*10^{-6}$
11	0.575	2277.44	1.13	0.000004	0.0111	$1.16*10^{-6}$
12	0.5578	2282.74	1.19	0.000004	0.0122	$1.1*10^{-6}$
13	0.5148	2272.98	1.22	0.000004	0.0122	$1.08*10^{-6}$
Z	8.3999	35666.51	19.171	0.00547	0.2316	$1.66*10^{-6}$
Average						

Table 5 (continuation)

Alloy no	**X_9^2**	**X_{10}^2**	**X_{11}^2**	**X_{12}^2**	**X_{13}^2**	**X_1y**
1	214.5	$5.99*10^{-3}$	$6.39*10^{-3}$	0.036	$4.9*10^{-7}$	0.485
2	360.87	$5*10^{-3}$	$24.2*10^{-3}$	0.037	$2.7*10^{-7}$	0.588
3	541.3	$6.8*10^{-3}$	$26.9*10^{-3}$	0.062	$12.99*10^{-7}$	2.887
4	673.6	$4.7*10^{-3}$	$5.07*10^{-3}$	0.027	$9.02*10^{-7}$	2.308
5	890.32	$3.98*10^{-3}$	$24.4*10^{-3}$	0.0197	$1.68*10^{-7}$	2.674
6	1054	$3.82*10^{-3}$	$0.8*10^{-3}$	0.0178	$1.37*10^{-7}$	2.797
7	653.16	$2.45*10^{-3}$	$34.2*10^{-3}$	0.0248	$5.04*10^{-7}$	0.333
8	627.2	$2.62*10^{-3}$	$5.23*10^{-3}$	0.023	$2.3*10^{-7}$	0.381
9	588.7	$2.91*10^{-3}$	$2.37*10^{-3}$	0.021	$3.25*10^{-7}$	0.546
10	580.81	$2.98*10^{-3}$	$0.38*10^{-3}$	0.020	$2.3*10^{-7}$	0.512
11	590.33	$3.29*10^{-3}$	$8.2*10^{-3}$	0.024	$3.25*10^{-7}$	3.634
12	590.75	$2.43*10^{-3}$	$22.5*10^{-3}$	0.016	$1.37*10^{-7}$	8.301
13	603.38	$2.43*10^{-3}$	$2.61*10^{-3}$	0.012	$0.78*10^{-7}$	11.835
Z	7973.92	$49.1*10^{-3}$	$163.2*10^{-3}$	0.34	$50.95*10^{-7}$	37.281
Average						

Table 5(continuation)

Alloy no	**X_2y**	**X_3y**	**X_4y**	**X_5y**	**X_6y**	**X_7y**
1	70.823	3.46	241.16	4.91	0.088	0.683
2	76.154	3.91	241.85	5.54	0.187	0.656
3	179.325	9.11	536.78	13.83	0.348	1.469
4	171.973	7.31	480.5	11.92	0.282	1.323
5	185.464	7.37	492.73	12.37	0.147	1.153
6	190.85	7.03	481.7	13.42	0.213	1.333
7	49.359	2.83	195.59	4.18	0.0068	0.461
8	70.452	2.91	211.57	4.33	0.0078	0.479
9	105.25	4.01	244.81	5.82	0.0096	0.567
10	120.26	3.57	244.74	4.88	0.0094	0.484
11	315.325	9.49	597.49	13.32	0.025	1.321
12	419.964	12.64	808.4	18.47	0.034	1.873
13	427.93	12.26	826.22	19.16	0.035	1.918
Z	2383.13	85.9	5583.54	132.15	1.3926	14.02
Average						

Table 5(continuation)

Alloy no	**X_8y**	**X_9y**	**$X_{10}y$**	**$X_{11}y$**	**$X_{12}y$**	**$X_{13}y$**
1	$55.5*10^{-3}$	55.65	0.294	0.3039	0.721	$2.66*10^{-3}$
2	$5.21*10^{-3}$	77.88	0.290	0.6378	0.790	$2.13*10^{-3}$
3	$13.8*10^{-3}$	228	0.809	1.608	2.441	$13.7*10^{-3}$
4	$11.2*10^{-3}$	238.77	0.631	0.655	1.52	$8.74*10^{-3}$
5	$13.4*10^{-3}$	301.36	0.637	1.5787	1.42	$4.14*10^{-3}$
6	$11.2*10^{-3}$	337.64	0.643	0.296	1.39	$3.85*10^{-3}$
7	$2.41*10^{-3}$	86.89	0.168	0.629	0.536	$2.40*10^{-3}$
8	$3.19*10^{-3}$	97.67	0.199	0.282	0.591	$1.87*10^{-3}$
9	$4.65*10^{-3}$	116.46	0.259	0.234	0.699	$2.73*10^{-3}$
10	$4.43*10^{-3}$	113.27	0.257	0.092	0.665	$2.26*10^{-3}$
11	$13.5*10^{-3}$	304.19	0.719	1.132	1.967	$7.14*10^{-3}$
12	$17.7*10^{-3}$	412.29	0.835	2.541	2.173	$6.26*10^{-3}$
13	$18*10^{-3}$	425.69	0.855	0.885	1.916	$4.85*10^{-3}$
Z	$124.74*10^{-3}$	2795.76	6.596	0.874	16.829	0.0624
Average						

Table 5(continuation)

Alloy no	**X_1X_2**	**X_1X_3**	**X_1X_4**	**X_2X_3**	**X_2X_4**	**X_3X_4**
1	2.377	0.1161	8.0961	16.9797	1182.83	57.776
2	2.664	0.1369	8.4602	17.7375	1095.68	56.331
3	4.84	0.2738	16.1368	17.005	1002.27	50.902
4	4.69	0.1994	13.1061	14.8515	976.29	41.496
5	4.86	0.1931	12.9169	13.3928	895.84	35.582
6	4.936	0.1818	12.4597	14.406	849.96	31.312
7	1.423	0.0817	5.5834	12.1061	826.60	47.482
8	1.765	0.0728	5.3001	16.4617	978.99	40.426
9	2.495	0.095	5.8036	18.3217	1118.32	42.617
10	2.787	0.0829	5.2092	19.4723	1223.56	36.388

11	7.312	0.2201	13.8548	19.0988	1201.93	36.189
12	12.178	0.3664	23.4418	18.5377	1185.88	35.684
13	16.864	0.4832	32.5596	17.4703	1177.26	33.73
Z	69.191	2.5032	162.984	210.841	13716.41	545.915
Average						

- Calculating the partial correlation coefficients τ_{yx} between independent variables (x_i) representing the proportion of different chemical elements in the steel composition, and the dependence (y) representing the proportion of carbides.
- The statistical significance of the calculated coefficients is checked using the Student criterion. The end of this stage is the validation or invalidation of the significance of each calculated coefficient (x_i). An independent variable is considered statistically influenced if the correlation coefficient between it and the dependency variance (t_{yx}) is not within the tabulated limits of the Student criterion, for a certain significance threshold (s) chosen. In the statistical processing of the data, the value of (α=0.1) was chosen as the level of the significance Start, meaning that the obtained equation will express with almost 90% probability the relation between the dependent and independent variables. this significance threshold has been used to cover as much as possible the effects of unpredictable situations that can not be controlled and accurately done.
- Calculation of internal correlation coefficients t_{ij} (also can be written t_{xixj}), for the variables that were discussed after the previous statistical checks.
- Determining and solving the system of standardized equations.
- Calculation and verification of the regression equation coefficients, b_0, b_1, b_2, ….. , b_n.
-Calculation of determination coefficients R2 (represents the probability of expressing the relation between the variables by the regression equation.

Calculation of partial correlation coefficients τ_{yx}

$$\tau_{yx} = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left[n\sum_{i=1}^{n} x_i{}^{2\ x^2} - (\sum_{i=1}^{n} x_i)^2\right]\left[n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2\right]}} \quad (1)$$

i=1….13 Observation

$\tau_{yx1} = +0.949 \cong 0.95$ Representing the correlation between the percentage of carbon and the percentage of carbide

$\tau_{yx2} = +0.547$ Representing the correlation of the percentage of Chromium and the percentage of Carbide

$\tau_{yx3} = -0.489$	Representing the correlation of the percentage of Manganese and the percentage of Carbide
$\tau_{yx4} = -0.649$	Representing the correlation of the percentage of Iron and the percentage of Carbide
$\tau_{yx5} = -0.365$	Representing the correlation of the percentage of Silicon and the percentage of Carbide
$\tau_{yx6} = -0.086$	Representing the correlation of the percentage of Niobium and the percentage of Carbide
$\tau_{yx7} = -0.45$	Representing the correlation of the percentage of Molybdenum and the percentage of Carbide
$\tau_{yx8} = +0.0272$	Representing the correlation of the percentage of Boron and the percentage of Carbide
$\tau_{yx9} = +0.338$	Representing the correlation of the percentage of Nickel and the percentage of Carbide
$\tau_{yx10} = -0.226$	Representing the correlation of the percentage of Vanadium and the percentage of Carbide
$\tau_{yx11} = +5.14 * 10^{-5}$	Representing the correlation of the percentage of Aluminum and the percentage of Carbide
$\tau_{yx12} = -0.3399$	Representing the correlation of the percentage of Cobalt and the percentage of Carbide
$\tau_{yx13} = -0.142$	Representing the correlation of the percentage of Calcium and the percentage of Carbide

Since the number of degrees of freedom is n = 13-2 = 11, the zero (insignificant) theory will be accepted for the variables at which the Student (t) test falls within the limits $-1.793 < t < +1.796$. (Tabulated values); $\alpha=0.1$, $\nu=11$

For an accepted level of significance of $\alpha=0.1$ (statistical probability 90%) the calculated Student criteria (t_{calc}) will be:

$$t_{calc} = \frac{\tau_{xy}\sqrt{n-2}}{\sqrt{1-\tau_{xy}^2}} \tag{2}$$

This is how it results: t_{calc}-C= 10.096, t_{calc}-Cr= 2.167 , t_{calc}-Mn= 1.859 , t_{calc}-Nb= 0.286 , t_{calc}-Mo= 1.67, t_{calc}-B= 0.096 , t_{calc}-Ni= 1.191 , t_{calc}-V= 0.769 , t_{calc}-Al= 1.704 * 10-4 , t_{calc}-Co= 1.198 , t_{calc}-Ca= 0.4758

Comparing the calculated values of the Student criterion with the tabulated ones (-1.796 <t_{tab} <+1.796), it is found that with the exception of the correlation coefficients partially related to carbon, chromium, manganese and iron (which are outside the corresponding t_{tab} range) all others have an influence statistically insignificant and are therefore neglected.

Calculation of internal correlation coefficients $\tau_{x_i y_j}$

$$\tau_{x_i x_j} = \frac{n\sum_{i,j=1}^{n} x_i x_j - \sum_{i=1}^{n} x_i \sum_{j=1}^{n} x_j}{\sqrt{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[n\sum_{j=1}^{n} x_j^2 - \left(\sum_{j=1}^{n} x_j\right)^2\right]}} \quad (3)$$

$\tau_{x_1x_2}$=+0.42 , $\tau_{x_1x_3}$=-0.4 , $\tau_{x_1x_4}$=-0.51

$\tau_{x_2x_3}$=-0.34 , $\tau_{x_2x_4}$=-0.602 , $\tau_{x_3x_4}$=+0.77

Building the system of standardized equations

C1. General form

$$\begin{cases} B_1 + \tau_{x_1x_2}B_2 + \tau_{x_1x_3}B_3 + \tau_{x_1x_4}B_4 = \tau_{yx_1} \\ B_2 + \tau_{x_2x_1}B_1 + \tau_{x_2x_3}B_3 + \tau_{x_2x_4}B_4 = \tau_{yx_2} \\ B_3 + \tau_{x_3x_1}B_1 + \tau_{x_3x_2}B_2 + \tau_{x_3x_4}B_4 = \tau_{yx_3} \\ B_4 + \tau_{x_4x_1}B_1 + \tau_{x_4x_2}B_2 + \tau_{x_4x_3}B_3 = \tau_{yx_4} \end{cases} \quad (4)$$

C2. Customized form

$$\begin{cases} B_1 + 0.42B_2 - 0.40B_3 - 0.51B_4 = 0.95 \\ B_2 + 0.42B_1 + 0.34B_3 - 0.605B_4 = 0.547 \\ B_3 - 0.40B_1 - 0.34B_2 + 0.77B_4 = -0.489 \\ B_4 - 0.51B_1 - 0.605B_2 + 0.77B_3 = -0.649 \end{cases} \quad (5)$$

$\tau_{x_1x_2}$=$\tau_{x_2x_1}$, $\tau_{x_1x_3}$=$\tau_{x_3x_1}$, etc.

By solving the system of standard normalized equations results:

B_1=0.85 , B_2=0.141 , B_3=-1.62*10-3 , B_4=-0.08

Calculation of Regression Coefficients

$$b_i = B_i \frac{S_y^2}{S_{xi}^2} = B_i \frac{S_y}{S_{yi}} \quad (6)$$

In which average standard deviations S_y, S_x can be calculated using the following relationships:

$$S_y = \sqrt{\frac{n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2}{n(n-1)}} \tag{7}$$

and respectively

$$S_x = \sqrt{\frac{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}{n(n-1)}} \tag{8}$$

The obtained values were:

$$S_y = \pm 4.91,\ S_{x_1} = \pm 0.173,\ S_{x_2} = \pm 3.56,\ S_{x_3} = \pm 0.087,\ S_{x_4} = \pm 5.26$$

$$b_1 = \pm 24.12;\ b_2 = +0.194;\ b_3 = -0.093;\ b_4 = -0.074$$

b_o will be calculated using the relationship:

$$b_0 = \frac{\sum_{i=1}^{n} y_i}{n} - \frac{b_1\sum_{i=1}^{n} x_{1i}}{n} - \frac{b_2\sum_{i=1}^{n} x_{2i}}{n} - \frac{b_3\sum_{i=1}^{n} x_{3i}}{n} - \frac{b_4\sum_{i=1}^{n} x_{4i}}{n} \tag{9}$$

The value of b_0 is 2.512

The final form of the correlation equation will be:

$$y = \%Carbide = 2.512 + 24.12x_1 + 0.154x_2 - 0.093x_3 - 0.074x_4 \tag{10a}$$

Or otherwise expressed:

$$y = \%carbides = 2.512 + 24.12\%C + 0.154\%Cr - 0.093\%Mn - 0.074\%Fe \tag{10b}$$

Calculation of the determination coefficient, R2

$$R^2 = \left[1 - \frac{n-1}{n-(k+1)}\right] - \frac{n-1}{n-(k+1)}\left[-B_1\tau_{yx_1} - B_2\tau_{yx_2} - B_3\tau_{yx_3} - B_4\tau_{yx_4}\right] \tag{11}$$

When K = 4 is the number of the regression equation coefficients (except b_0). The resulted value of R2 is 0.906 which means that 90.6% of the carbide variation in the Cr-Ni austenitic stainless steel whose composition was taken in the molded analysis can be explained by varying the concentration of the Carbon, Chromium, Manganese and Iron [6].

5. Conclusions

The determined regression equation determined in this study highlights how the component of Cr-Ni austenitic steels influences their solidification structure, with a direct effect on their service characteristics.

Analyzing the regression equation, one may see that Cr and C have the strongest influence on the content of the eutectic carbides in Ni-Cr steels. The increasing of chromium percentage in the steel composition leads to an increase of the carbides proportion in as casted steel state. The effect of carbon is much stronger than that of chromium. Manganese and iron act in opposite direction as against Carbon and Chromium. Manganese being a strong gammageneous element increases the proportion of austenite and implicitly binds some of the carbon, thereby generating a decrease in chromium availability for carbide synthesis.

The equation is useful both for monitoring the steels framing in structural requirements imposed by the field of use and for establishing the necessary chemical composition corrections since the steel was made (in liquid state).

To use the prediction equation, it is necessary and sufficient to determine the chemical composition of the steel in the liquid state. The values obtained for each element are introduced into the equation and the percentages of carbides in the steel structure are determined. The result is compared to the standard values for the cast steel type and as function of the result the steel is declared to be in accordance with the requested features or not. For inadequate material, the analysis should continue in order to establish which components should be corrected for achieving the requested values.

In this way, possible non-conformities in the material's characteristics as results of deviations in the chemical thus structural steel composition can be predicted and avoided.

R E F E R E N C E S

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