Supplementary Materials

Modelling of the Steel High-Temperature Deformation Behavior Using Artificial Neural NetworkXianghong

Ge [1],*, Hui Liu[2, 3], Xingxing Ding [1], Yanyan Liu[2, 4], Xingsheng Li [2], Xianli Wu [2] and Baojun Li[1],*

[1] Department of Physical Metallurgy of Non-Ferrous Metals, National University of Science and Technology "MISiS", Leninskiy Prospekt 4, 119049 Moscow, Russia; m1805037@edu.misis.ru

[2] Joint-stock company "Advanced Research Institute of Inorganic Materials named after Academician A.A. Bochvar", Rogova str. 5a, 123098 Moscow, Russia, tachuryumova@bochvar.ru

[*] Correspondence: churyumov@misis.ru; Tel.: +7-495-955-0134

The constructed artificial neural network may be described by the following formulas:

$$y_i = \tanh \left[bo\,out + \sum wk\,out \tanh \{ bk\,2h + \sum wkj\,2h \tanh(bj\,1h + n\,j{=}1\,p\,k{=}1 \sum wji\,1h\,xi\,m\,i{=}1) \} \right] \qquad (S1)$$

Where y_i is a code value of the output parameter;

$bo\,out$ is a bias value of the output layer $bo\,out = -1.9871$;

p is a number of the neurons in the second hidden layer (p=15);

$wk\,out$ are the synapse values between k-th neuron in the second hidden layer and output layer;

$bk\,2h$ are the bias values of k -th neurons in the second hidden layer; n a number of the neurons in the first hidden layer (p=30);

$wkj\,2h$ are the synapse values between k-th neuron in the second hidden layer and j -th neuron in the first hidden layer;

$bj\,1h$ are the bias values of j -th neurons in the first hidden layer; m is a number of input parameters;

$wji\,1h$ are the synapse values between j -th neuron in the first hidden layer and i -th input parameter;

x_i is an code value of the i -th input parameter.

The calculation of the coded values of the input parameters was made using the following formula:

$$x_i = 1.8X_i\,Xmax{-}Xmin + 0.9 - 1.8Xmax\,Xmax{-}Xmin \qquad (S2)$$

where X_i , $Xmax$, $Xmin$ are the current, maximum and minimum real values of the input parameters (maximum and minimum values are presented in the Table S1).

Calculation of the real value of the true stress may be determined using the following formula:

$$True\ stress = y_i{-}0.9{-}\,1.8Ymax\,Ymax{-}Ymin\,0.9{-}\,1.8\,Ymax{-}Ymin \qquad (S3)$$

where $Ymax$, $Ymin$ are the maximum and minimum real values of the true stress which were used for the ANN construction ($Ymax = 808.6\,MPa$ $Ymin = 0.91MPa$).

The values of the biases and synapses are presented in Tables

Table S1. The values of the neuron's biases in the hidden layers.

Neuron number	$b1h_j$	$b2h_k$
1	3.3276	0.5404
2	-0.4222	0.5156
3	1.4999	-0.3671
4	-0.0583	0.5386
5	1.2189	-0.0428
6	0.0697	0.3828
7	-0.4248	0.1176
8	-1.3468	0.5359
9	-1.3637	0.5258
10	-0.3958	-0.6897
11	-0.2718	0.0458
12	-3.9270	-3.0092
13	-7.2307	-1.2704
14	-0.3054	1.5706
15	-6.9983	-0.9832
16	2.6126	-
17	-0.1399	-
18	2.3584	-
19	0.0607	-
20	1.3235	-
21	2.9790	-
22	-0.7381	-
23	-1.4009	-
24	5.6806	-
25	0.0076	-
26	0.4586	-
27	1.9211	-
28	-0.6790	-
29	0.1577	-
30	-0.7737	-

Table S2. The values of the synapses between j-th neuron in the first hidden layer and i-th input parameter (w^{1k}_{ji})

		The neuron number in the first hidden layer (j)																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
The number of input parameter (i)	1	-0.0315	-0.1307	-0.0099	0.1771	-0.4946	-0.4094	0.1785	-0.4468	-0.0509	-0.0489	0.0318	0.1446	0.7561	3.9082	-0.1538	-0.0389	-0.9227	-0.2632	-0.9483	-0.8539	-1.0049	-0.7301	-0.4344	0.6046	-0.5148	0.0782	0.6630	0.5024	-1.0347	-0.0629
	2	2.2400	-0.1094	0.9769	0.7579	0.0423	0.0246	0.4799	-0.2106	-0.0909	-2.2722	0.6335	-0.1535	-0.2204	1.2676	0.7625	0.4698	3.2664	0.0028	1.2694	1.6332	0.0617	0.7346	0.0684	-1.5371	-0.4308	0.6318	0.4075	-0.9931	-0.9904	-0.7387
	3	-0.0454	0.1923	1.6042	-0.1393	-0.0559	0.2692	0.7448	-0.1243	0.0600	-0.6128	1.7160	1.0865	-0.1395	-0.4562	-0.5495	0.9709	0.1655	-2.1201	0.8968	-0.2434	-0.4185	0.3059	-0.7573	0.5188	-0.4306	-1.1750	1.0671	-0.3475	-1.0792	0.1719
	4	-0.1852	0.9861	0.2426	-1.4839	0.3314	2.3066	-0.2395	0.3022	0.2089	-0.1228	0.2058	-0.4245	0.5236	-0.0492	-0.4295	0.7233	-0.4919	0.9105	-0.8815	-0.1714	0.3579	-0.0626	-0.8607	-1.0649	-0.1901	-0.2047	-0.8531	0.2928	-0.1169	2.2514
	5	-0.6830	0.2676	-0.0987	0.4010	-0.9525	-0.6561	-2.5903	0.0207	-0.2903	-1.1884	-0.1083	0.3605	-0.3524	-0.6780	0.3745	0.7439	-0.6214	0.3244	0.9706	-1.1081	-0.1880	-0.7916	-0.2302	-0.2387	0.3139	-1.0902	0.3574	0.0812	0.8930	0.6771
	6	0.1505	-0.6359	0.3408	-0.2139	-0.4215	-0.6090	0.0450	0.0333	-0.9413	0.0510	-1.2727	0.0581	0.0689	0.2270	0.4412	-2.2157	1.1730	0.0689	0.3295	-0.7895	1.1718	0.0001	1.0776	0.7578	0.5962	-0.0068	0.3427	0.5114	0.3187	0.3662
	7	0.2369	-0.3205	0.6736	-0.5381	0.3336	-0.1755	-0.4627	4.2397	0.2468	0.8822	0.1968	-8.5088	0.2811	0.3645	0.0795	-0.0677	0.8381	-0.0040	0.0993	-0.1411	0.2829	-0.2519	0.1424	0.1374	0.4039	0.5474	-0.0592	-9.3986	0.7687	-0.5509
	8	1.3481	0.3123	1.2244	-0.3711	0.2532	-0.7997	-0.0424	-0.2882	0.0855	0.1066	0.6009	1.1292	0.6972	0.2498	0.3427	0.4745	-0.0254	-0.2120	1.0877	0.2617	-0.0651	-0.2184	0.2203	-0.1940	0.1220	0.0883	0.4842	-0.2160	-0.2936	-8.1706
	9	0.3456	-2.6089	0.0781	-0.0658	0.6427	0.4659	-0.3862	0.6314	-0.1917	0.3225	0.2452	-2.0249	-0.8027	6.4941	0.3933	-0.0108	0.0480	1.8253	0.2337	-0.5574	1.0468	-1.5356	0.3325	-0.2956	0.4355	-0.3032	-0.4453	-0.4111	0.1081	-1.2391
	10	-1.0069	0.0589	0.2452	1.4012	-0.5888	1.0447	0.7619	-0.0473	0.5551	-1.3477	-0.1805	-0.1615	0.1441	1.0517	0.5547	0.4409	-0.8752	0.1919	-0.2065	0.2987	-0.0851	0.8452	-0.5775	-0.6016	0.4475	-0.2413	-0.6225	0.2967	-0.5564	0.1493
	11	-0.4738	1.5493	0.6629	0.0145	-0.6287	-0.0121	0.4186	-1.3803	-0.1629	-0.1505	0.4686	-0.3949	-0.3101	0.1838	-0.6254	-0.0748	1.1512	0.9971	2.1668	-0.3151	-0.0389	3.5921	-0.3360	-0.0349	0.1051	0.4232	-0.7085	0.4469	0.0729	0.4840
	12	-0.4785	-1.3164	-0.4296	1.7102	-0.7449	-0.0320	0.4862	-0.3705	0.2654	-0.0344	0.4969	1.3439	-0.2652	-0.5421	0.1282	0.7684	-1.2145	-0.3090	-0.7945	-0.3669	-0.0949	-0.1184	0.5720	-1.1395	-0.3778	0.9683	-0.1602	0.2393	-0.4002	-0.0331
	13	-0.3131	0.0421	-0.6984	0.6255	0.3753	-0.2192	-0.0925	-0.1126	0.1396	-1.0839	0.2739	-0.1044	0.2959	0.5314	-0.2104	-0.0014	0.1973	-0.1039	-0.1261	0.0808	-0.0340	7.3915	-0.8446	0.0417	-0.3078	-0.0318	0.0365	-0.4914	0.2251	-0.1556
	14	-0.1634	2.3682	-0.2280	-0.2078	0.0772	0.7924	-0.5134	-0.9015	1.0639	-0.0534	-0.0191	-0.7089	0.3236	-0.5131	0.4367	0.4765	-0.0155	-0.1236	0.1036	0.0503	0.5902	-0.6691	0.2717	1.3109	-0.8436	0.0201	-1.3656	1.3893	0.0982	0.4853
	15	-0.0755	-0.5130	1.8534	0.1614	-0.2115	-0.3945	0.6664	-0.2040	0.6732	-1.1993	0.0403	-0.0074	0.1491	1.5663	0.7188	-0.8343	0.6797	-0.4792	-1.3295	0.1561	0.4579	-0.5242	0.8802	0.1988	-0.3883	0.3958	0.2081	0.2713	-0.4059	-0.0466
	16	-0.1524	0.3719	0.3701	-0.2901	0.2045	0.4847	0.1867	-0.3411	0.2622	-0.8832	-0.3948	-0.0675	-2.0440	0.0984	0.4644	0.9186	0.4300	1.1287	-0.3479	0.0392	0.6758	-0.3400	-0.0550	0.2994	-0.1433	-0.0951	-0.1322	-1.4629	-1.4096	0.1797

Table S3. The synapse values between k-th neuron in the second hidden layer and j-th neuron in the firsthidden layer ($w\overset{9}{k}j$);

		The neuron number in the second hidden layer (k)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1	-0.3138	-2.3008	-0.4117	-0.5524	1.4613	1.1172	0.2668	-1.1979	-0.5059	0.2043	1.8460	-2.3757	-1.1477	2.2287	-7.1742
	2	-0.8998	0.5491	0.7260	-0.4307	0.5358	0.9055	0.4856	1.1395	0.2894	0.3933	1.2918	-1.0645	0.9742	-0.4298	-0.7892
	3	1.9477	0.8823	-0.4545	-0.4567	1.3097	-0.0269	-1.7013	-0.0390	-0.1762	-2.2036	0.0690	-0.1723	0.1044	-0.4665	1.3110
	4	2.6121	1.3411	1.4847	0.6816	-0.4169	0.5024	0.5573	-0.7705	4.5311	-0.5346	-0.9913	0.7595	-0.1550	-0.8267	-0.6195
	5	-0.0964	-0.2476	0.1083	0.1954	0.0713	0.4318	0.2710	0.1628	0.8532	0.5017	0.0888	0.9106	-0.5503	0.3960	-0.2272
	6	0.1841	-0.3876	-1.2231	0.0886	-1.2919	0.5600	0.4124	-0.2928	-0.0605	-0.3924	-0.4198	0.1389	1.5344	0.1534	-0.5346
	7	1.8897	0.8297	-0.3889	-0.3834	1.0805	-0.0622	-1.1613	0.2956	-0.2605	-0.8941	0.0138	-0.2696	-0.0177	-0.8397	1.8950
	8	2.0473	0.9770	0.9874	0.5156	-0.6894	0.2750	0.1552	-0.6716	2.0739	-0.5633	-0.5482	0.5103	-0.1244	-0.7770	-0.2530
	9	-0.2652	0.9304	0.5386	0.1780	0.4322	-0.0206	0.0016	0.0649	-0.9858	-0.2114	-0.4401	0.2190	1.1378	-0.0886	0.5870
	10	-0.0762	0.3372	0.6583	-0.6652	-0.1204	-0.0505	-0.1465	0.8536	0.3843	0.9624	0.3926	-0.2260	-1.5262	0.0243	0.0786
	11	0.0608	0.8084	-0.6531	-0.4710	0.2063	0.1275	-0.9825	0.0218	1.0972	0.2069	1.0957	-0.4673	1.2503	-0.0635	-1.1970
	12	-0.5332	0.5635	0.2677	1.2111	0.5323	1.0029	0.8965	-0.9686	-0.6074	0.0642	-0.3274	-0.4990	0.4432	-0.6709	0.7970
	13	-0.4481	-0.3113	-1.3498	-0.8769	0.0614	0.0145	-0.5272	-1.7892	-0.0952	1.0738	0.4906	-0.2413	0.1790	-0.7657	-0.9760
	14	-0.1769	-0.2104	-1.5641	0.3608	-0.2019	-0.6300	-0.3469	-0.4964	-0.3940	-0.7929	0.0176	0.0264	0.0256	0.5960	1.5023
	15	-1.5279	-0.7317	1.0224	-0.6169	0.6755	0.0656	0.6034	-0.1494	0.0255	1.0148	1.3243	-0.8797	0.8315	-2.0652	-0.6868
	16	-0.2023	0.0160	-0.3764	0.2791	0.3736	0.9116	-1.0802	-0.2201	-0.3459	-0.5805	-0.7041	-0.9626	0.3505	-0.9136	1.4142
	17	-0.9339	0.4841	1.3261	0.4702	0.0387	0.1718	-0.0213	0.3381	-0.1363	-0.8062	0.5641	0.6668	-0.0901	1.0512	-0.9078
	18	0.0844	-0.1499	0.1405	-0.3113	0.3775	1.2348	0.6419	0.0011	-0.1832	-0.6746	0.9862	0.3283	-1.1659	-0.7608	-0.1727
	19	1.0716	-1.0103	1.4809	-0.0311	0.5282	0.0506	-0.6021	0.8338	0.7309	0.3036	-0.1186	0.4298	0.5592	-0.2806	-1.6374
	20	0.5195	-0.1445	1.2624	-0.1182	0.4699	1.3508	0.4970	-0.6888	-0.9244	0.3749	0.0185	-0.0741	1.0159	-0.4134	-0.8599
	21	-0.7910	-0.0454	0.5815	-0.2324	0.3338	0.0452	-0.4281	-0.6210	0.0166	-0.4424	0.6640	0.2154	-0.1885	-0.6739	0.2927
	22	-0.1353	0.2696	0.2138	0.2446	0.0798	0.3623	0.1807	-0.1771	0.0052	0.0543	-0.1929	-0.5046	0.1770	-0.4281	-0.2051
	23	-5.1012	0.8823	-1.2750	0.6532	-1.8287	0.0502	0.3077	-1.0978	1.3960	0.1623	-0.5407	0.3577	-0.6614	0.6925	0.4584
	24	-3.4840	-0.2290	-1.0518	-2.2040	0.8321	-2.3610	0.3765	1.4776	-1.6170	-0.8543	-0.9499	0.1757	0.2491	0.0376	1.9007
	25	-0.3416	-0.4754	0.3880	0.4945	-0.5679	0.0082	0.7587	-0.3255	-0.0862	0.0241	0.4706	-0.9931	-0.0236	0.2768	-1.4009
	26	-0.1045	-0.2894	-0.7834	0.0347	0.5338	0.0228	-0.4291	0.0439	0.2914	-0.8001	0.4409	0.1345	0.1398	-0.0495	0.4239
	27	0.1364	-1.3655	-0.0447	-1.3130	0.9238	-0.0373	-0.2022	0.4438	-0.7588	1.3445	-0.3695	0.4377	0.5067	0.6377	-0.4750
	28	-1.1109	0.2393	-0.0091	1.4154	-0.2571	0.8760	-0.2978	-0.9701	-2.0139	0.2287	-2.3044	-0.8265	-0.7967	0.3379	-0.1544
	29	-0.3596	0.6202	-0.2261	0.3033	1.0726	0.6698	-0.0804	-1.2673	0.1062	0.7120	-0.3275	3.9514	-4.5485	-2.2443	-0.7037
	30	-1.4628	0.8502	0.7107	0.4344	0.8688	0.1570	0.8043	0.6581	0.4775	0.3196	2.0734	0.3099	-0.6549	-0.6747	-0.4457

The neuron number in the first hidden layer (j)