UNIVERSITÀ DEL SALENTO

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MODELING OF THE BORIDING PROCESS BY THE EVOLUTIONARY DESIGN (ED) ALGORITHM IN modeFRONTIER® AND PRE-PROCESSING OF THE DATA IN ANSYS

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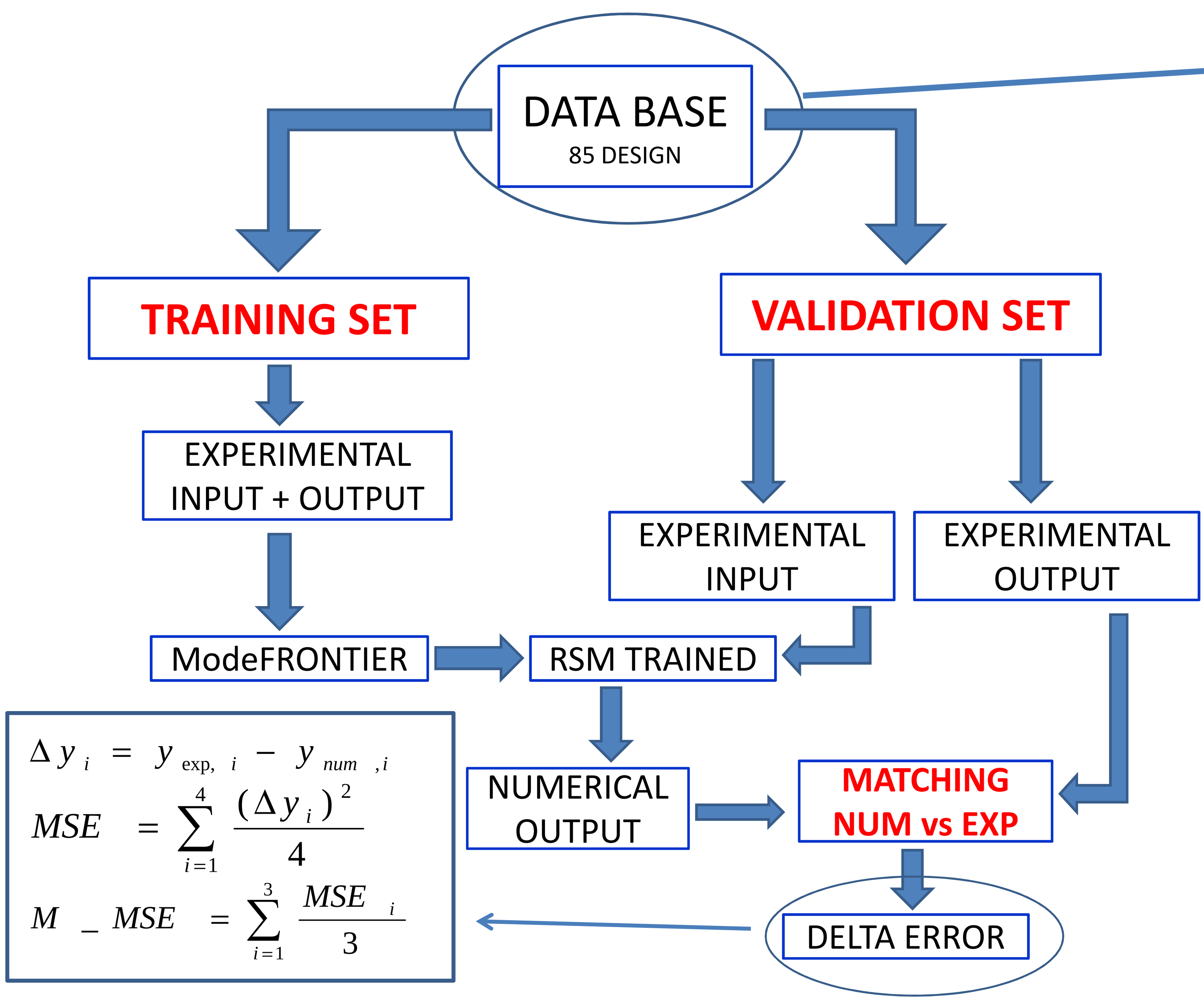
Experimental and numerical procedure

The aim of activity was to build up a numerical model of boriding process.The modeling of the process was performed on the basis of experimental results, which were collected in a database and processed in modeFRONTIER® in order to obtain metamodels in the form of analytical formula by using the ED algorithm. Then the physical models have been calibrated and validated through a detailed analysis in modeFRONTIER®. The relative error between experimental and numerical results has been calculated. The analysis led to the prediction of surface hardened layers dimensions and hardness in commercial steels.

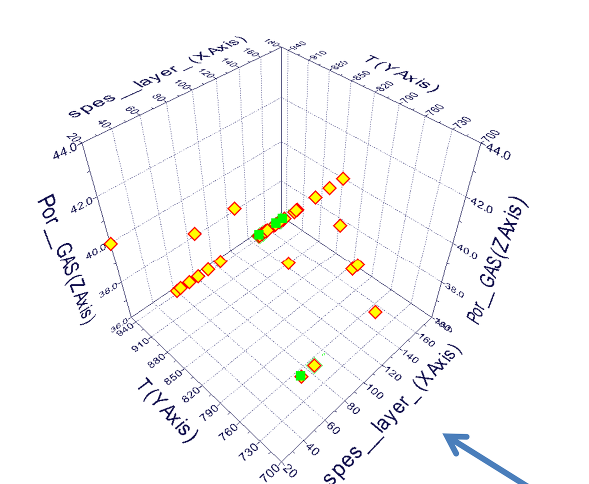
COMP	Por_GAS	Pr_GAS	t	T	spes_layer	Hv_0_05	Hv_0_075	Hv_0_15
BCl3 /H2 (1/15)	l/h	mm Hg	h	°C	µm			
0.0666	40	200	1	850	97	1590	1400	300
0.0666	40	300	1	850	108	1400	1400	300
0.0666	40	400	1	850	110	1625	1580	630
0.0666	40	200	2	850	113	1620	1410	300
0.0666	40	300	2	850	115	1700	1500	698
0.0666	40	400	2	850	115	1600	1500	780
0.0666	40	200	0.5	850	117	1580	1510	300
0.0666	40	200	1	850	128	1700	1700	1700
0.0666	40	200	3	850	131	1700	1700	1550
0.0666	40	200	4	850	118	1500	1500	1400
0.0666	40	200	5	850	60	1700	1680	1550
0.0666	40	200	6	850	35	1560	1500	1400
0.0666	40	200	2	700	35	1625	1580	630
0.0666	40	200	2	750	115	1625	1580	630
0.0666	40	200	2	800	90	1625	1580	630
0.0666	40	200	2	900	65	1625	1580	630
0.0666	40	200	2	950	20	1625	1580	630
0.0666	40	200	2	700	45	1625	1580	630
0.0666	40	200	2	750	120	1625	1580	630
0.0666	40	200	2	800	140	1625	1410	630



$$\Delta y_i = y_{\exp,\ i} - y_{num\ ,i}$$

$$MSE = \sum_{i=1}^{4} \frac{(\Delta y_i)^2}{4}$$

$$M\_MSE = \sum_{i=1}^{3} \frac{MSE_i}{3}$$



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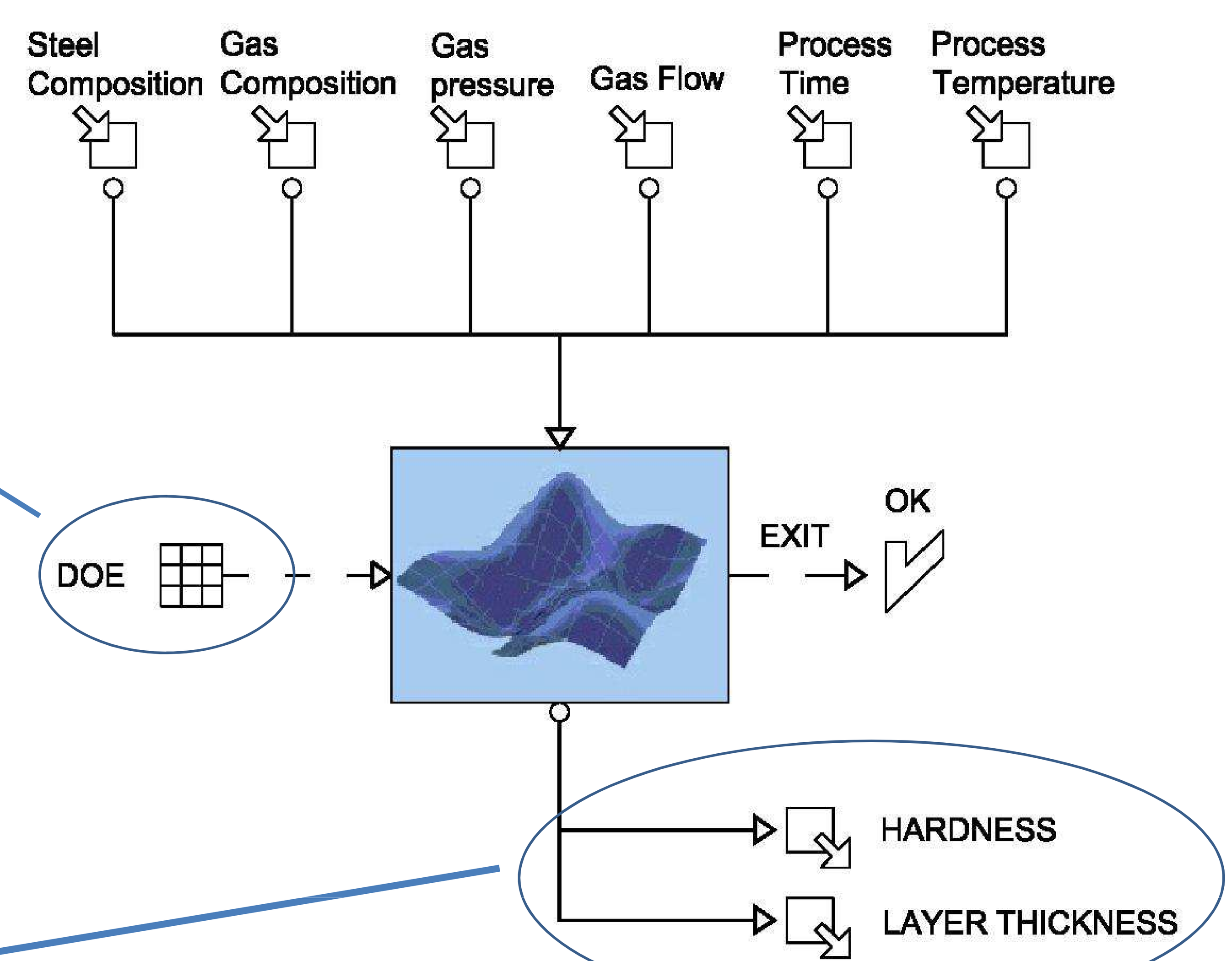


The analytical instrument used for the calculation of the error between output numerically and experimentally has been the Mean Square Error (MSE) applied on the points of measurement of the specific size of output and in turn mediated on 4 different design of the validation set (M_MSE: Mean_Mean Square Error).

OUTPUTS	MSE	M_MSE	RAD. Q. MSE	RAD. Q. M_MSE
Spes_layer	23.25		4.48	
Hv_00_5	23.50	26.08	4.84	5.10
Hv_00_75	26.85		5.12	
Hv_0_15	28.85		5.33	

Through the numerical implementation has been carried out the pre-processing of the data in order to reproduce a code via FEM results obtained with the response surfaces. This is done using the software ANSYS through the programming language APDL (Ansys Parametric Design Language) with which have been implemented numerically systems of equations representative of phenomenological models of the process of boriding.

EQUATIONS BORIDING PROCESS

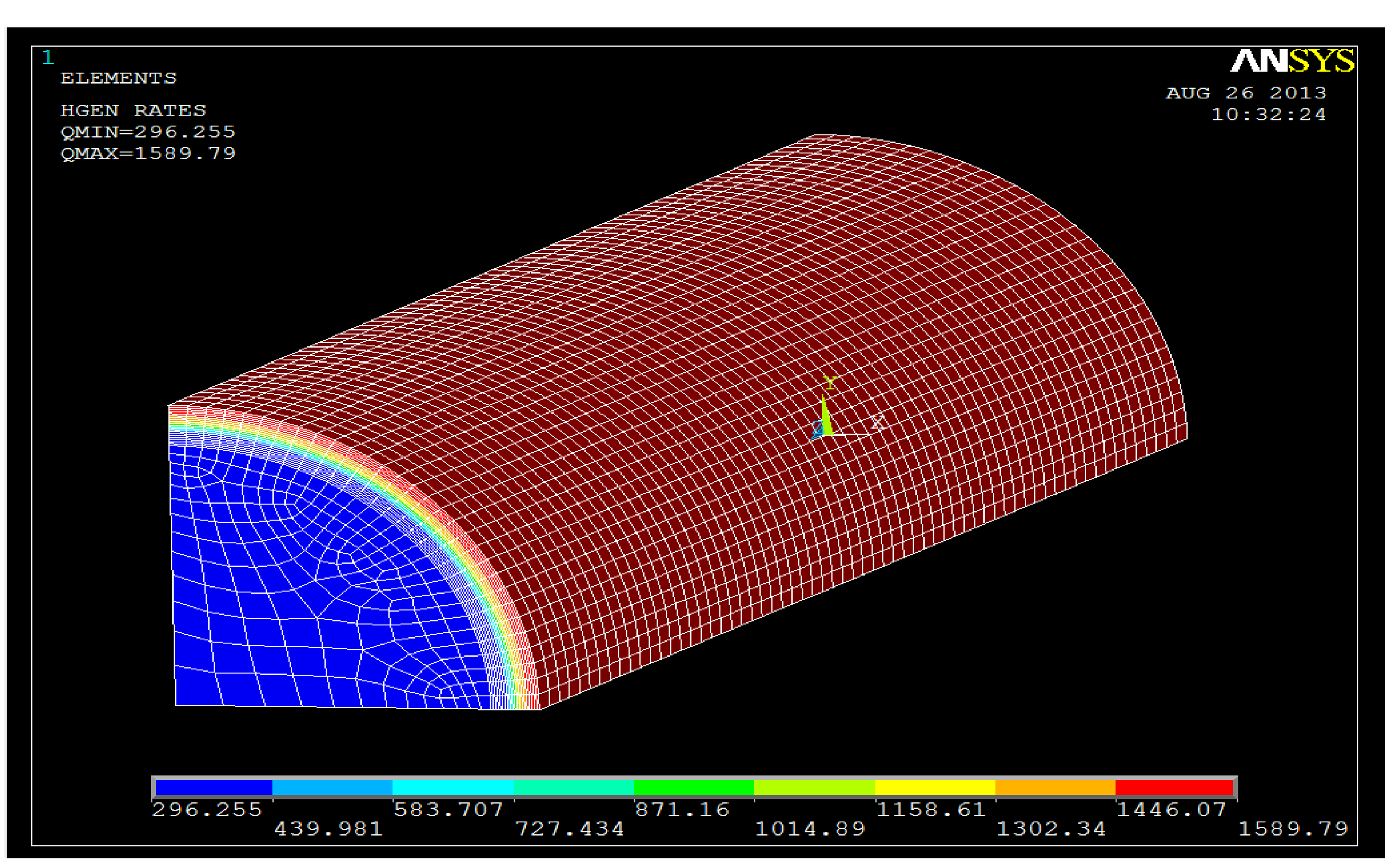
Hv_00_5 = Vickers hardness 0.05 mm of thickness of hardened layer
Hv_00_75 = Vickers hardness at 0.075 mm layer thickness
Hv_0_15 = Vickers hardness 0.15 mm layer thickness
spes_layer = thickness of hardened layer Layer in µm

Analytical formulations by Evolutionary Design

Hv_00_5 = 1607.3717315298804 + (((((((p_C / p_P) / cos(Pr__GAS)) - (((t_ - cos (Pr__GAS)) / cos((t_ - sin(t_)))) + (t_ - (cos(t_) - t_)))) + ((p_C / p_P) / cos(((p_Mn * 10) / (sin(t_) + ((p_Mn / t_) * (Pr__GAS * p_C))))))) + ((p_Mn * 10) / cos(((p_Mn * 10) / (sin(t_) + ((p_Mn / t_) * (Pr__GAS * p_C))))))) + ((((t_ - ((p_C / p_P) / (Pr__GAS * cos(Pr__GAS)))) - sin((((p_P * 10) / cos(Pr__GAS)) + (t_ - (cos(1) / Pr__GAS))))) - sin((((p_P * 10) / cos(Pr__GAS)) + (t_ - cos(Pr__GAS))))) / sin((sin(sin((sin(sin(t_)) + ((p_Mn / t_) * cos(p_Mn))))) + (sin(((sin(t_)/ cos(Pr__GAS)) + (t_ - exp(p_P)))) / Pr__GAS))))) + (((p_C / p_P) / cos((cos((exp(sin(0.1)) + ((t_ - (p_Mn / 0.1)) * (Pr__GAS * Pr__GAS)))) / (sin(t_) + ((p_Mn / t_) * cos(Pr__GAS)))))) / ((cos(((p_Mn / (Pr__GAS * cos(Pr__GAS))) / cos(Pr__GAS))) + ((t_ / sin(t_)) / cos((t_- ((p_Mn * 10) / cos(Pr__GAS)))))) + ((cos((cos((t_ - cos(Pr__GAS))) + ((Pr__GAS * p_C) * (Pr__GAS * Pr__GAS)))) / Pr__GAS) / cos((((sin(t_) * ((p_C / p_P) / Pr__GAS)) * (t_ - (0.1 / (p_Mn * 10)))) + (((p_Mn / t_) * (Pr__GAS * p_C)) * cos(Pr__GAS))))))))

spess_layer = -52.33770322754191 + ((((((((p_P - (0.1 * T)) - exp(t_)) / (sin(T) * ln(Pr__GAS))) - (cos((((T - 1) / p_Fe) - 1)) * ((cos((t_ + 1)) * ((T + p_Fe) / (0.1 * T))) + (0.1 * T)))) * (cos((cos(sin(t_)) * (((t_ - 1) + (0.1 * T)) + cos(sin(t_))))) + (sin((((ln(Pr__GAS) + (0.1 * T)) * Pr__GAS)) + cos(((exp(t_) * p_Fe) * 1))))) - exp(t_)) / (sin(T) * ln(Pr__GAS))) + (sin(T) * ((((cos((((T + 0.1) / p_Fe) - 1)) * (cos(((0.1 * T) * (p_C - 1))) + ((ln(Pr__GAS) + (0.1 * T)) + cos(t_)))) + (sin(((ln(Pr__GAS) + (0.1 * T)) * Pr__GAS)) + cos(((p_Fe * p_Fe) * (ln(Pr__GAS) * (p_C - 1)))))) + ((cos((((T - p_Fe) * ln(Pr__GAS)) - sin(t_)))) / cos((((T - 1) / p_Fe) - 1))) + (sin(((sin(t_) + (T + p_Fe)) * Pr__GAS)) + (cos(sin(t_)) * (cos(t_) + (0.1 * T)))))) - ((p_C - 1) * p_Fe))))

The advantage of this procedure was to obtain as output a contour plot of the desired size on a three-dimensional model.



Vickers hardness in three-dimensional Boriding model