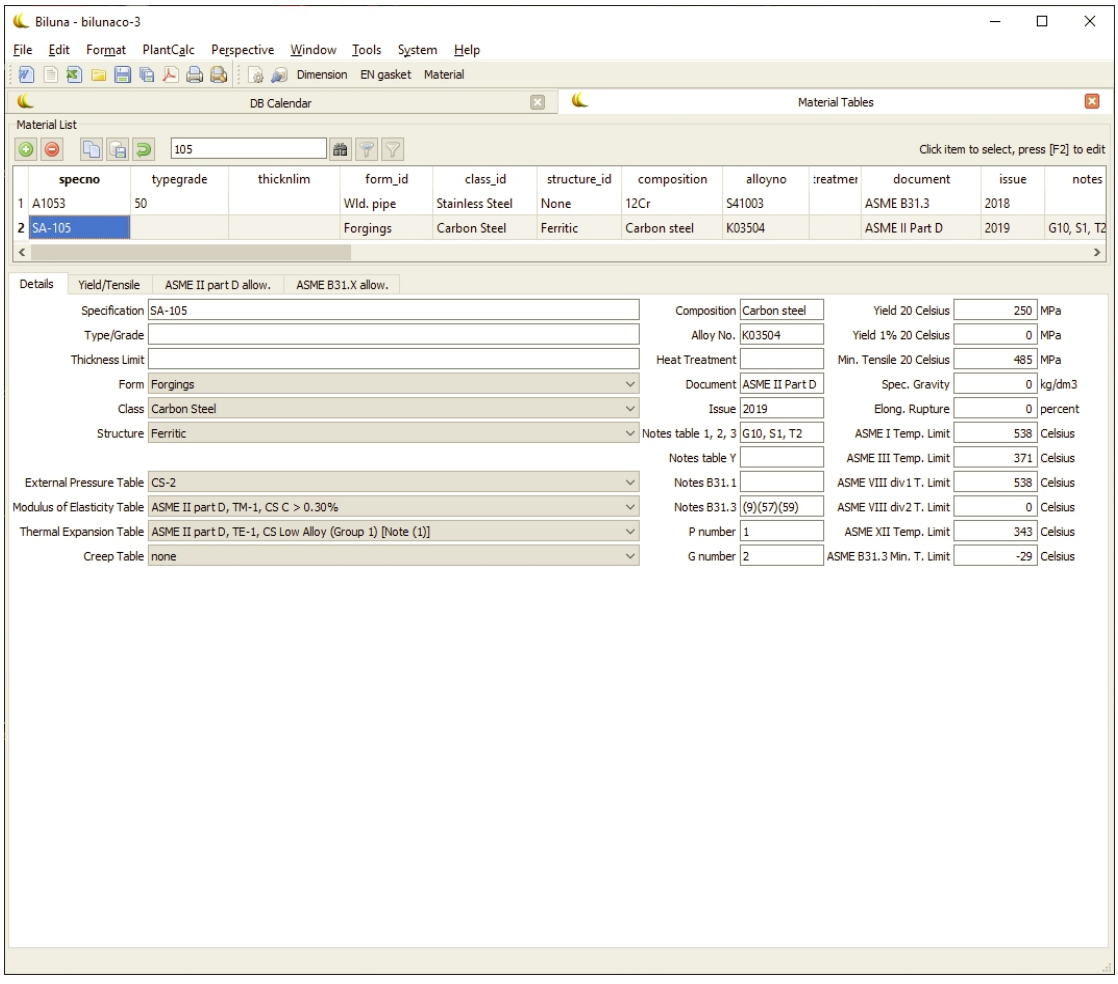
7. ANEXOS

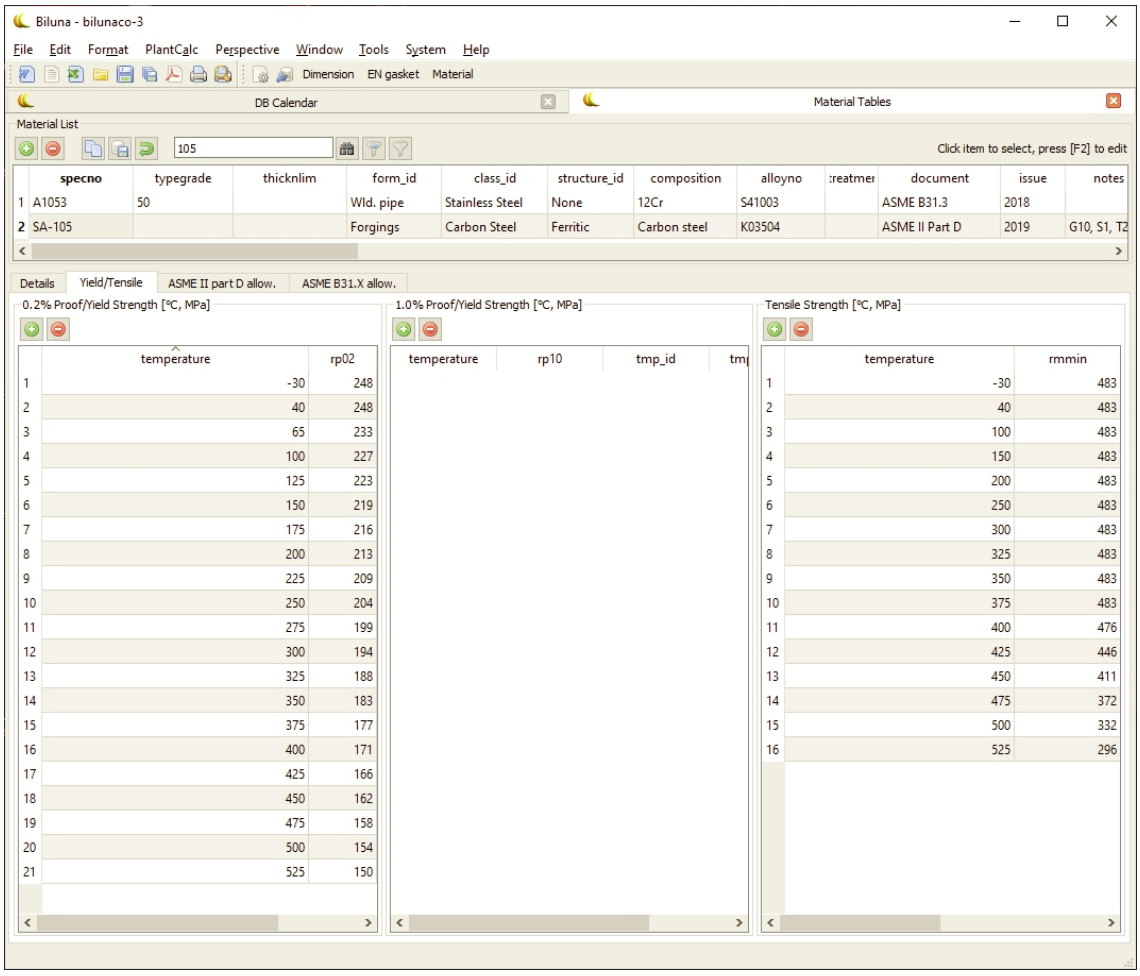
ANEXO A : Propiedades de los materiales

Los materiales utilizados en este proyecto son de Burrull Allan, Xavier [1] excepto de la junta. Todos los materiales están siendo recomendados por la empresa Red-Bag y se confirma que cumplen con los criterios mencionados en ASME B16.5 2009 [2].

❖ **La brida y la tubería (ASME SA 105)**

Los materiales utilizados para la brida y la tubería son el material de acero al carbono (A-105) con la siguiente especificación. La Imagen 1 se muestra la diagrama tensión-deformación según el comportamiento plástico bilineal.





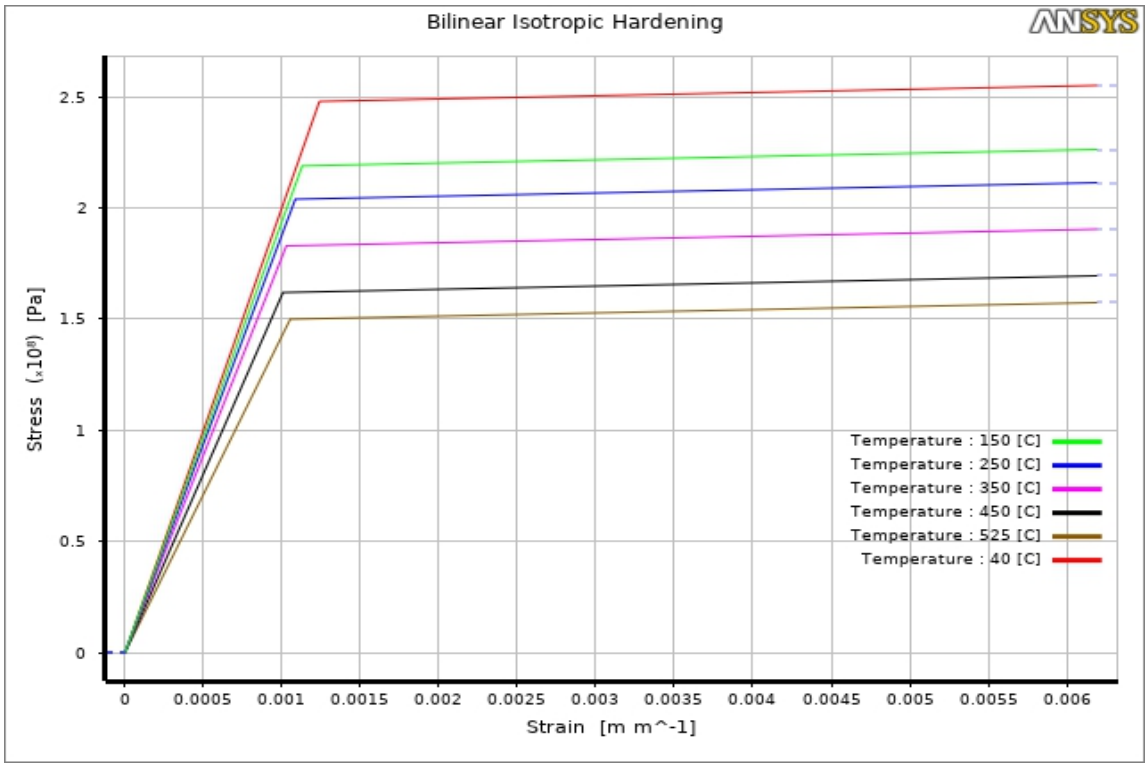
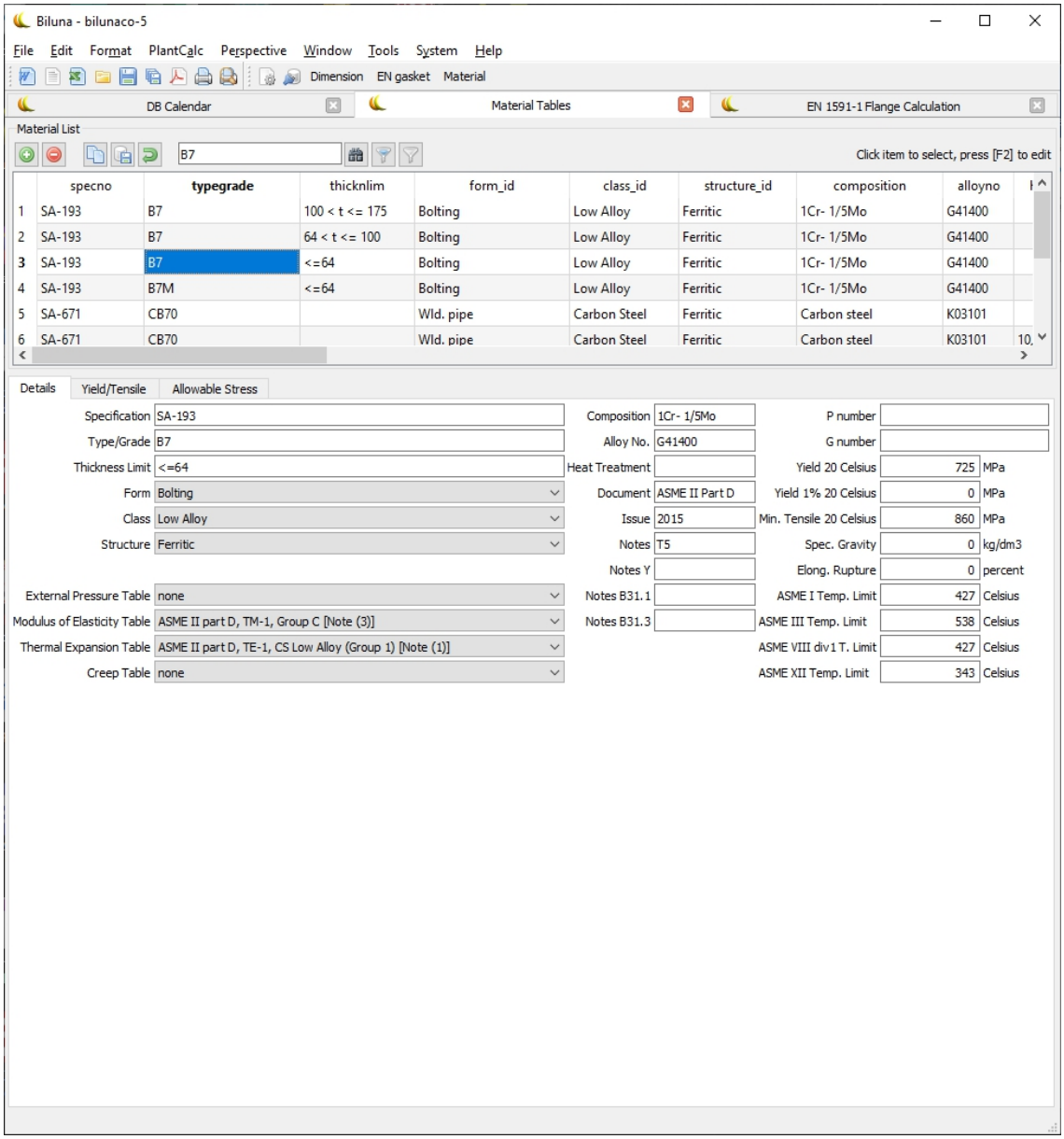
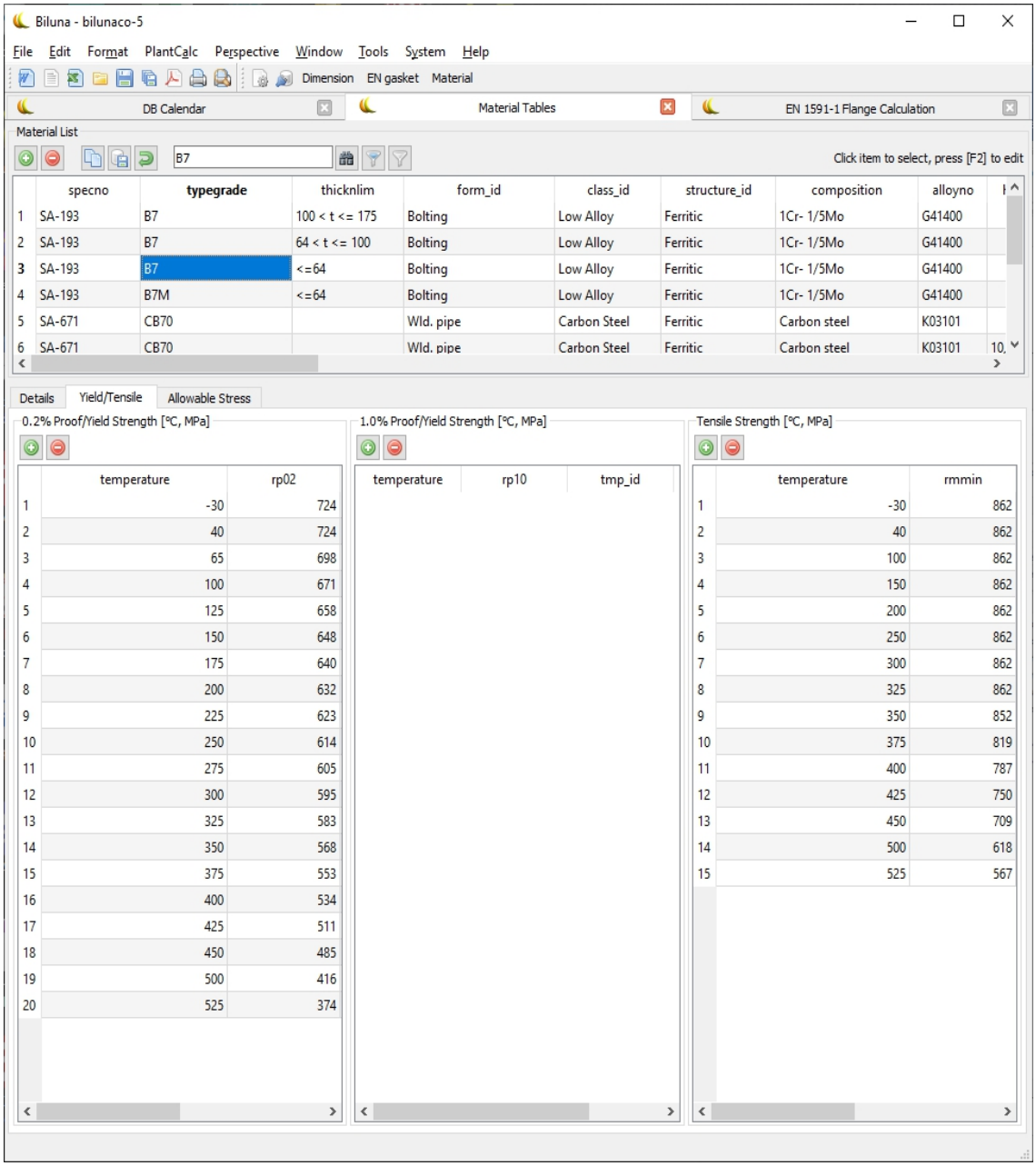


Imagen 1: Diagrama tensión-deformación para el ASME SA105 en ANSYS

❖ Los tornillos (ASME SA 193 B7)

En cuanto al tornillo, optamos por simular el tornillo que está hecho de acero al cromo, (A-193 B7). La siguiente tabla muestra las propiedades del tornillo según lo recomendado por la empresa Red-Bag.





	specno	typegrade	thicknlim	form_id	class_id	structure_id	composition	alloyno
1	SA-193	B7	100 < t <= 175	Bolting	Low Alloy	Ferritic	1Cr- 1/5Mo	G41400
2	SA-193	B7	64 < t <= 100	Bolting	Low Alloy	Ferritic	1Cr- 1/5Mo	G41400
3	SA-193	B7	<=64	Bolting	Low Alloy	Ferritic	1Cr- 1/5Mo	G41400
4	SA-193	B7M	<=64	Bolting	Low Alloy	Ferritic	1Cr- 1/5Mo	G41400
5	SA-671	CB70		Wld. pipe	Carbon Steel	Ferritic	Carbon steel	K03101
6	SA-671	CB70		Wld. pipe	Carbon Steel	Ferritic	Carbon steel	K03101

	temperature	rp02
1	-30	724
2	40	724
3	65	698
4	100	671
5	125	658
6	150	648
7	175	640
8	200	632
9	225	623
10	250	614
11	275	605
12	300	595
13	325	583
14	350	568
15	375	553
16	400	534
17	425	511
18	450	485
19	500	416
20	525	374

temperature	rp10	tmp_id

	temperature	rmmin
1	-30	862
2	40	862
3	100	862
4	150	862
5	200	862
6	250	862
7	300	862
8	325	862
9	350	852
10	375	819
11	400	787
12	425	750
13	450	709
14	500	618
15	525	567

A continuación, la Imagen 2 se muestra la diagrama tensión-deformación para el acero al cromo (A-193 B7) según el comportamiento plástico bilineal.

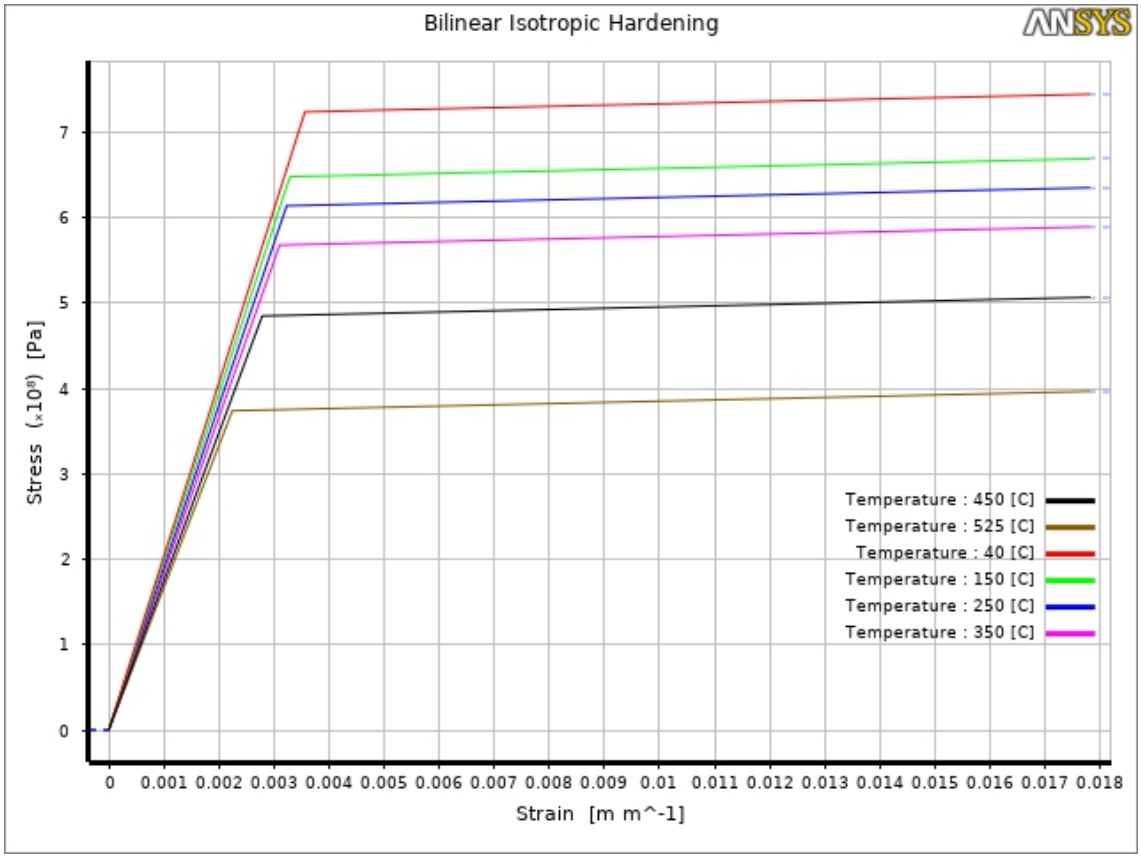


Imagen 2: Diagrama tensión-deformación para el ASME SA 193-B en ANSYS

❖ La junta (Acero inoxidable NL)

Por un lado, la selección del material de la junta es muy importante para evitar fugas. El acero inoxidable NL con endurecimiento isotrópico bilineal se utiliza según lo recomendado por Mohit, 2020 [8].

Properties of Outline Row 6: Stainless Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7750	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion	1.7E-05	C^-1		
6	Isotropic Elasticity				
7	Derive from	Young's Modulus and Poiss...			
8	Young's Modulus	1.93E+11	Pa		
9	Poisson's Ratio	0.31			
10	Bulk Modulus	1.693E+11	Pa		
11	Shear Modulus	7.3664E+10	Pa		
12	Bilinear Isotropic Hardening				
13	Yield Strength	2.1E+08	Pa		
14	Tangent Modulus	1.8E+09	Pa		
15	Tensile Yield Strength	2.07E+08	Pa		
16	Compressive Yield Strength	2.07E+08	Pa		
17	Tensile Ultimate Strength	5.86E+08	Pa		
18	Compressive Ultimate Strength	0	Pa		
19	Isotropic Thermal Conductivity	15.1	W m^-1 C^-1		

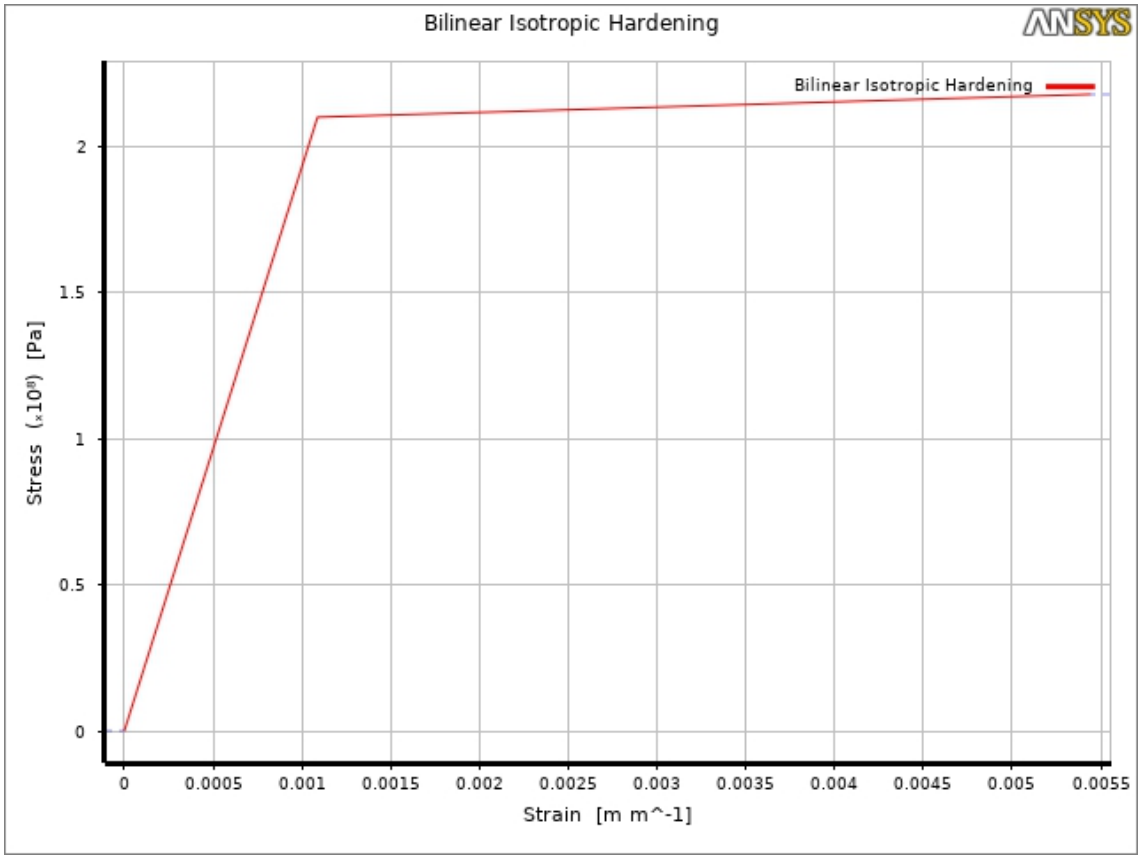
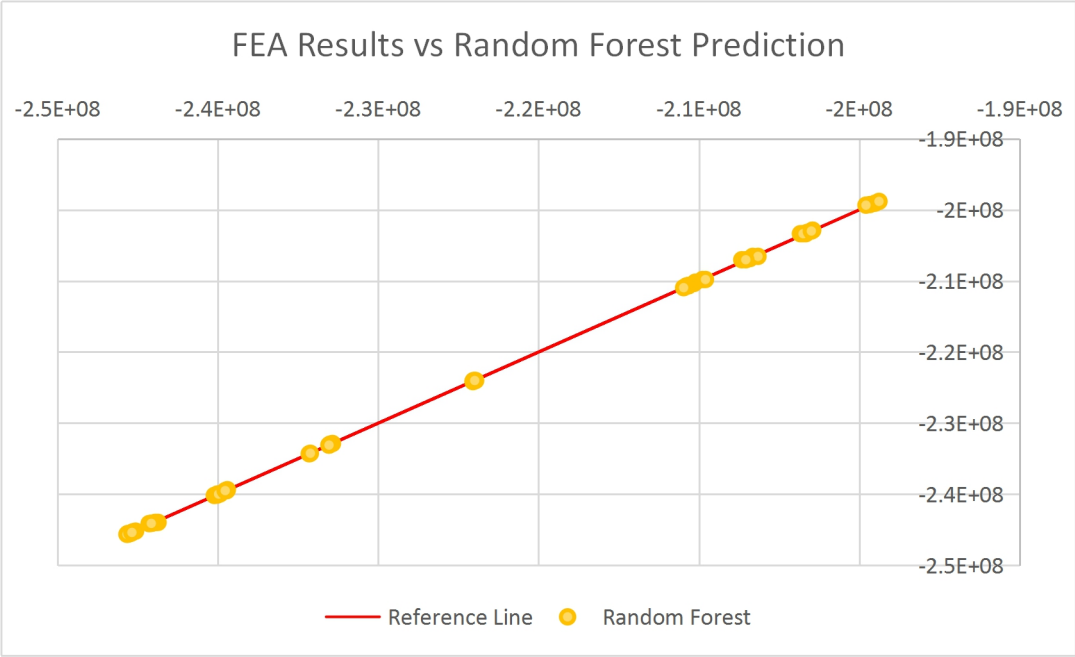


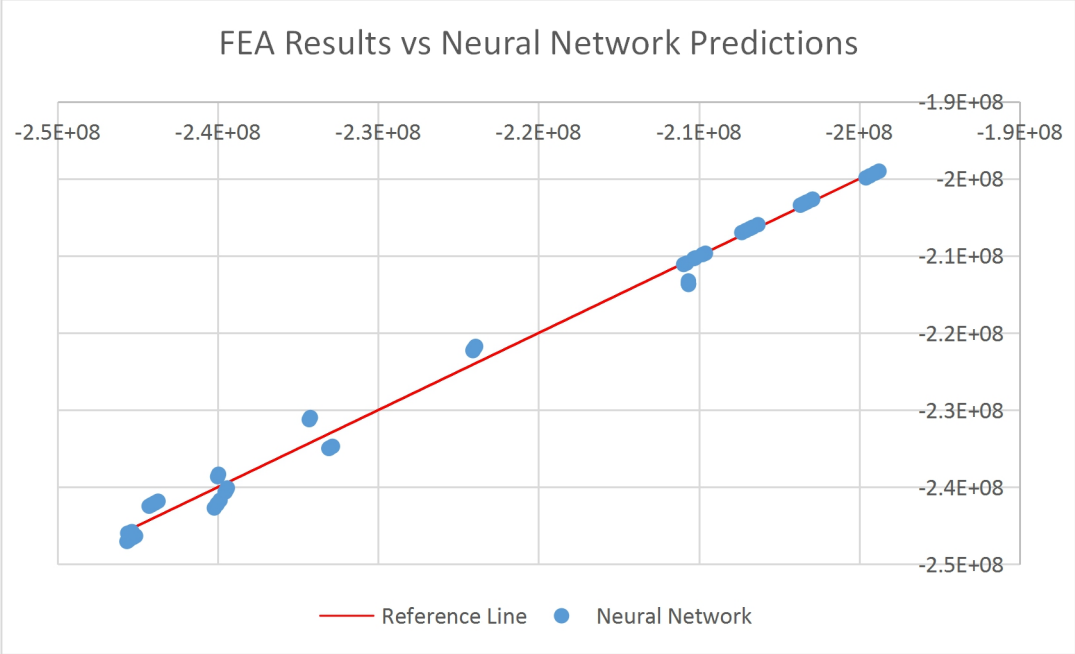
Imagen 3: Diagrama tensión-deformación para el acero inoxidable NL en ANSYS

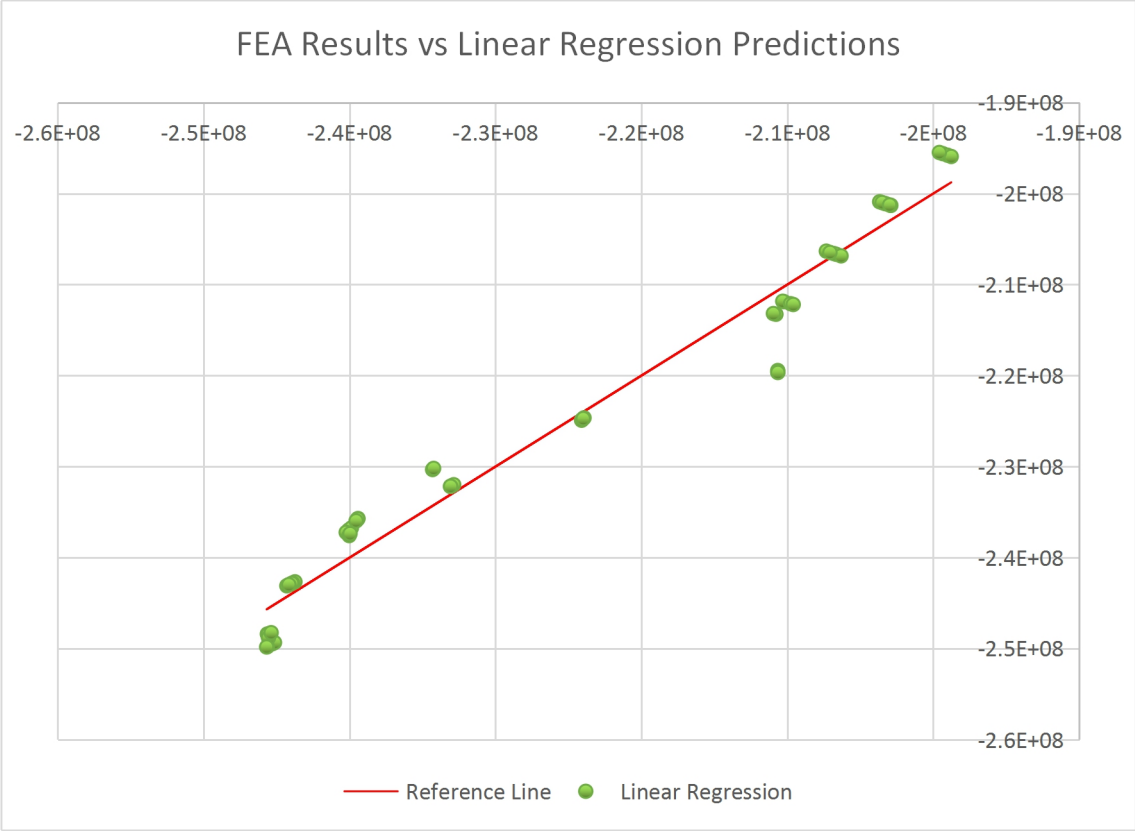
ANEXO B: Gráfico de dispersión de los resultados previstos.

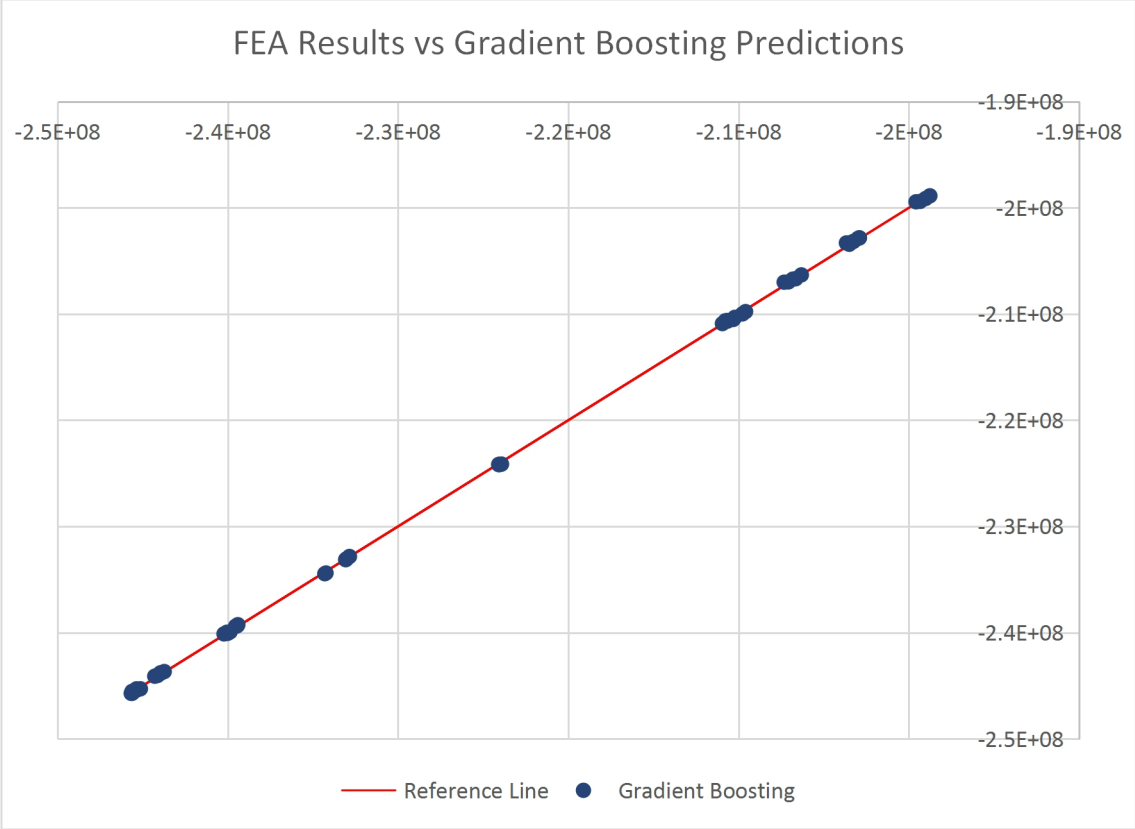
Desde el widget de predicción en Orange, los valores de salida predichos se han trazado para compararlos con los resultados de FEA. Como se mencionó anteriormente, cuanto más cerca esté el valor predicho de la línea diagonal, más preciso será el valor, mejor sea el modelo.

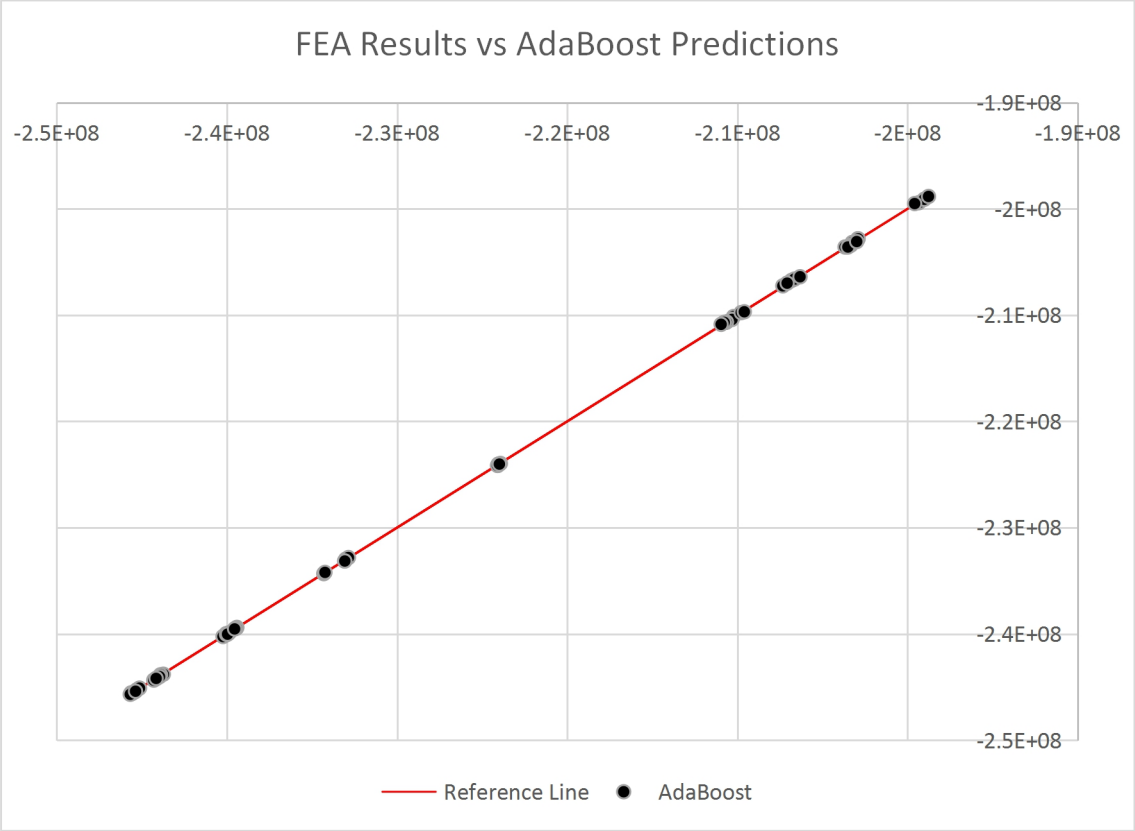
❖ Gráficos de la presión normal de la brida (diámetro exterior)

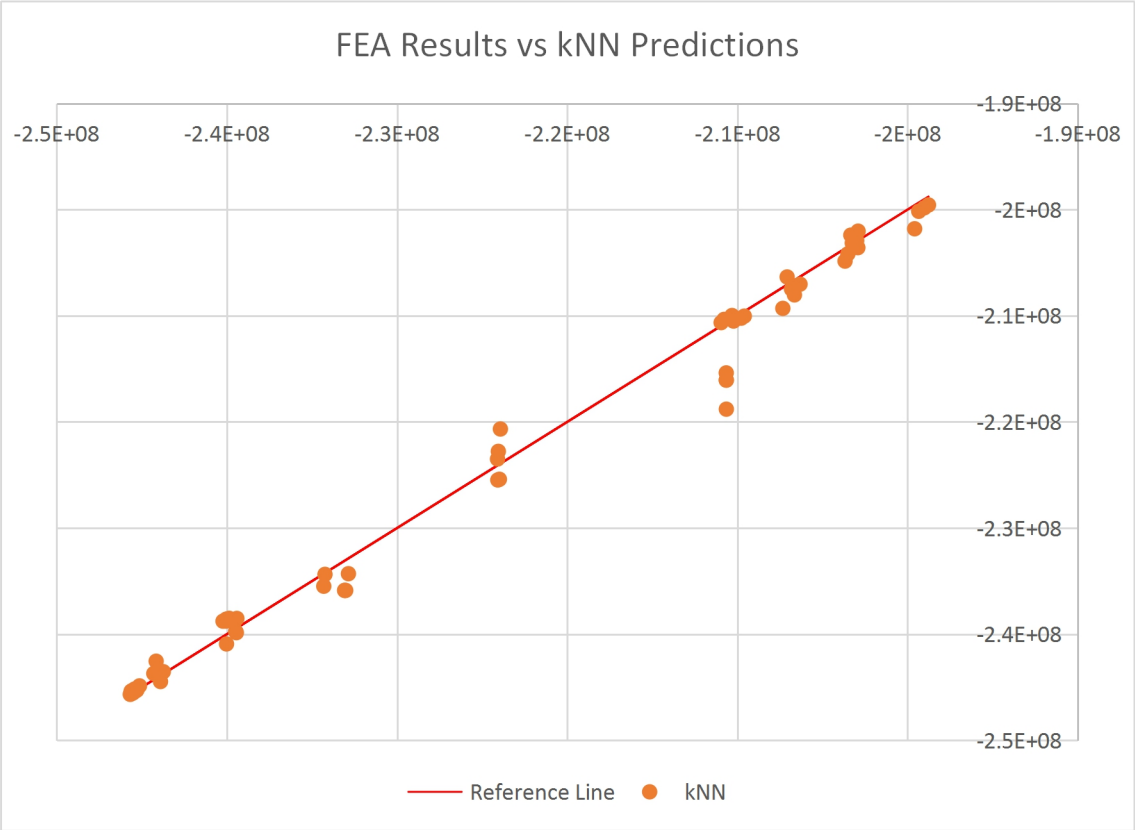




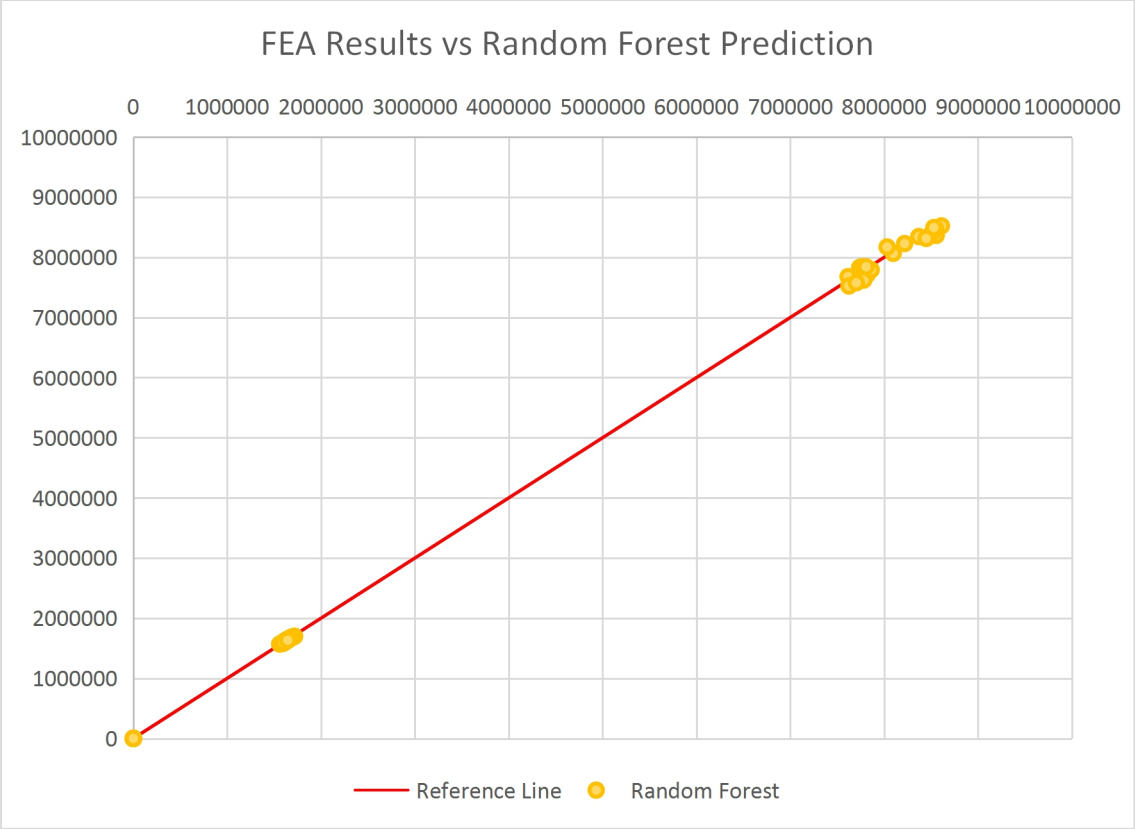

FEA Results vs Linear Regression Predictions
-2.6E+08
-2.5E+08
-2.4E+08
-2.3E+08
-2.2E+08
-2.1E+08
-2E+08
-1.9E+08
-1.9E+08
-2E+08
-2.1E+08
-2.2E+08
-2.3E+08
-2.4E+08
-2.5E+08
-2.6E+08
Reference Line
Linear Regression

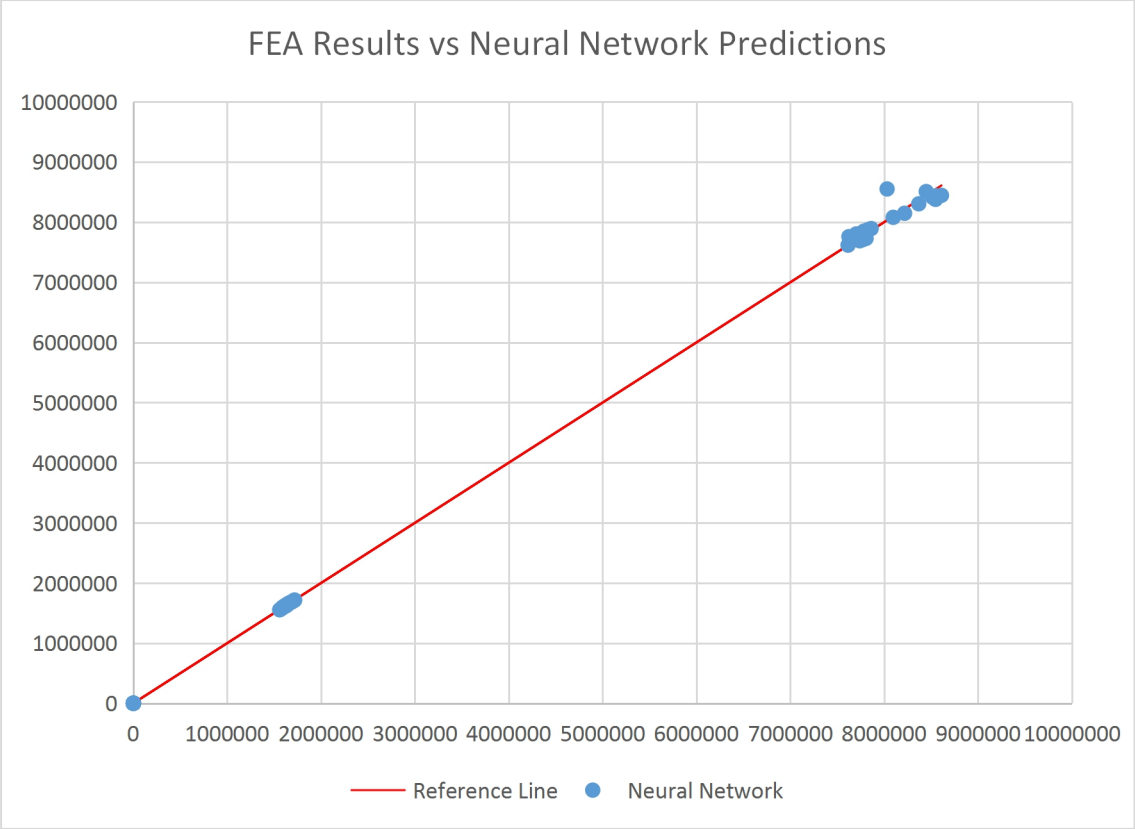

FEA Results vs Gradient Boosting Predictions
-2.5E+08
-2.4E+08
-2.3E+08
-2.2E+08
-2.1E+08
-2E+08
-1.9E+08
-1.9E+08
-2E+08
-2.1E+08
-2.2E+08
-2.3E+08
-2.4E+08
-2.5E+08
Reference Line
Gradient Boosting

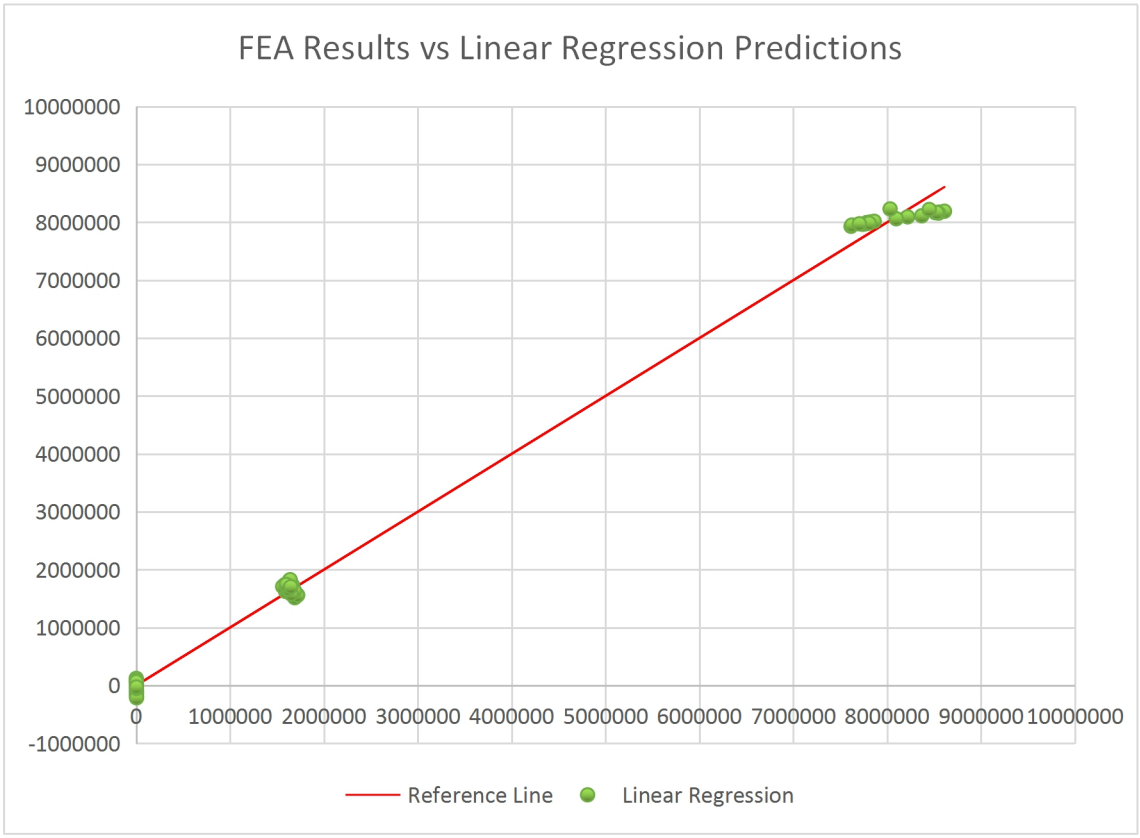

FEA Results vs AdaBoost Predictions
-2.5E+08
-2.4E+08
-2.3E+08
-2.2E+08
-2.1E+08
-2E+08
-1.9E+08
-1.9E+08
-2E+08
-2.1E+08
-2.2E+08
-2.3E+08
-2.4E+08
-2.5E+08
Reference Line
AdaBoost

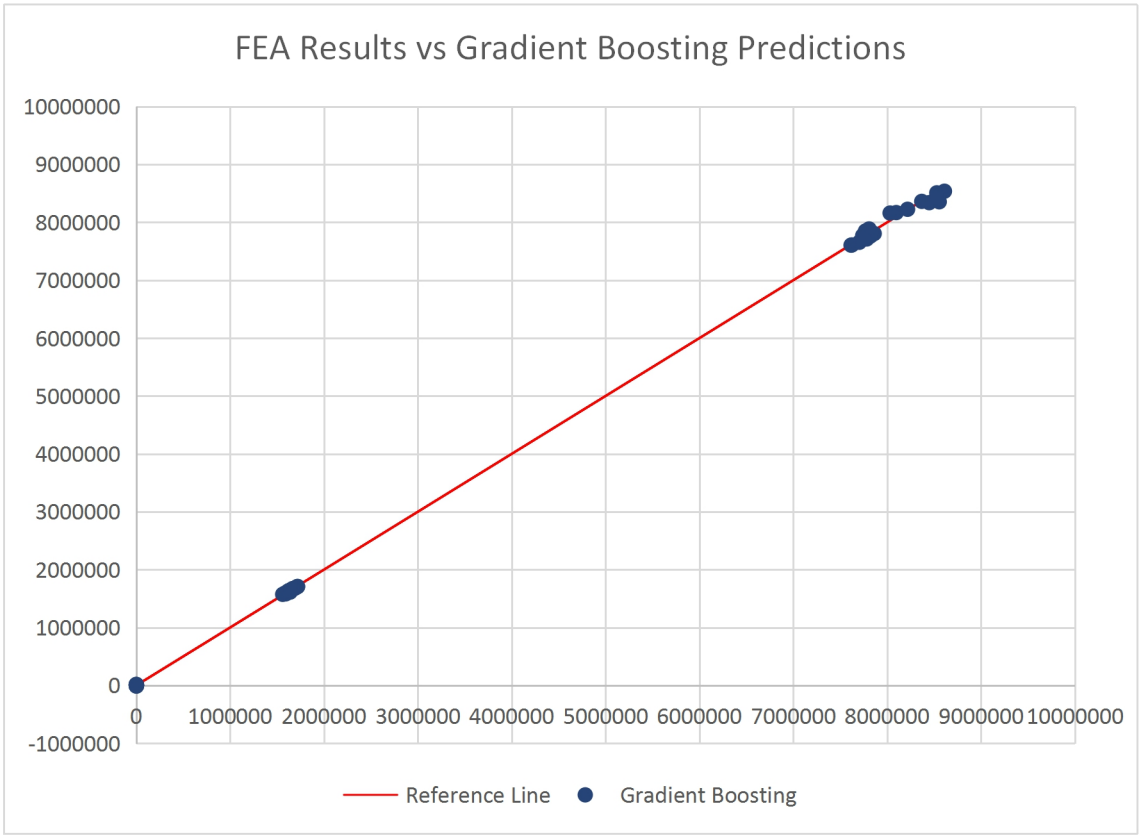

FEA Results vs kNN Predictions
-2.5E+08
-2.4E+08
-2.3E+08
-2.2E+08
-2.1E+08
-2E+08
-1.9E+08
-1.9E+08
-2E+08
-2.1E+08
-2.2E+08
-2.3E+08
-2.4E+08
-2.5E+08
Reference Line
kNN

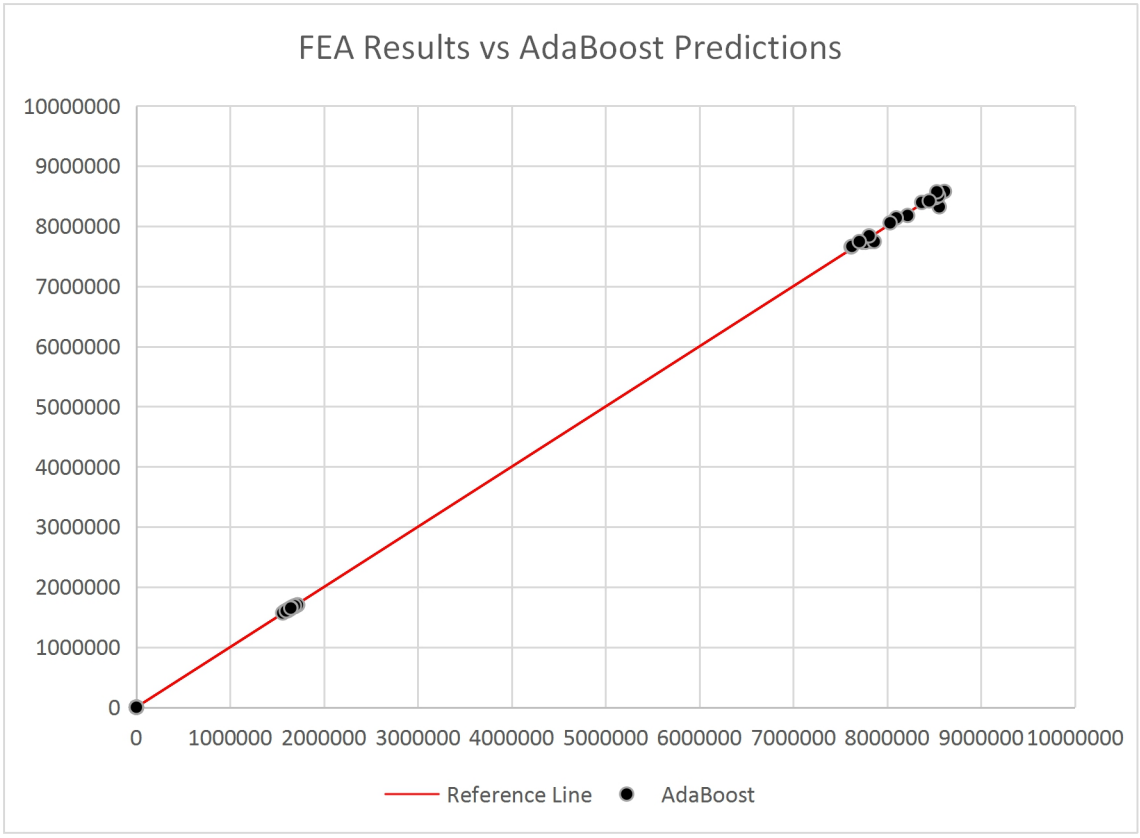
❖ Gráficos de la presión normal de la brida (centro)

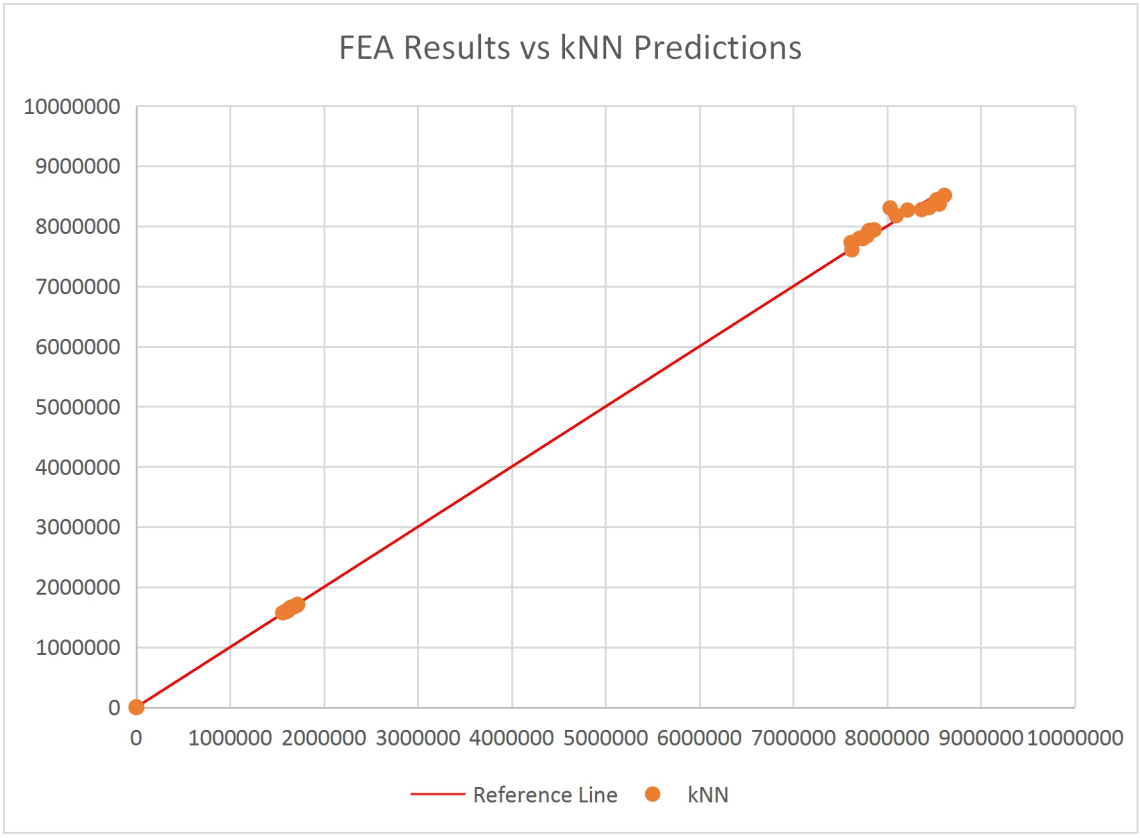




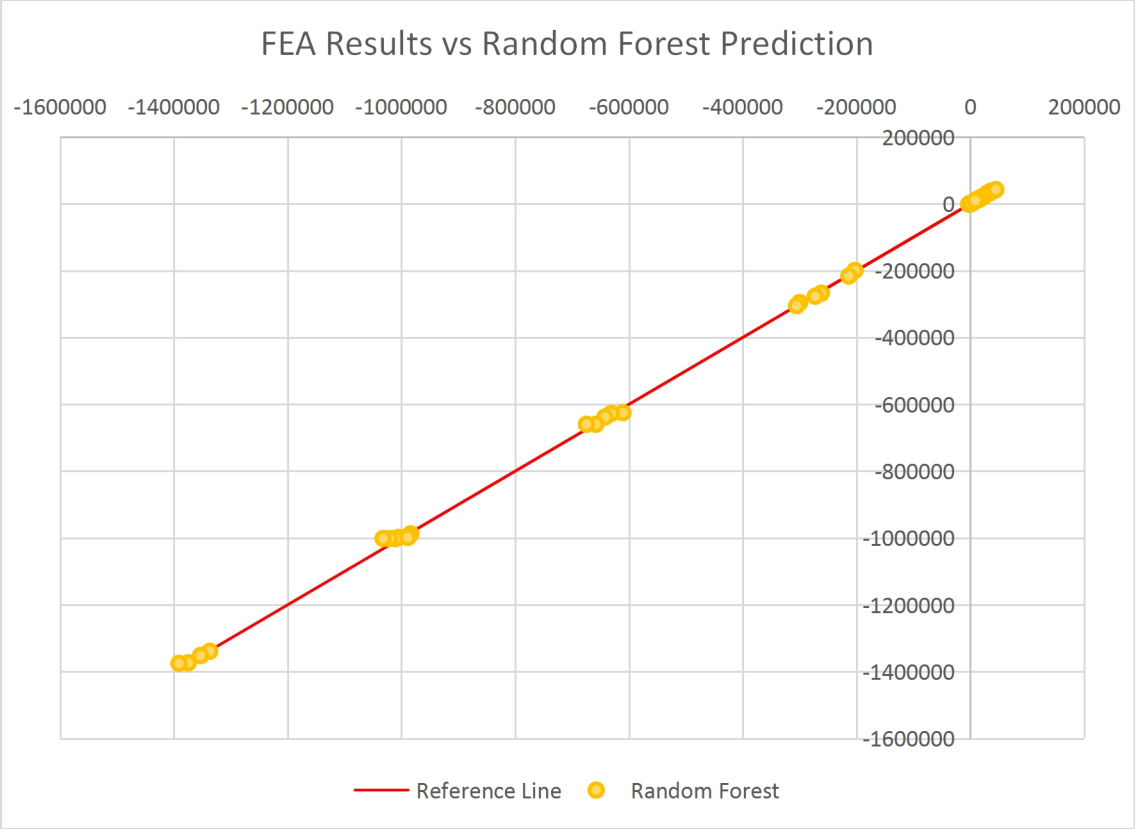

FEA Results vs Linear Regression Predictions
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
-1000000
0
1000000 2000000 3000000 4000000 5000000 6000000 7000000 8000000 9000000 10000000
Reference Line
Linear Regression

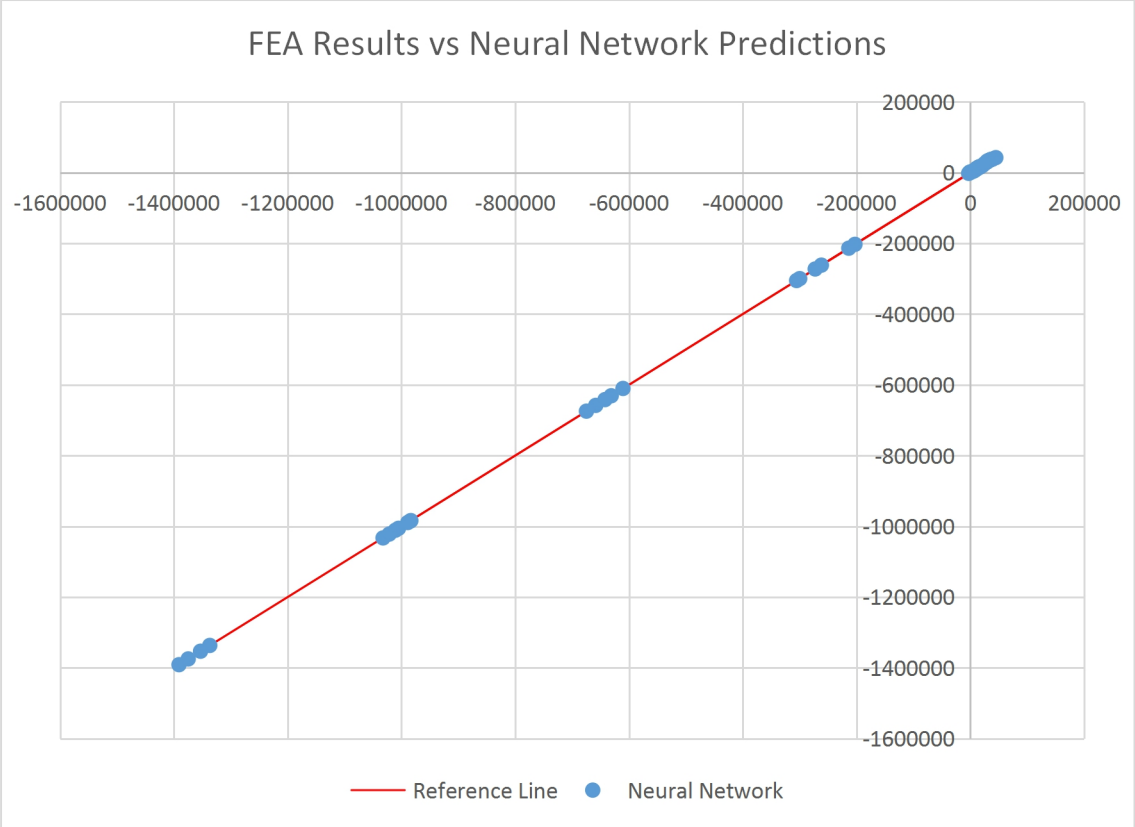

FEA Results vs Gradient Boosting Predictions
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
-1000000
0
1000000 2000000 3000000 4000000 5000000 6000000 7000000 8000000 9000000 10000000
Reference Line
Gradient Boosting

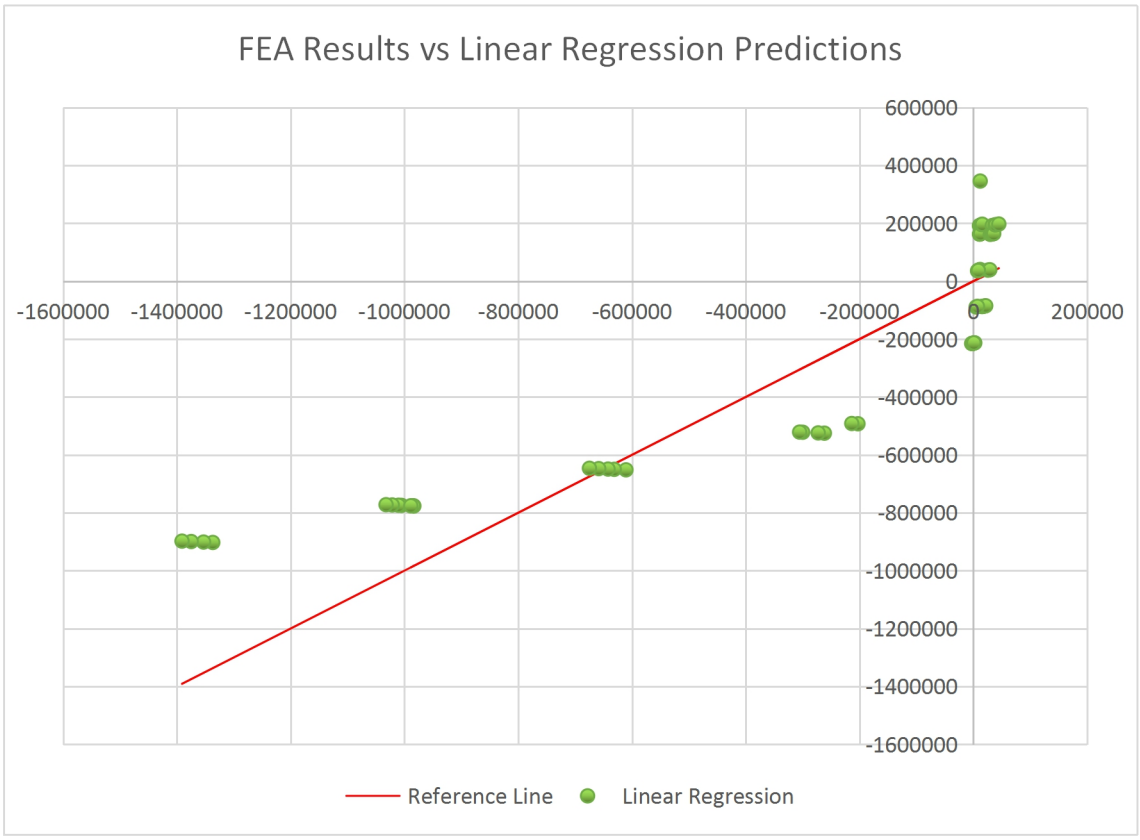

FEA Results vs AdaBoost Predictions
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
8000000
9000000
10000000
Reference Line
AdaBoost

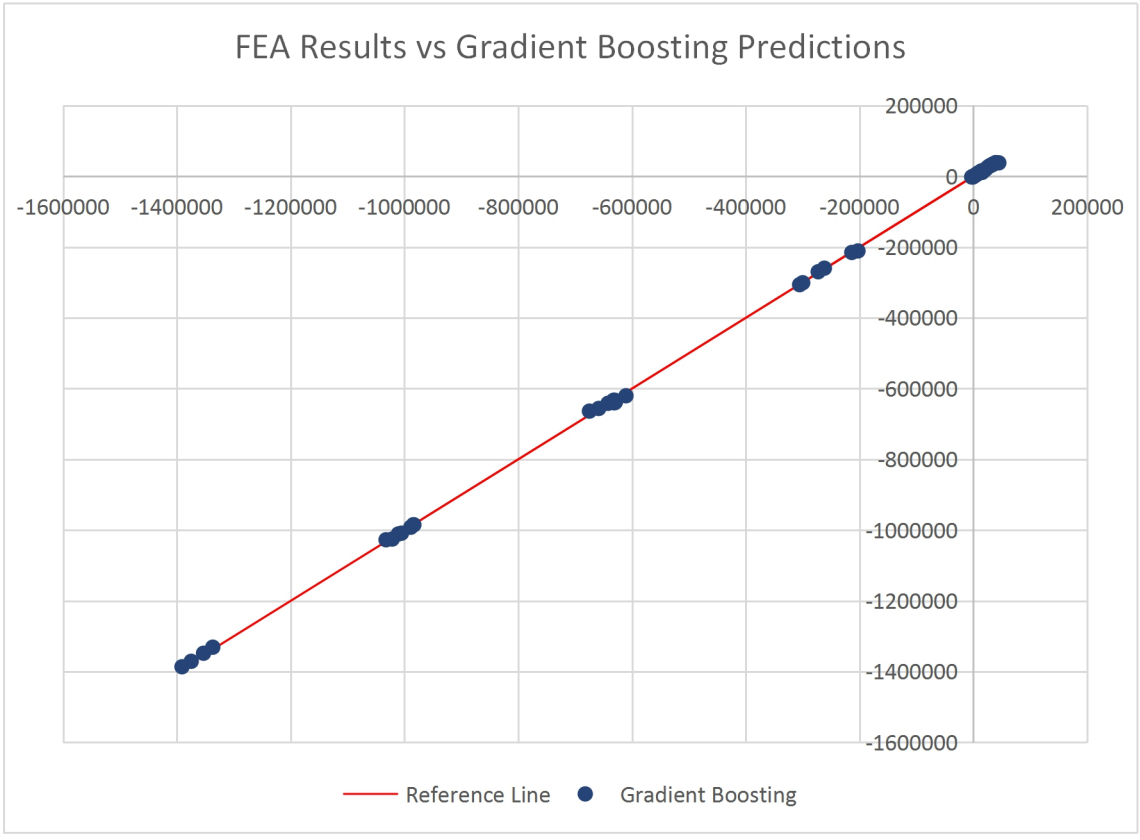

FEA Results vs kNN Predictions
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
8000000
9000000
10000000
Reference Line
kNN

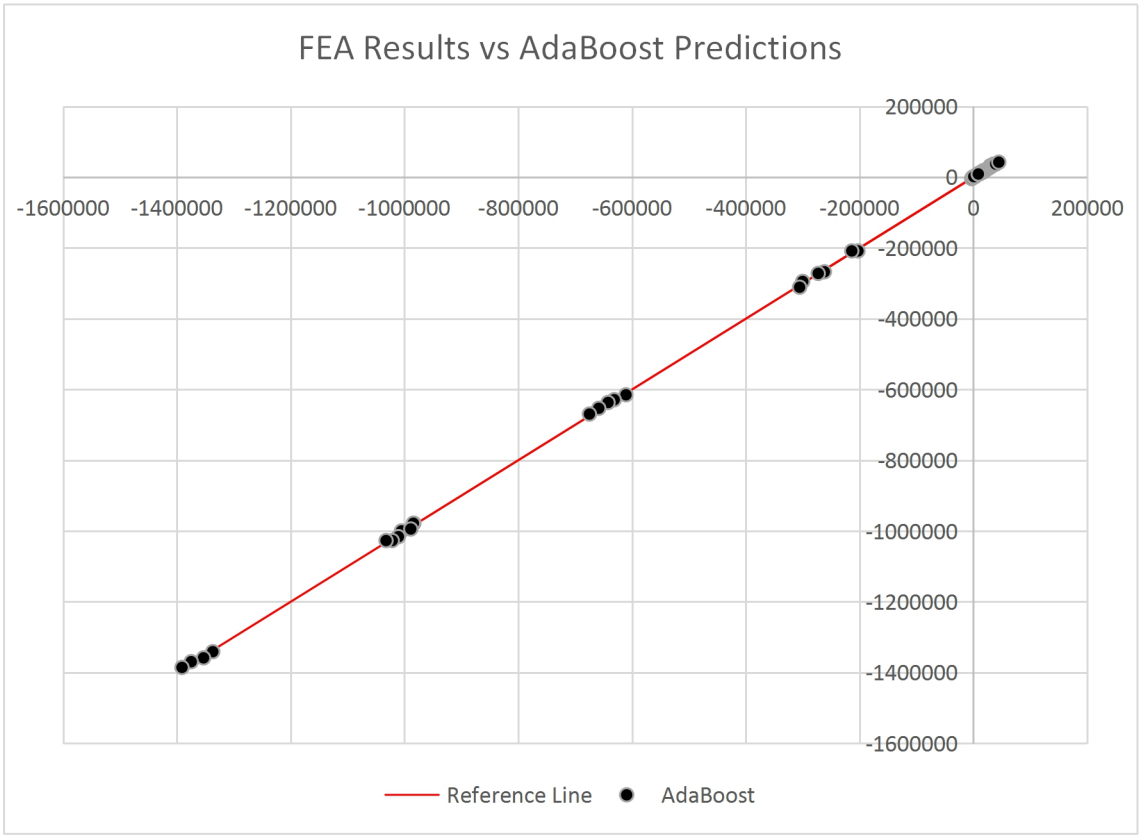
❖ Gráficos de la presión normal de la brida (interno)

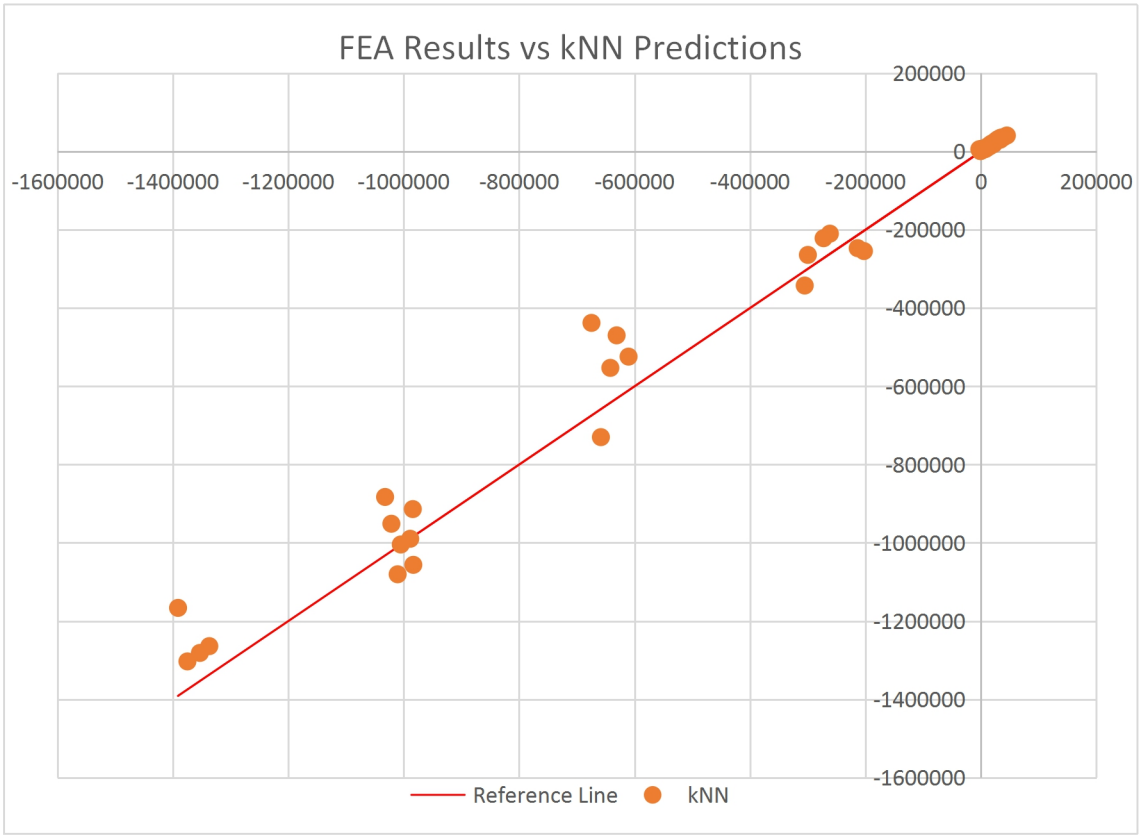




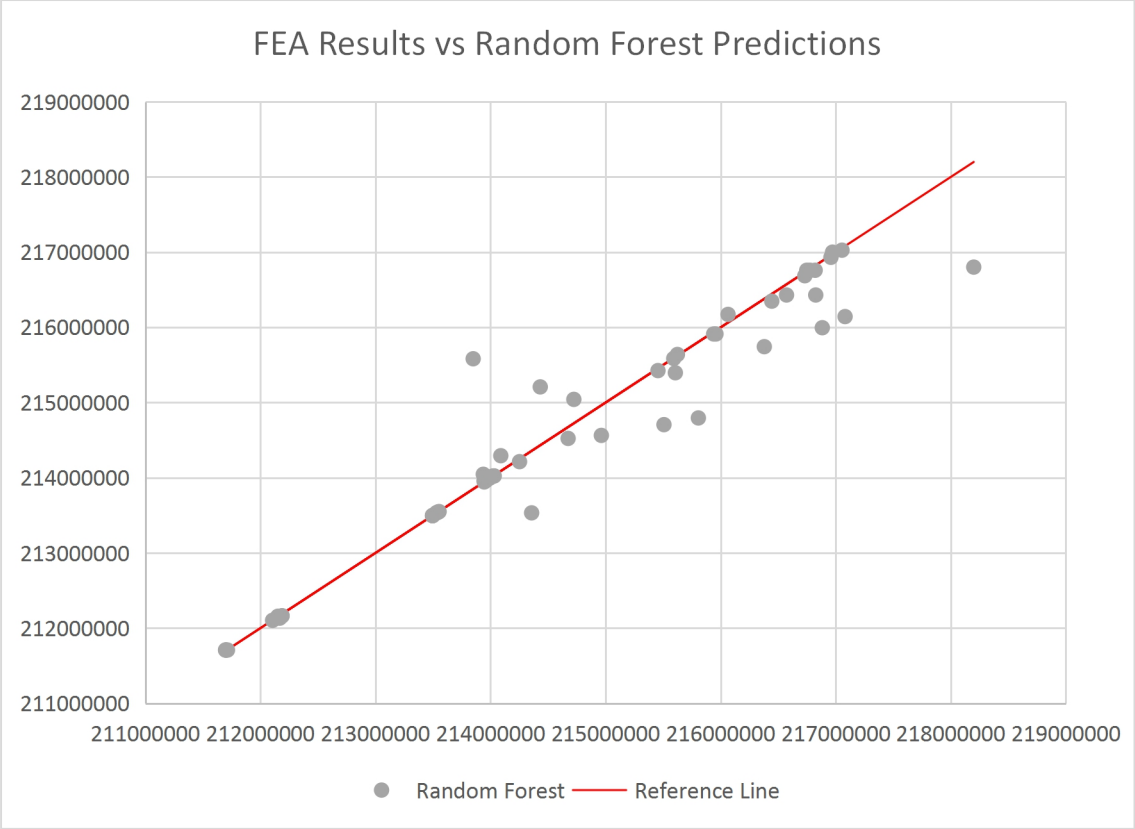

FEA Results vs Linear Regression Predictions
600000
400000
200000
0
-200000
-400000
-600000
-800000
-1000000
-1200000
-1400000
-1600000
-1600000
-1400000
-1200000
-1000000
-800000
-600000
-400000
-200000
0
200000
Reference Line
Linear Regression

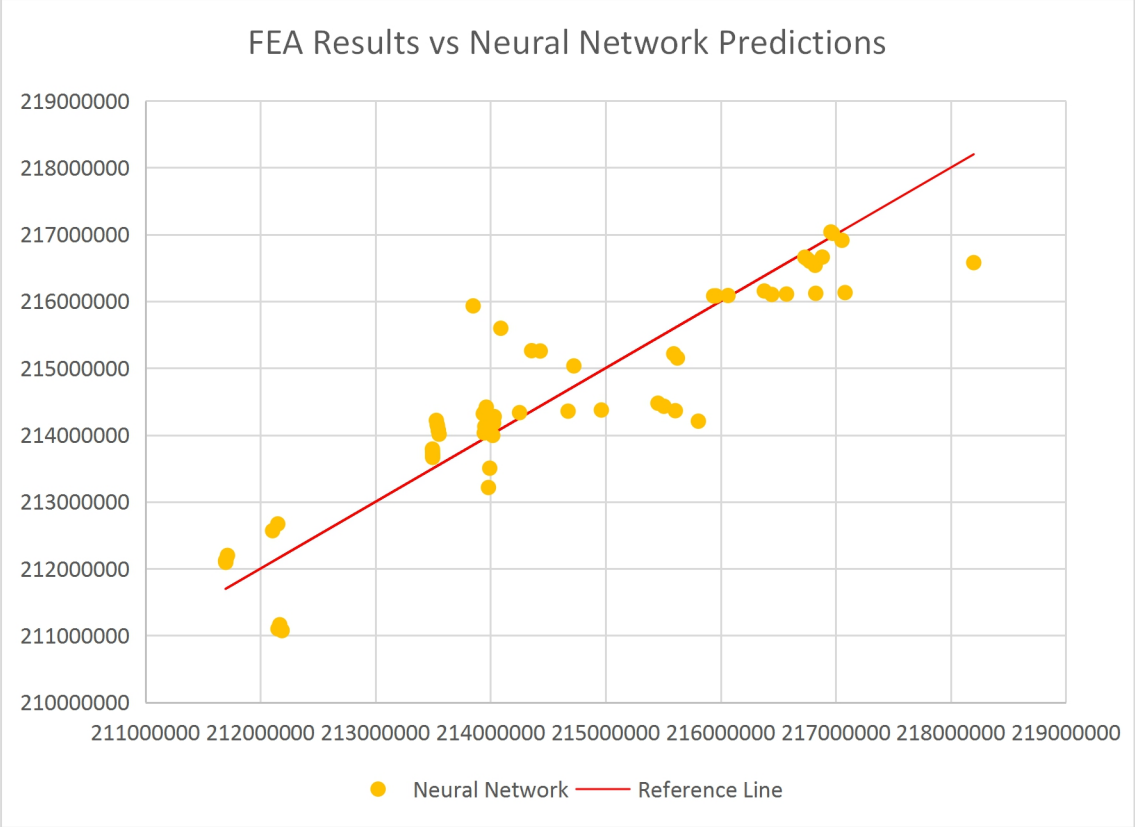

FEA Results vs Gradient Boosting Predictions
200000
0
-200000
-400000
-600000
-800000
-1000000
-1200000
-1400000
-1600000
-1600000
-1400000
-1200000
-1000000
-800000
-600000
-400000
-200000
0
200000
Reference Line
Gradient Boosting

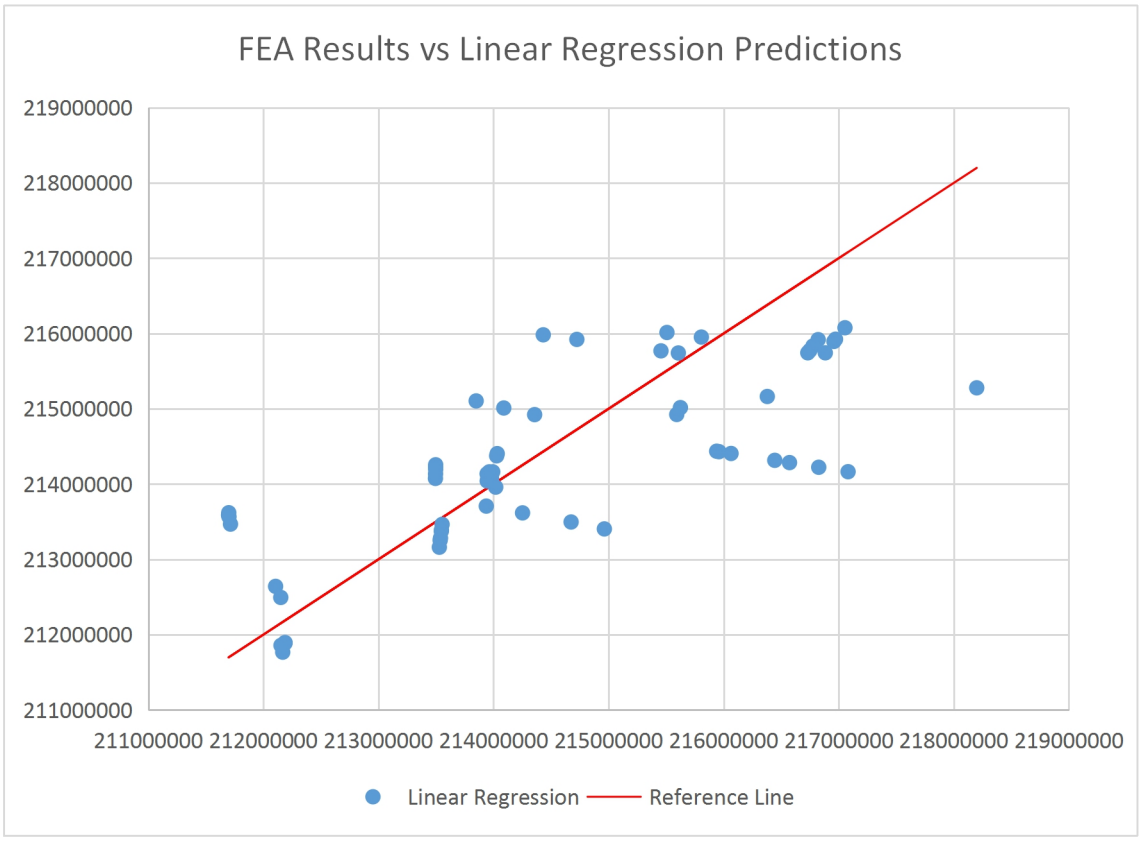

FEA Results vs AdaBoost Predictions
200000
0
-200000
-400000
-600000
-800000
-1000000
-1200000
-1400000
-1600000
-1600000
-1400000
-1200000
-1000000
-800000
-600000
-400000
-200000
0
200000
Reference Line
AdaBoost

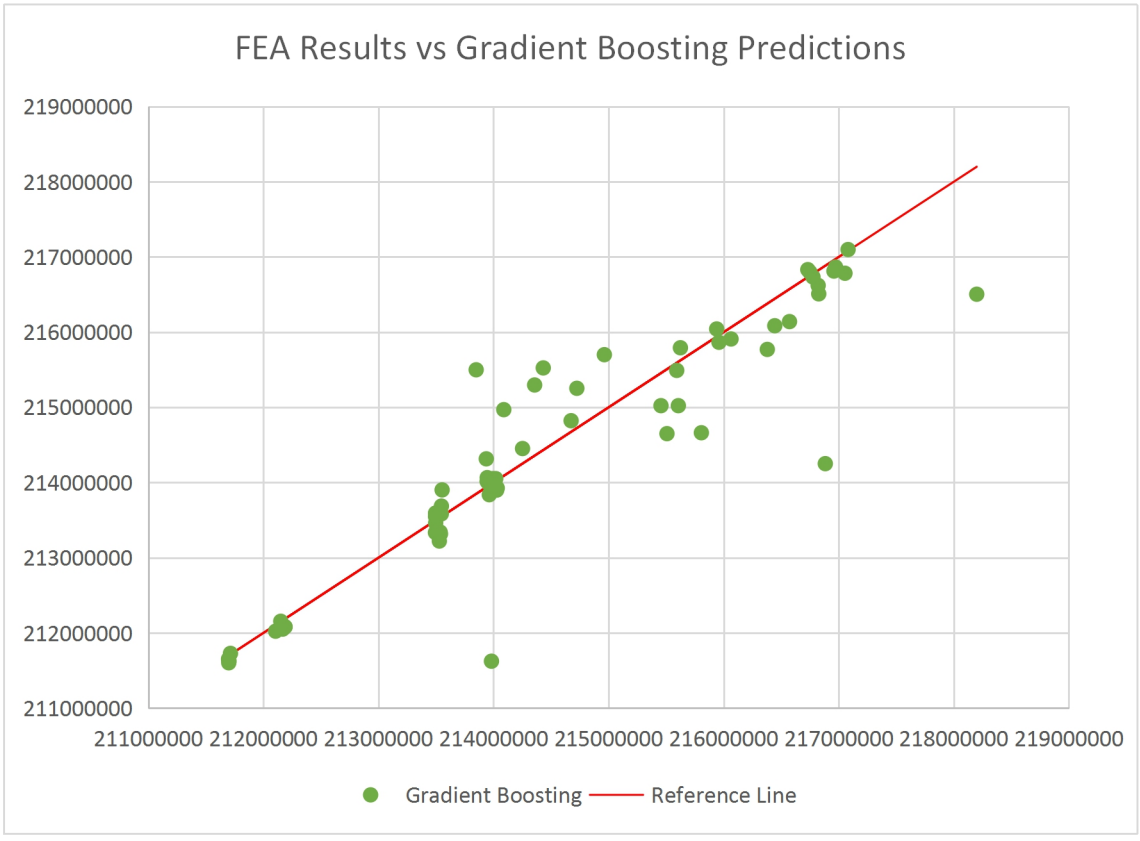

FEA Results vs kNN Predictions
200000
0
-200000
-400000
-600000
-800000
-1000000
-1200000
-1400000
-1600000
-1600000
-1400000
-1200000
-1000000
-800000
-600000
-400000
-200000
0
200000
Reference Line
kNN

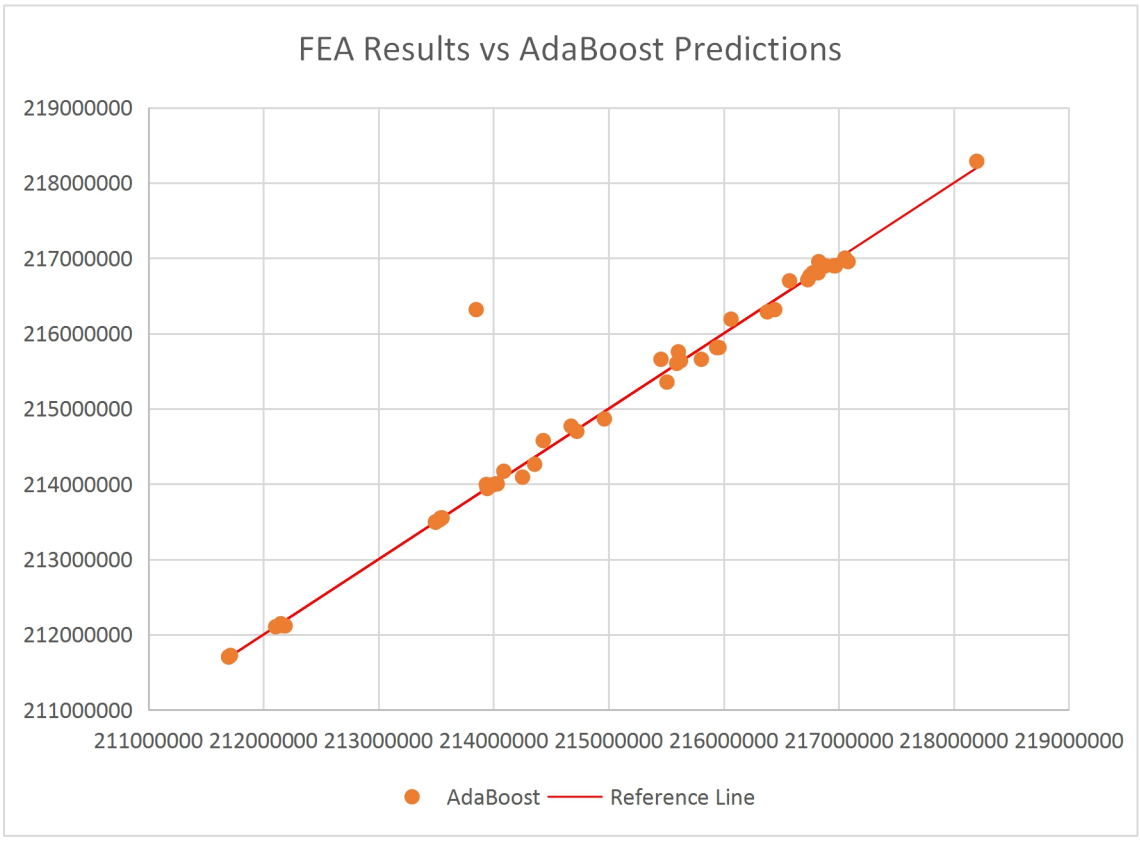
❖ Gráficos de las tensiones equivalentes Von Mises (la junta)

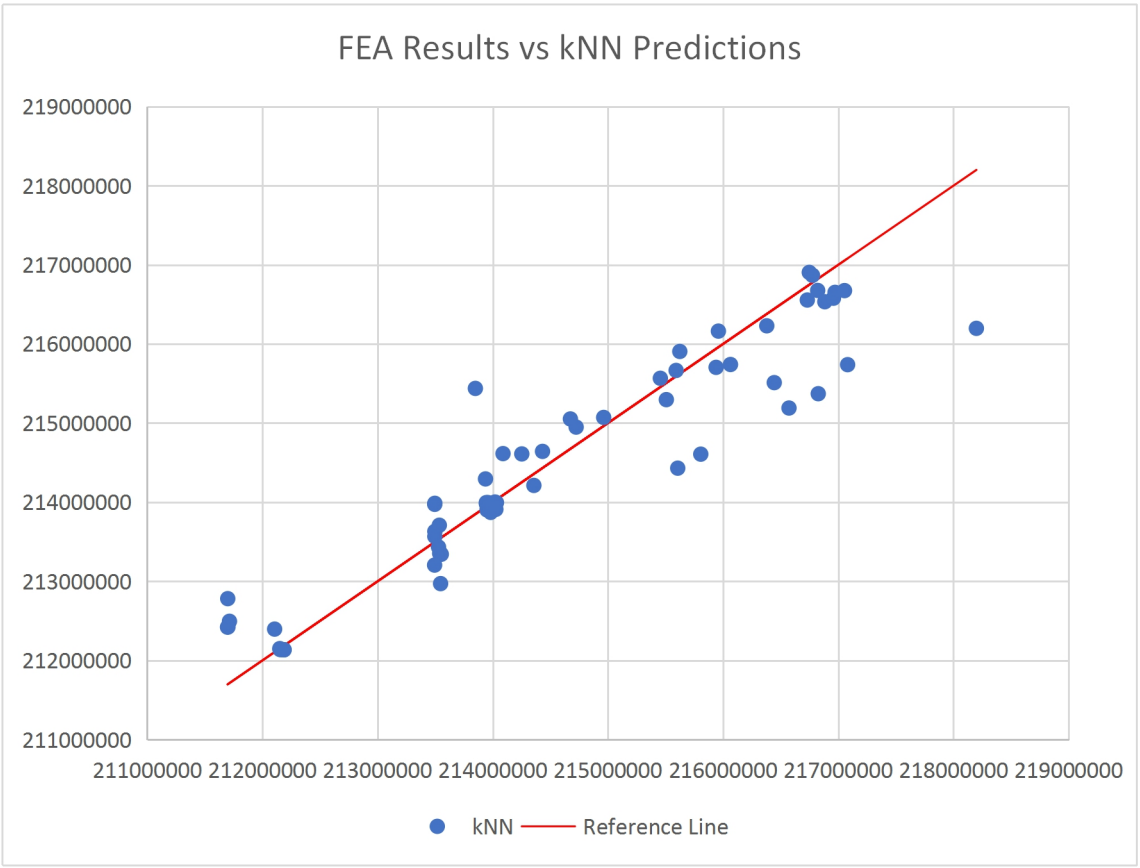




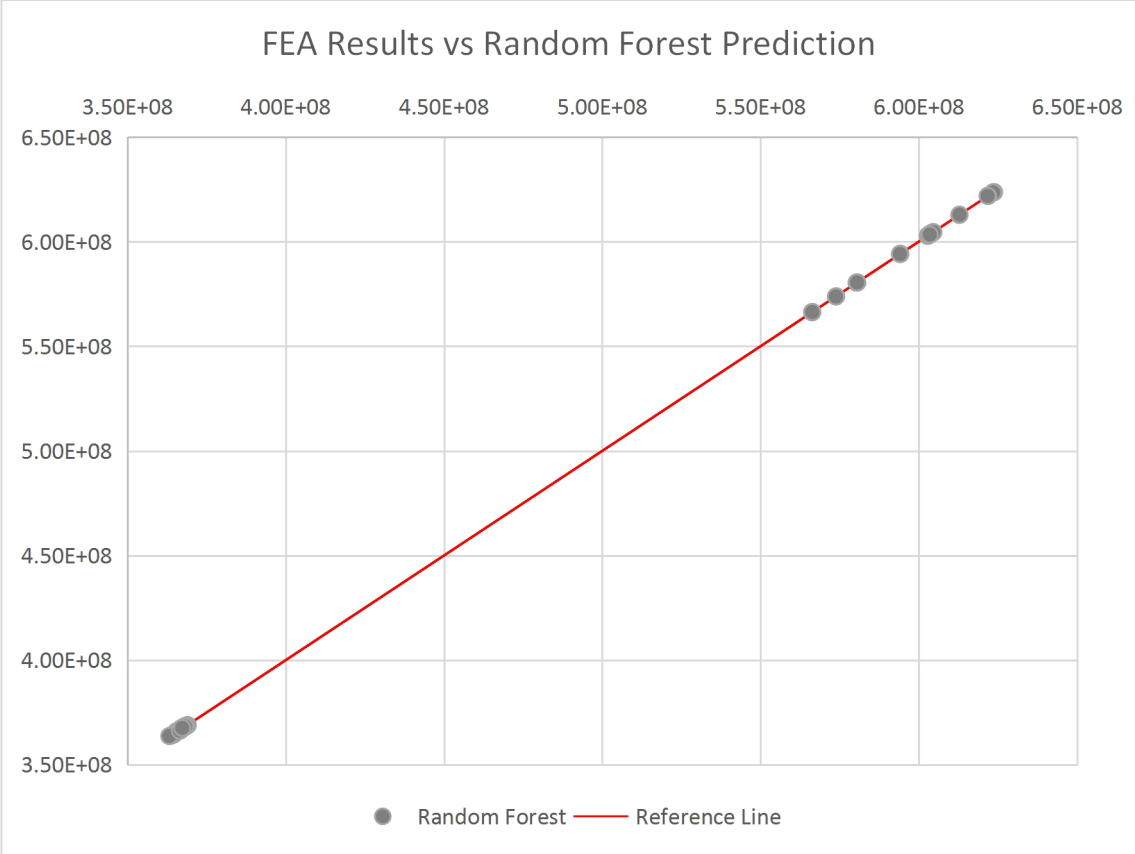

FEA Results vs Linear Regression Predictions
219000000
218000000
217000000
216000000
215000000
214000000
213000000
212000000
211000000
211000000 212000000 213000000 214000000 215000000 216000000 217000000 218000000 219000000
Linear Regression
Reference Line

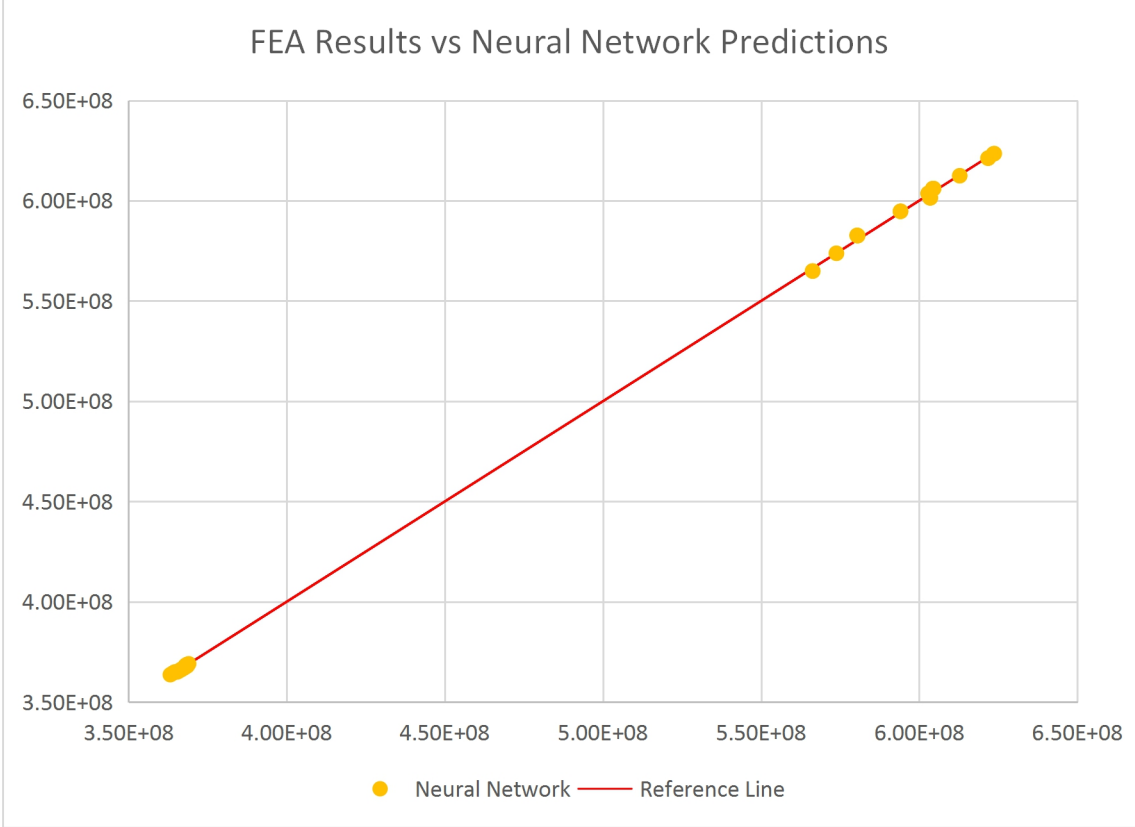

FEA Results vs Gradient Boosting Predictions
219000000
218000000
217000000
216000000
215000000
214000000
213000000
212000000
211000000
211000000 212000000 213000000 214000000 215000000 216000000 217000000 218000000 219000000
Gradient Boosting
Reference Line

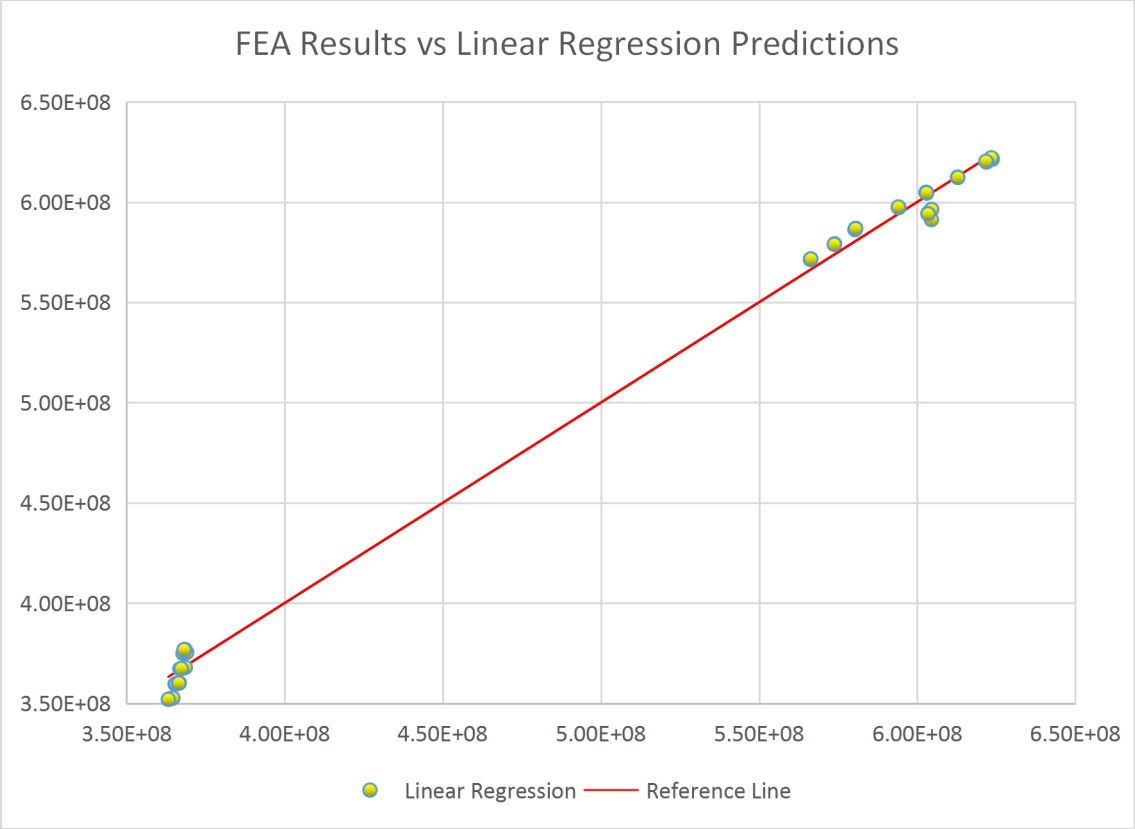

FEA Results vs AdaBoost Predictions
219000000
218000000
217000000
216000000
215000000
214000000
213000000
212000000
211000000
211000000 212000000 213000000 214000000 215000000 216000000 217000000 218000000 219000000
AdaBoost
Reference Line

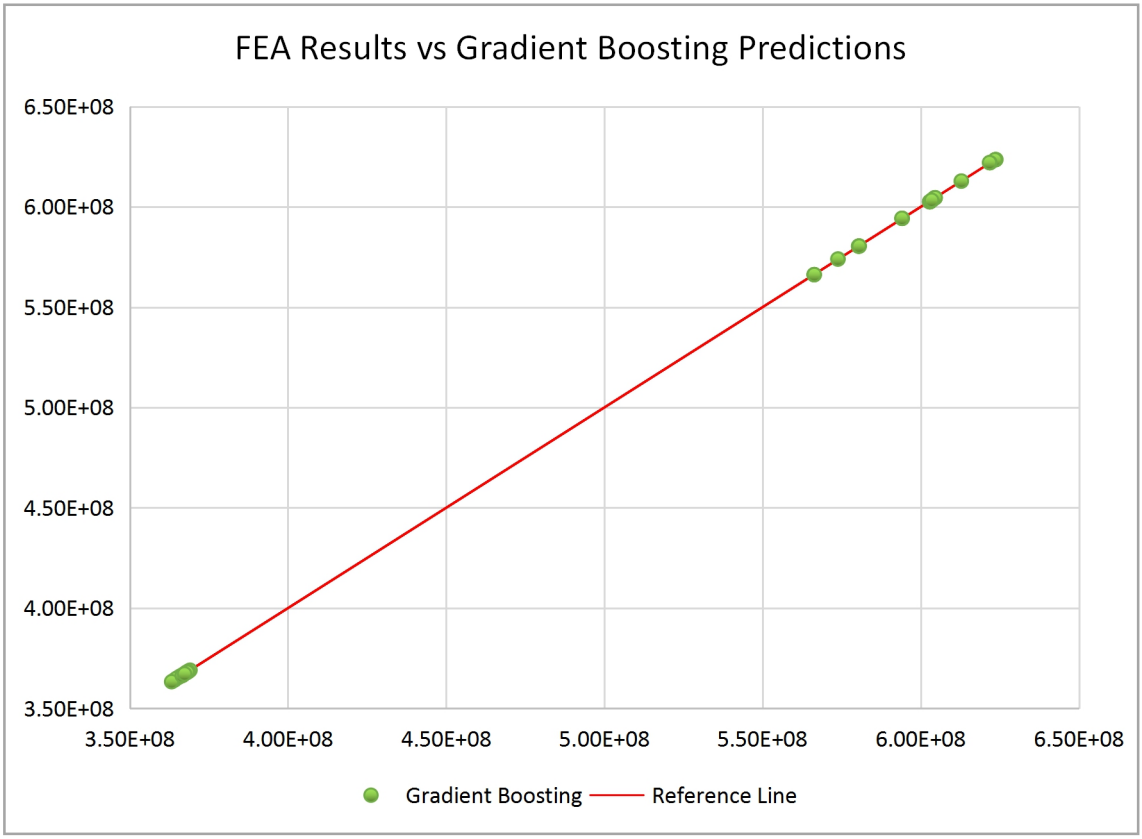

FEA Results vs kNN Predictions
219000000
218000000
217000000
216000000
215000000
214000000
213000000
212000000
211000000
211000000 212000000 213000000 214000000 215000000 216000000 217000000 218000000 219000000
kNN
Reference Line

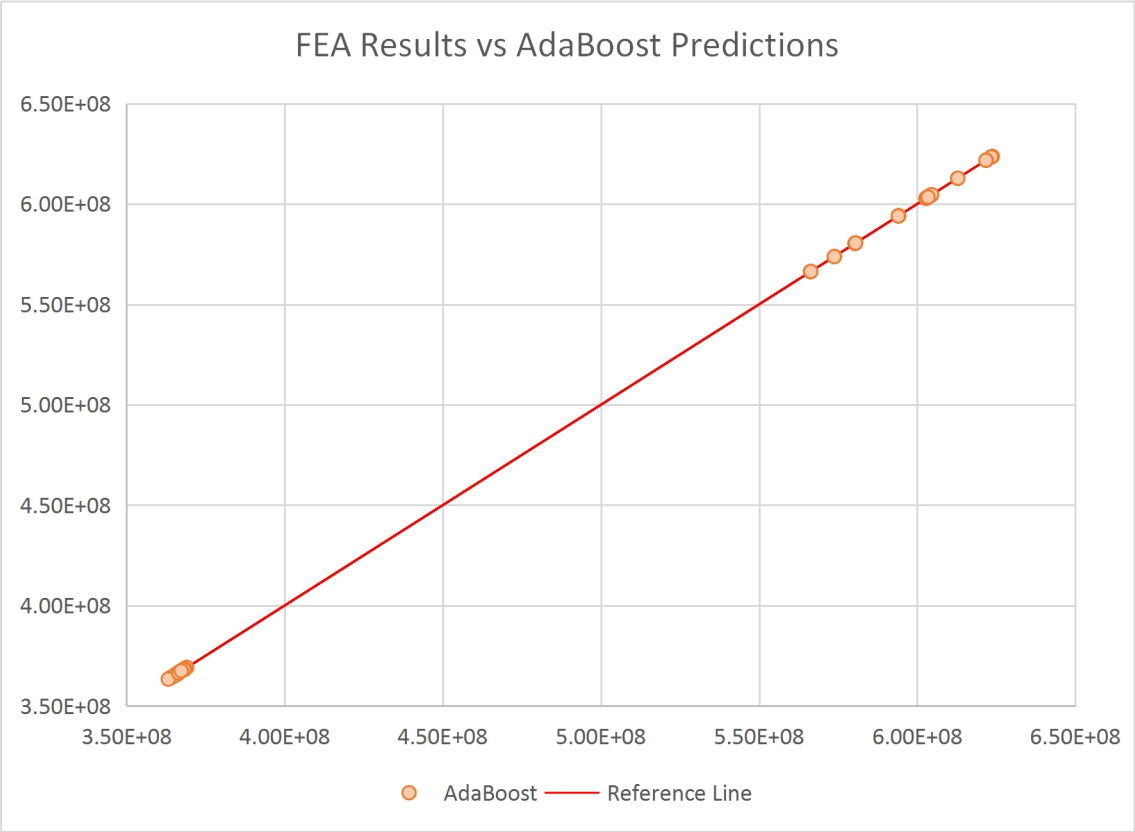
❖ Gráficos de las tensiones equivalentes Von Mises (el tornillo)

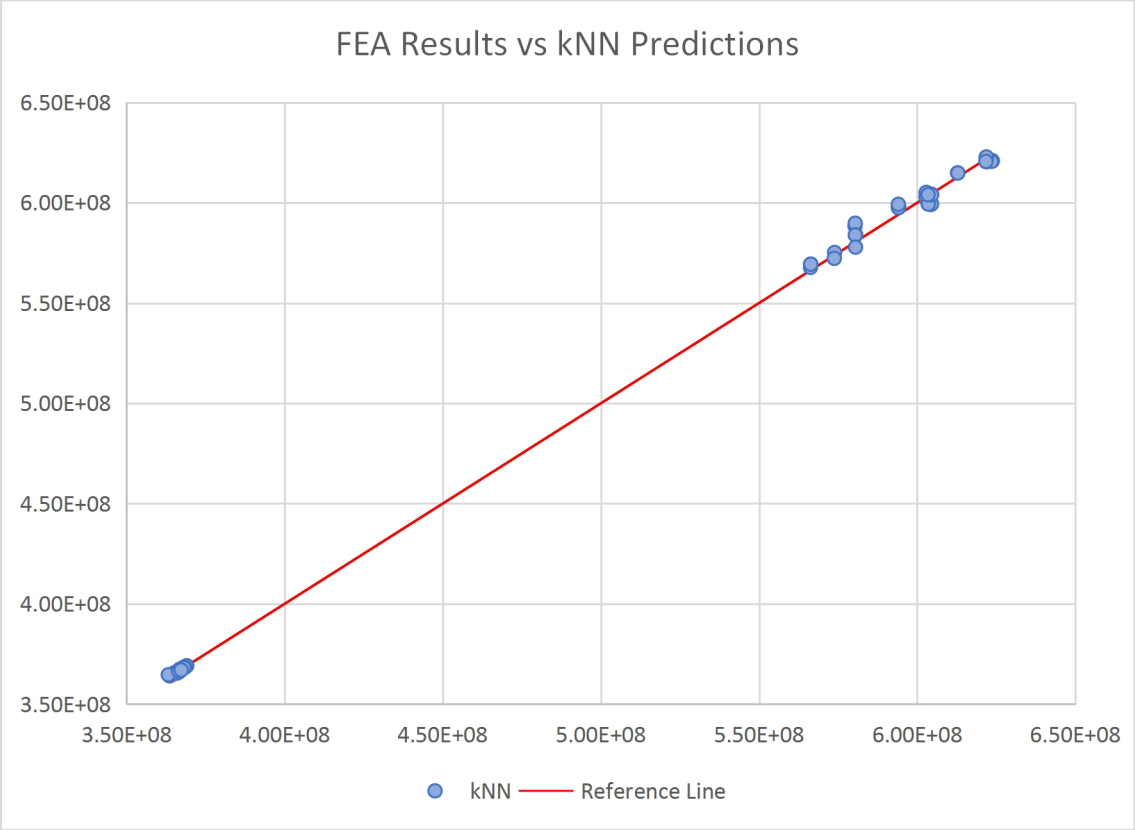




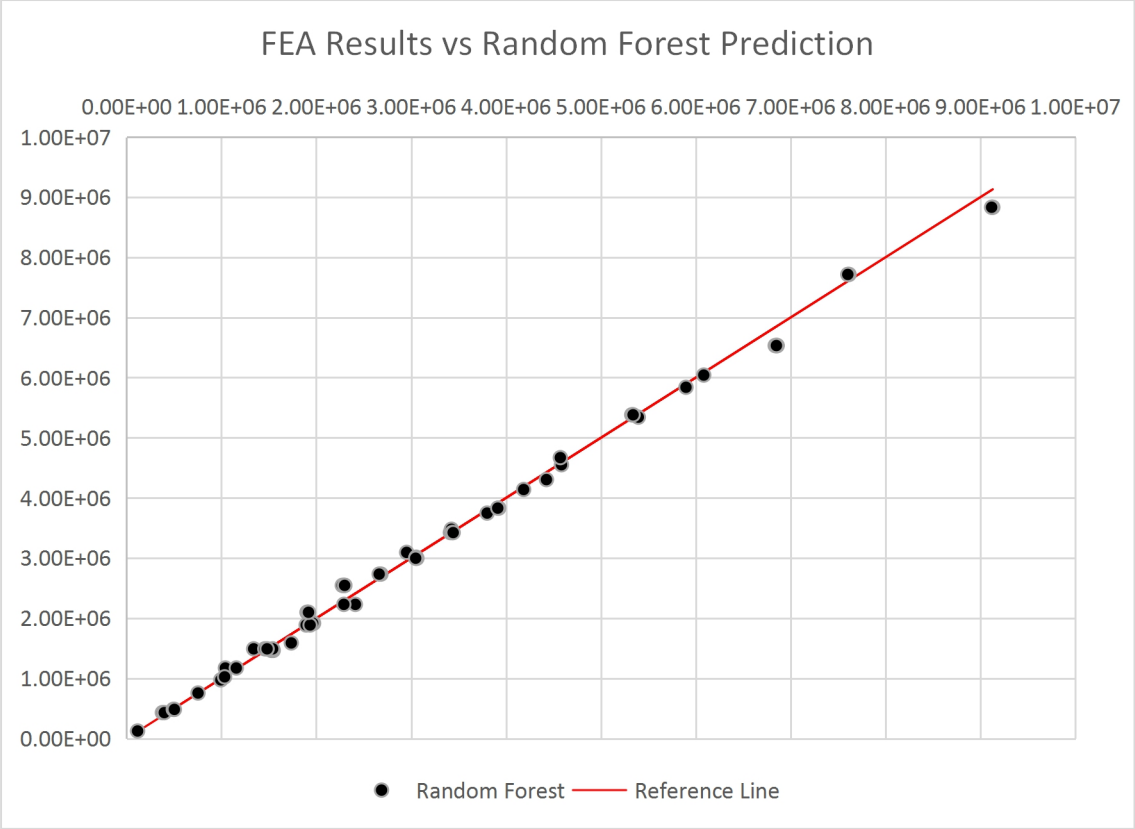

FEA Results vs Linear Regression Predictions
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.50E+08
4.00E+08
4.50E+08
5.00E+08
5.50E+08
6.00E+08
6.50E+08
Linear Regression
Reference Line

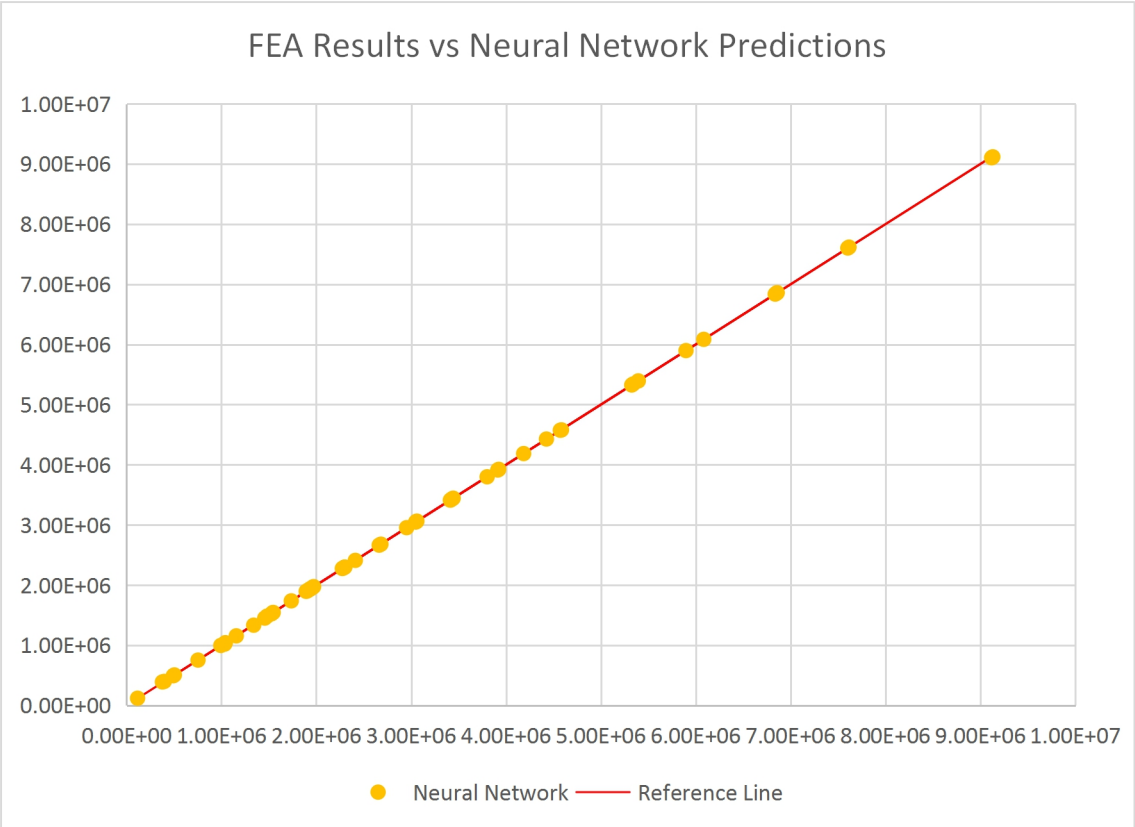

FEA Results vs Gradient Boosting Predictions
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.50E+08
4.00E+08
4.50E+08
5.00E+08
5.50E+08
6.00E+08
6.50E+08
Gradient Boosting
Reference Line

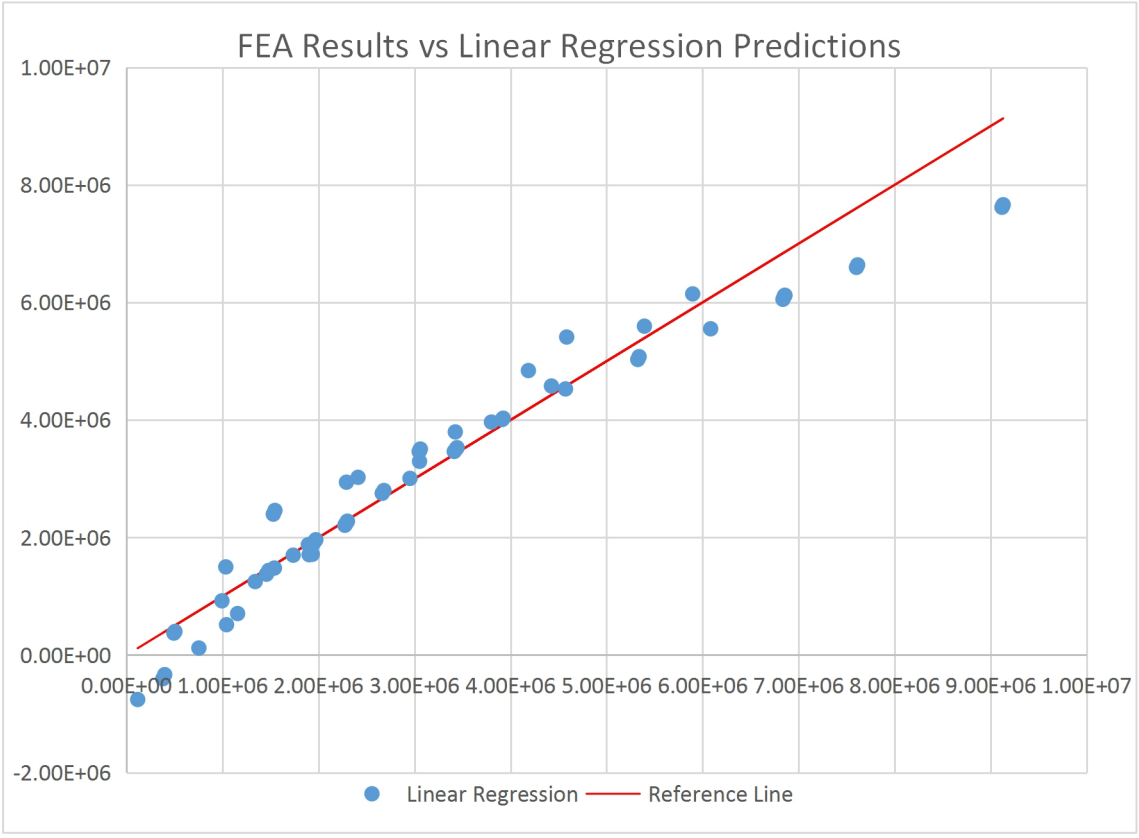

FEA Results vs AdaBoost Predictions
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.50E+08
4.00E+08
4.50E+08
5.00E+08
5.50E+08
6.00E+08
6.50E+08
AdaBoost
Reference Line

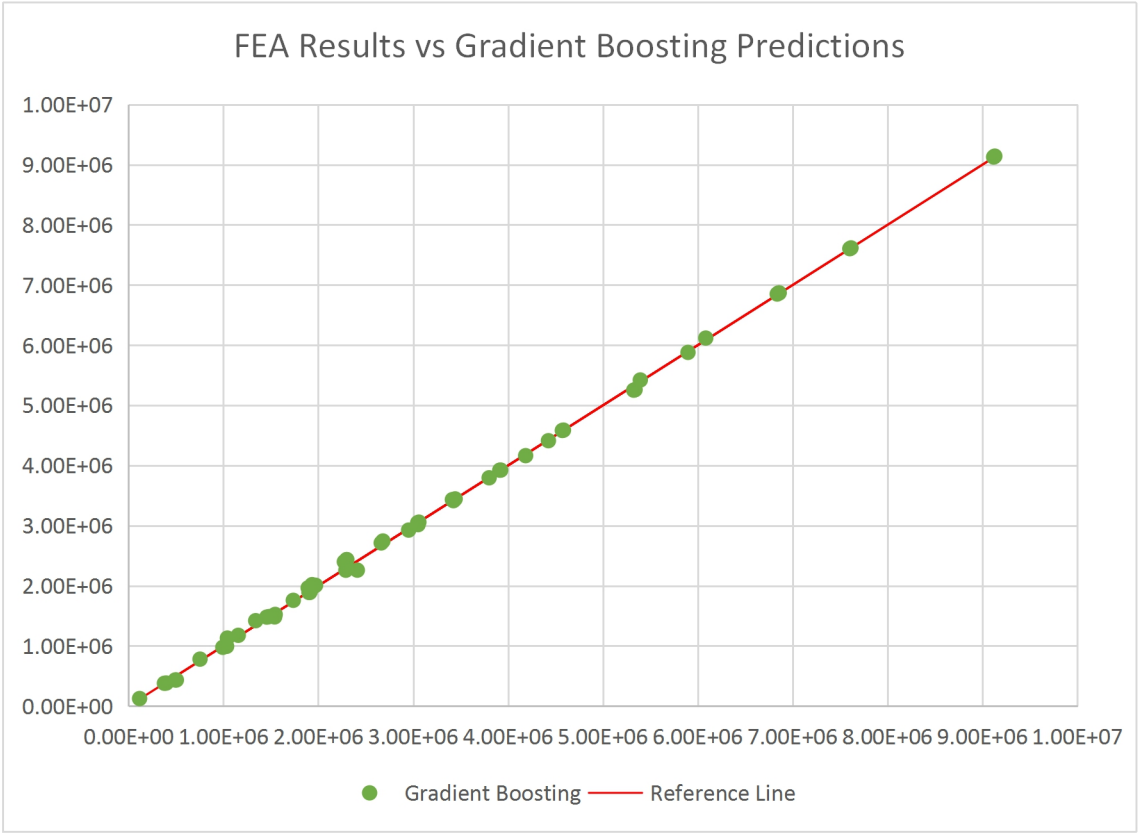

FEA Results vs kNN Predictions
6.50E+08
6.00E+08
5.50E+08
5.00E+08
4.50E+08
4.00E+08
3.50E+08
3.50E+08
4.00E+08
4.50E+08
5.00E+08
5.50E+08
6.00E+08
6.50E+08
kNN
Reference Line

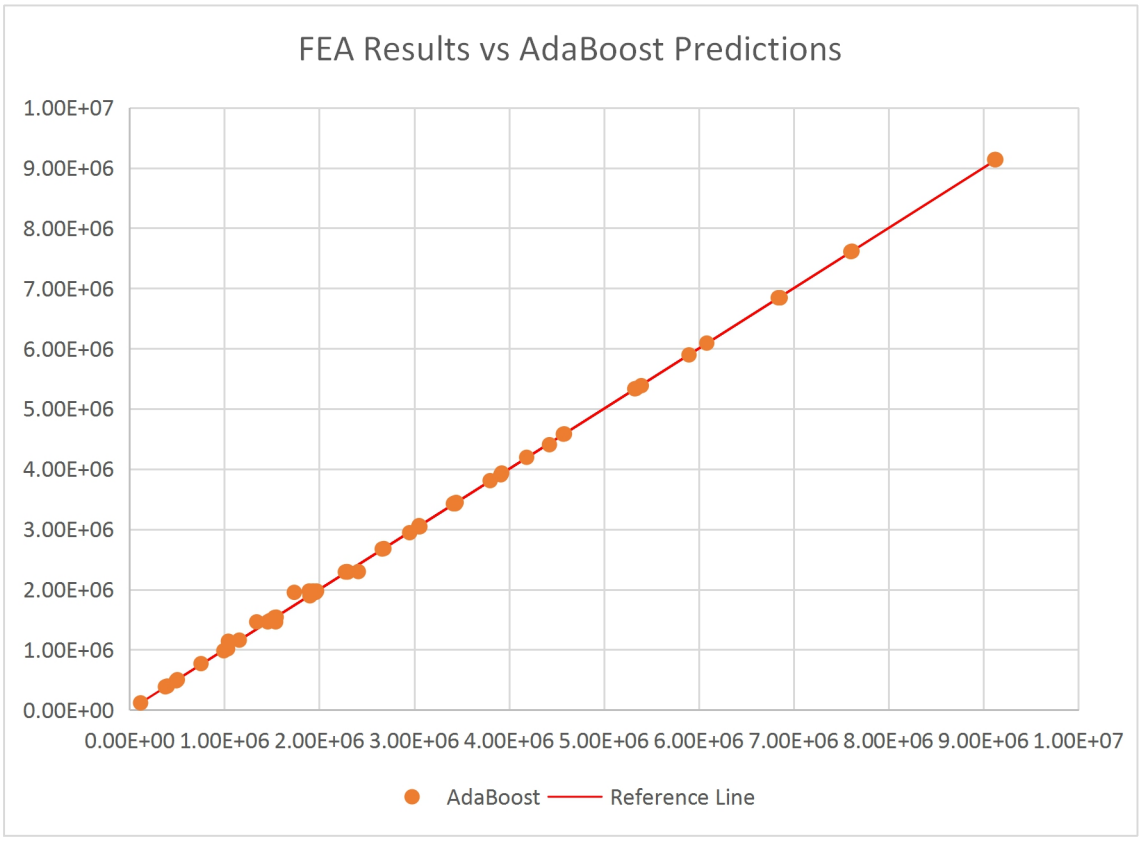
❖ Gráficos de las tensiones equivalentes Von Mises (la tubería)

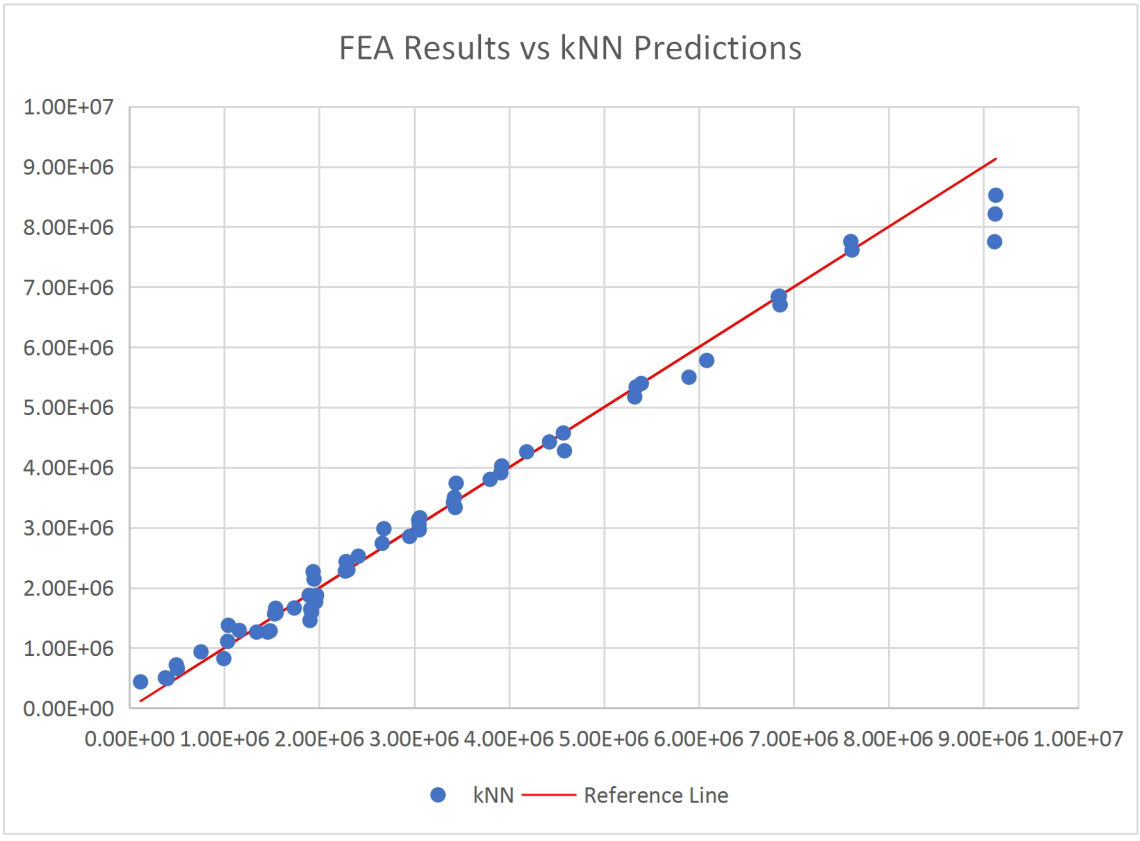




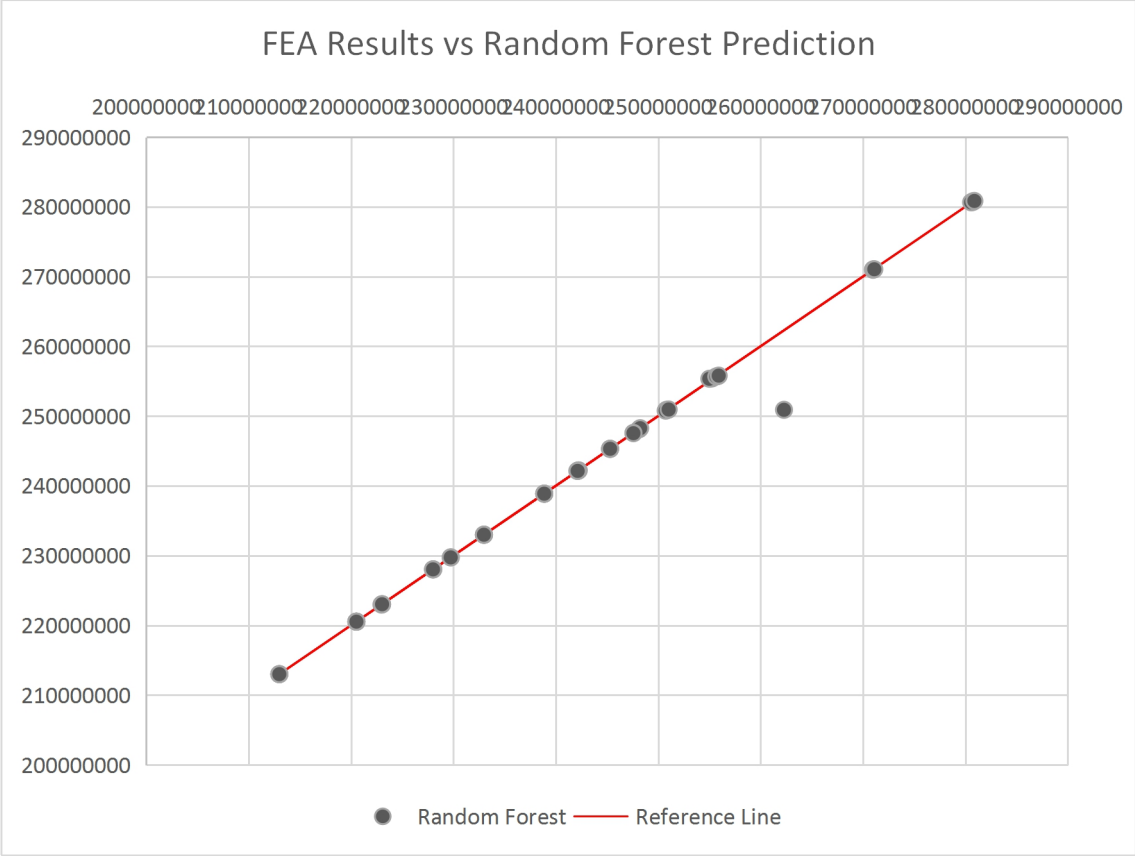

FEA Results vs Linear Regression Predictions
1.00E+07
8.00E+06
6.00E+06
4.00E+06
2.00E+06
0.00E+00
-2.00E+06
0.00E+00 1.00E+06 2.00E+06 3.00E+06 4.00E+06 5.00E+06 6.00E+06 7.00E+06 8.00E+06 9.00E+06 1.00E+07
Linear Regression
Reference Line

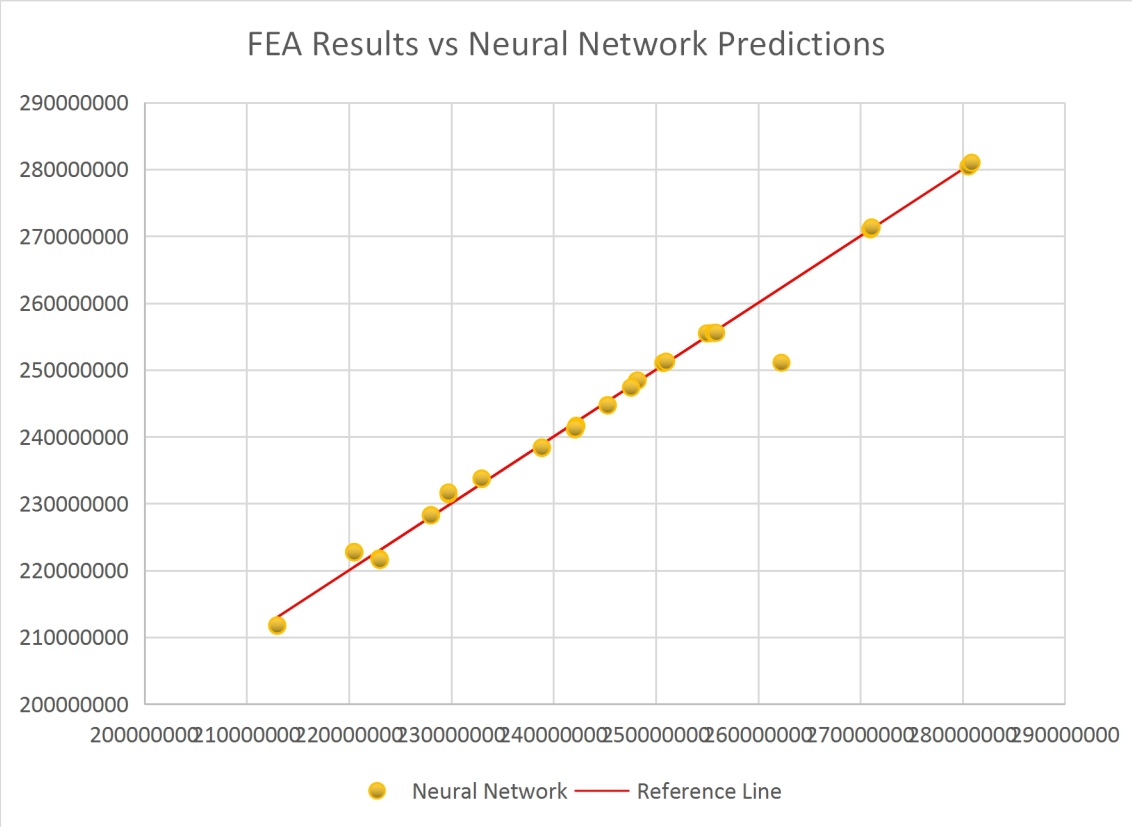

FEA Results vs Gradient Boosting Predictions
1.00E+07
9.00E+06
8.00E+06
7.00E+06
6.00E+06
5.00E+06
4.00E+06
3.00E+06
2.00E+06
1.00E+06
0.00E+00
0.00E+00 1.00E+06 2.00E+06 3.00E+06 4.00E+06 5.00E+06 6.00E+06 7.00E+06 8.00E+06 9.00E+06 1.00E+07
Gradient Boosting
Reference Line

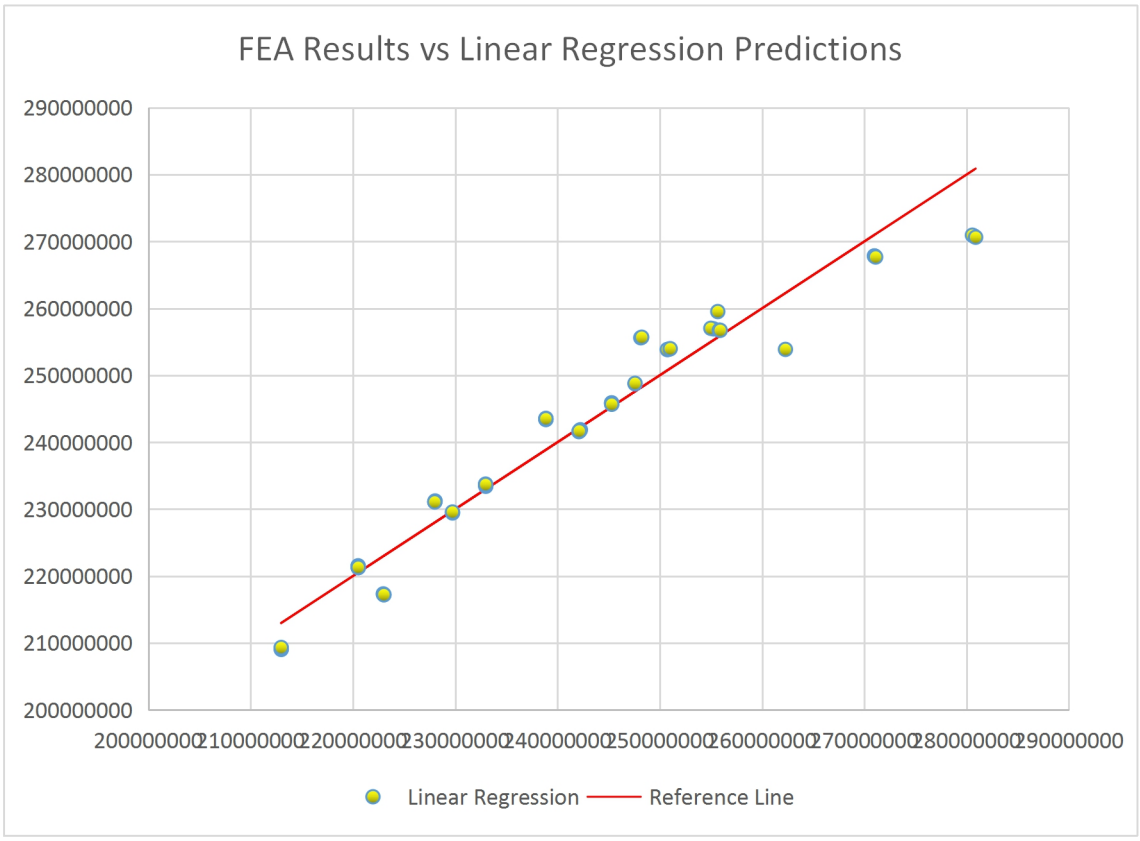

FEA Results vs AdaBoost Predictions
1.00E+07
9.00E+06
8.00E+06
7.00E+06
6.00E+06
5.00E+06
4.00E+06
3.00E+06
2.00E+06
1.00E+06
0.00E+00
0.00E+00 1.00E+06 2.00E+06 3.00E+06 4.00E+06 5.00E+06 6.00E+06 7.00E+06 8.00E+06 9.00E+06 1.00E+07
AdaBoost
Reference Line

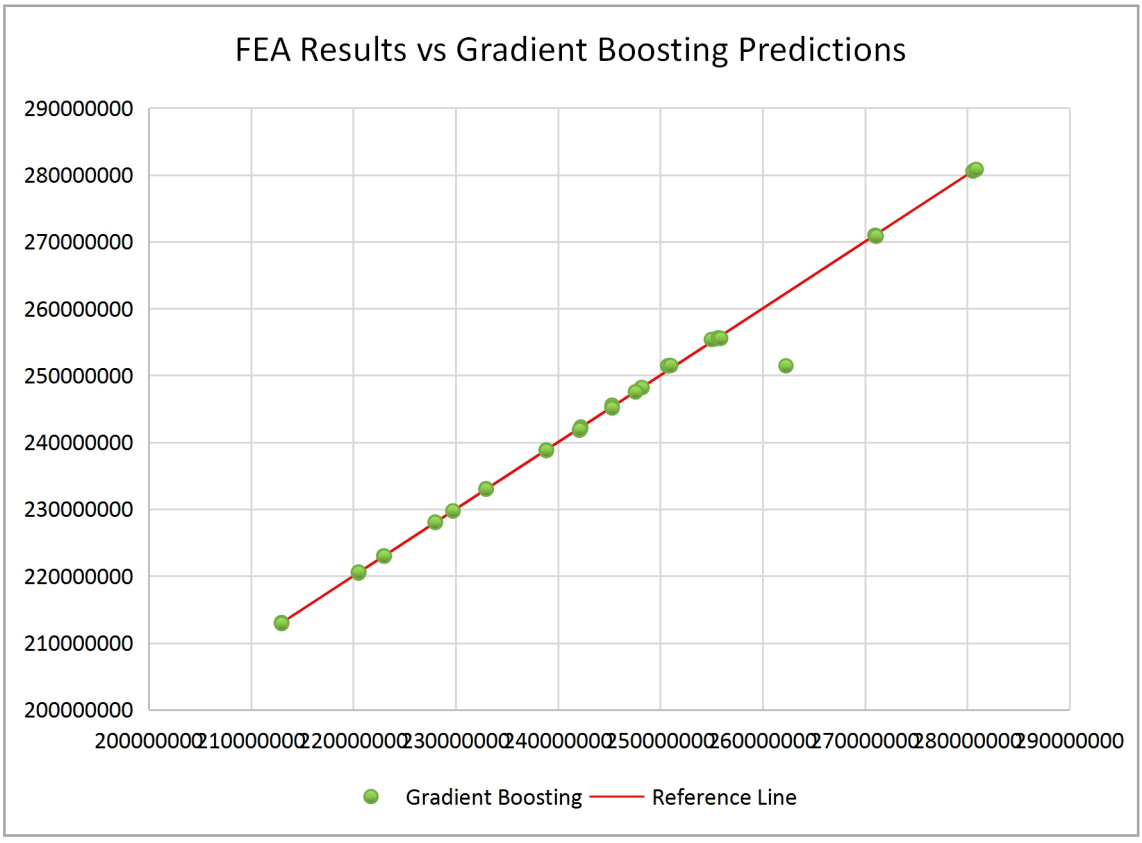

FEA Results vs kNN Predictions
1.00E+07
9.00E+06
8.00E+06
7.00E+06
6.00E+06
5.00E+06
4.00E+06
3.00E+06
2.00E+06
1.00E+06
0.00E+00
0.00E+00 1.00E+06 2.00E+06 3.00E+06 4.00E+06 5.00E+06 6.00E+06 7.00E+06 8.00E+06 9.00E+06 1.00E+07
kNN
Reference Line

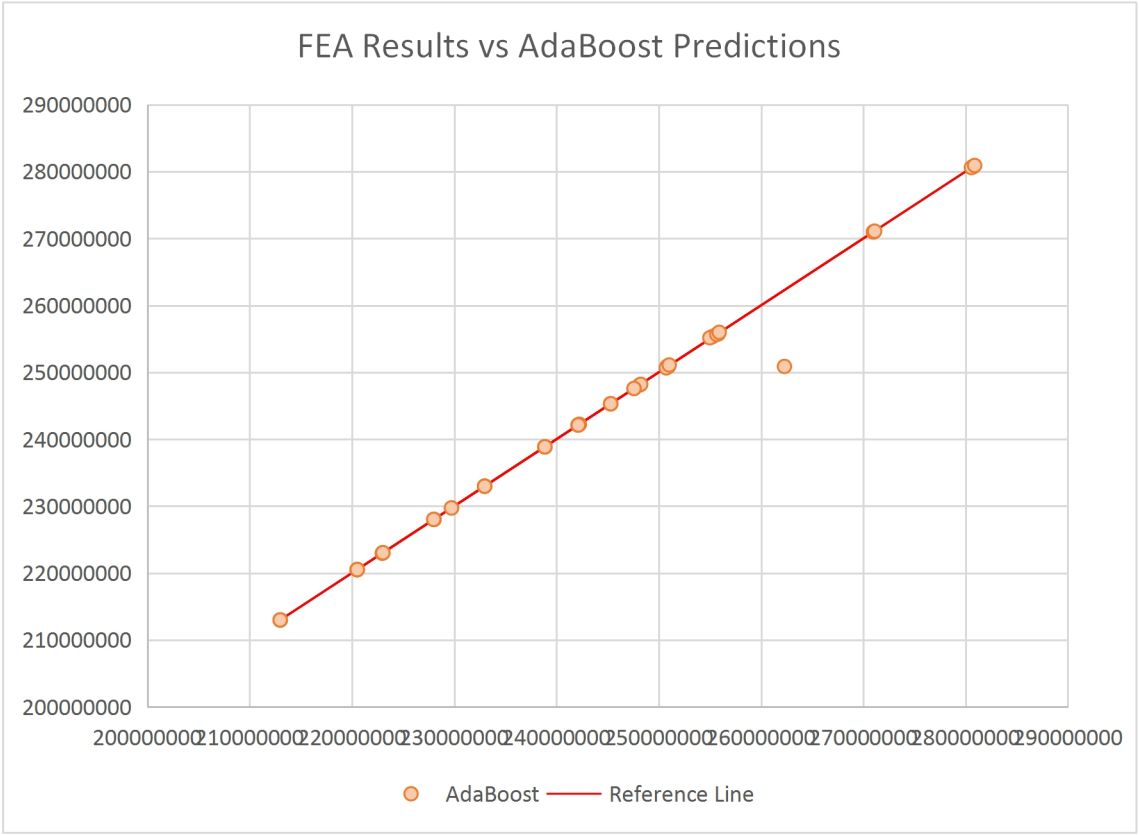
❖ Gráficos de las tensiones equivalentes Von Mises (la brida)

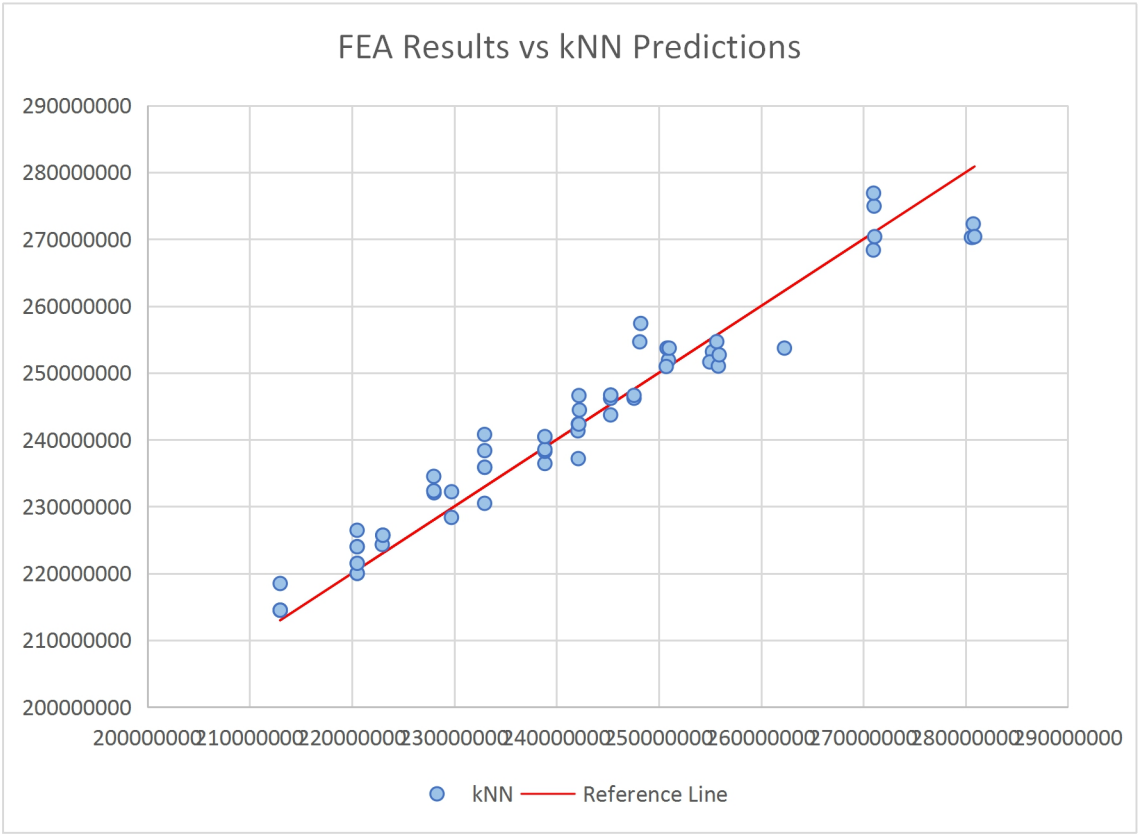





FEA Results vs Linear Regression Predictions
290000000
280000000
270000000
260000000
250000000
240000000
230000000
220000000
210000000
200000000
200000000 210000000 220000000 230000000 240000000 250000000 260000000 270000000 280000000 290000000
Linear Regression
Reference Line


FEA Results vs Gradient Boosting Predictions
290000000
280000000
270000000
260000000
250000000
240000000
230000000
220000000
210000000
200000000
200000000 210000000 220000000 230000000 240000000 250000000 260000000 270000000 280000000 290000000
Gradient Boosting
Reference Line


FEA Results vs AdaBoost Predictions
290000000
280000000
270000000
260000000
250000000
240000000
230000000
220000000
210000000
200000000
200000000 210000000 220000000 230000000 240000000 250000000 260000000 270000000 280000000 290000000
AdaBoost
Reference Line


FEA Results vs kNN Predictions
290000000
280000000
270000000
260000000
250000000
240000000
230000000
220000000
210000000
200000000
200000000 210000000 220000000 230000000 240000000 250000000 260000000 270000000 280000000 290000000
kNN
Reference Line

ANEXO C: Test and score Orange

Según la [13], las definiciones de los parámetros de resultados son:

- MSE = El promedio de los cuadrados de los errores o desviaciones, que es la diferencia entre el estimador y lo que se estima.
- RMSE = La raíz cuadrada de la media aritmética de los cuadrados de un conjunto de números que refleja la imperfección del estimador de los datos.
- MAE = La medición que refleja la proximidad entre los predicciones de los resultados finales.
- R^2 = La proporción de la varianza en la variable dependiente que es predecible a partir de la variable independiente.

A continuación, se muestran los resultados de "test and score" de cada variables de salidas según el modelo aprendizaje automático correspondiente. Cuanto más se acerque la puntuación R^2 a 1, mejores serán el modelo.

Test and Score Thu May 27 21, 16:54:55

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	3592294061271.113	1895334.8150844253	1190577.4222184562	0.9879307241810625
Random Forest	9192323046.504314	95876.60322781734	63433.39122378968	0.9999691159241496
Neural Network	2302281653285.5933	1517327.1411549961	1194028.9567364492	0.9922648670146589
Linear Regression	11107602835854.492	3332807.050498797	2663414.2222044435	0.9626810277703984
Gradient Boosting	14621958272.408089	120921.2895746985	99642.45943640574	0.9999508736076744
AdaBoost	3331868260.5745306	57722.33762222846	49283.68253971376	0.9999888056945385

outer normal stress

Test and Score Thu May 27 21, 16:57:36

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	4070204935.850882	63798.15777787696	33110.872191220245	0.9996498367398328
Random Forest	2993803350.841518	54715.65910085995	29372.631303318227	0.999742440501608
Neural Network	6776715426.90708	82320.8079825938	32673.75617878778	0.9994169932952982
Linear Regression	31825743441.953156	178397.71142577237	148212.50723896374	0.9972620036935435
Gradient Boosting	2032414768.995773	45082.31104319934	24512.333489852957	0.9998251495949859
AdaBoost	1543163680.8141148	39283.12208587951	18333.994543650853	0.9998672402903632

centre normal stress

Test and Score Thu May 27 21, 16:59:41

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	3541512003.478118	59510.60412630776	29448.41231422307	0.9823004606374789
Random Forest	39149687.40152967	6256.971104418629	3227.6647483178776	0.9998043402274189
Neural Network	855422.8085435296	924.8907008633666	712.9158675995783	0.9999957248232798
Linear Regression	41120999776.96629	202783.13484352265	169241.78362171876	0.7944881300800781
Gradient Boosting	9329965.245841658	3054.4991808546383	1901.019602349024	0.9999533713038505
AdaBoost	10053174.15010928	3170.6740844983233	2358.2838271643895	0.9999497568972198

inner normal stress

Test and Score Thu May 27 21, 17:07:31

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	346609207829.01074	588735.2612414266	383373.7165332995	0.8751687940564974
Random Forest	167878320295.2544	409729.56971062557	186198.37179880624	0.9395386715041787
Neural Network	468951178119.2002	684800.1008463713	525812.9823486431	0.8311073688436895
Linear Regression	1275375742776.2712	1129325.3485051468	863889.5073797291	0.5406737951393599
Gradient Boosting	413869060446.3021	643326.5581695676	359748.88770070294	0.8509451775911763
AdaBoost	102391807023.83551	319987.1982186717	90415.62709093046	0.9631236203170193

vm gasket

Test and Score Thu May 27 21, 17:09:07

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	77279579798.40945	277992.04988346243	170191.65540308546	0.9855360665186692
Random Forest	20338444317.217136	142612.9177782193	104016.24949089636	0.9961933811430477
Neural Network	19923209.39622234	4463.542247612578	2631.520601559277	0.9999962710980547
Linear Regression	300858606763.43445	548505.794648912	389483.27406274446	0.9436901845628082
Gradient Boosting	2612129633.9187756	51108.99758280117	34798.431377742614	0.9995111041057914
AdaBoost	1641012750.8477683	40509.41558264903	18948.60976246103	0.9996928619522493

vm pipe

Test and Score Thu May 27 21, 17:10:55

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	7047042513944.63	2654626.624206242	1813383.521287376	0.9994318509214386
Random Forest	27421966437.97412	165595.79233173202	102502.10568574781	0.9999977891768166
Neural Network	1260414175855.3713	1122681.6894629444	874431.0255351483	0.999898382456016
Linear Regression	39690992979876.79	6300078.807433824	5302063.785504849	0.996800019150717
Gradient Boosting	24385314402.342037	156157.97899032262	128315.89575486902	0.9999980339988186
AdaBoost	8656774205.479317	93041.78741554418	68098.72701675835	0.9999993020705809

vm bolt

Test and Score Thu May 27 21, 17:14:13

Settings

Sampling type: No sampling, test on testing data

Scores

Model	MSE	RMSE	MAE	R2
kNN	17953740117017.137	4237185.4003591975	3252802.3734838055	0.9454430897669328
Random Forest	2065212037843.3525	1437084.5618276442	206485.3002903627	0.993724338938488
Neural Network	3037489707029.2817	1742839.552864601	940923.0429148135	0.9907698311215282
Linear Regression	16323271864542.14	4040206.9086300693	2981651.7285110014	0.9503976735755639
Gradient Boosting	1906816158564.006	1380875.1422789847	294440.2490562801	0.9942056642618361
AdaBoost	2068122159760.1235	1438096.714327699	199782.99520323862	0.9937154958083577

vm flange