Paper 166-30

Statistical Analysis of Steel Formability

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ABSTRACT

Medium carbon steel structural grades of the hot rolled plates and sheets are commonly used for deep drawing applications [1]. Cracking on the bend faces of steel is a major defect, which usually causes rejection of the sufficient volumes of steel. Crack resistance during deep drawing, depends of multiple metallurgical factors. Some of these parameters are: steel chemistry and thickness, microstructure and cleanliness, strength level and degree of restraint, etc. In some cases, cracks also initiated, upon bending a sheared or burned edge. Usually this is not considered as a fault of the steel, but rather a function of the induced cold work or heat-affected zone [2, 3].

Article present results of susceptibility to cracking, on medium carbon mechanically capped (MCD), and silicon semi-killed (SSK) grades of hot rolled Q_BOP steel in gages up to 0.5" (12.5 mm), shipped as coils or plates, processed through the heavy gage shear line (HGSL) or Temper Mill.

SAMPLING PROCEDURE

To characterize steel susceptibility to cracking, samples of processed plates were collected from the outside, inside and middle wrap of the processed coils. "Hard way" test coupons (long axis of samples is parallel to the rolling direction) were made in accordance to the General Requirements for Steel, Sheet, Carbon, and High Strength, Low-Alloy, Hot-Rolled grades of steel (ASTM A568/A56SH-91a) [4, 5, 6]. The 100-ton hydraulic press was used for bending the specimen. Samples were bent 'flat-on-self, or until crack appeared on the upper bent surface. The maximum diameter of the bend at the point of cracking for each specimen measured, and then DT_RATIO (the bend diameter / coil gage - 0 is the best), were calculated, as a measure of the bendability. Two samples of each bent coupon, representing the edge and quarter location across the coil width, analyzed for steel cleanliness. Steel cleanliness rated in accordance with Method A, ASTM E-45. The cleanest rating being one, and the dirtiest being five. The table 1 shows number of tested samples by product type.

Table 1

Test Samples by Product Type

Deoxidation practice	Number of tested heats	Number of tested coils	Number of bend tests	Number of cleanliness tests
MCD	71	206	246	214
SSK	99	433	435	270
Total	170	639	681	484

DISCUSSION

Over 50 steelmakings, casting and hot rolling parameters were analyzed to determine their effect on steel susceptibility to cracking. Table2 shows standards' requirements for physical properties and chemical composition for analyzed grades of steel. Medium carbon structural grades of the hot rolled plates and coils are commonly used for deep drawing applications. Cracking on the bend faces of steel is a major defect, which usually causes rejection of the sufficient volumes of steel. Crack resistance commonly characterized by bend test, where sample, taken from the rolled product in longitudinal ("hard way") or transverse ("easy way") direction, in respect to rolling direction are bent flat.

Table 2

Standard Requirements

Item	Specification [*1]					
	ASTM A36-93, ASTM709-93A Grade 36, ASME SA-36 [*2]		ASTM A36-93, ASME SA-36, ABS Sec.43 Grade A		ASTM A516-90, ASME SA516 Grade 70	
	Min	Max	Min	Max	Min	Max
Yield Strength, ksi	36	-	36 [*7]	-	38	-
Tensile Strength, ksi	58	80	58	71	70	90
Elongation, % [*3]	20 [*4]	-	21 [*5]	-	21 [*8]	-
Carbon, %	-	0.25	-	0.21	-	0.27
Manganese, %	0.80 [*6]	-	0.60	1.14	0.85	1.20
Silicon, %	0.03	0.40	0.10	0.35	0.15	0.40
Phosphorus, %	-	0.040	-	0.020	-	0.035
Sulfur, %	-	0.045	-	0.030	-	0.030
Copper, %	-	-	-	0.35	-	0.40
Nickel, %	-	-	-	0.40	-	0.40
Chromium, %	-	-	-	0.25	-	0.30

Notes:
[*1] Related test specifications -ASTM A6, ASTM A370.
[*2] Plates 3/16" and under in thickness need not be subjected to tension testing, however chemistry consistent with the desired mechanical properties must be applied.
[*3] For allowable 8" elongation adjustments under 0.312", refer to chart from ASTM A6/A20.
[*4] Plates over 24" in width, the elongation % is reduced by 2%.
[*5] For material under 0.313" in thickness, a deduction of 1.25% from the percentage of elongation in 8" specified in table, is to made for each decrease of 0.031" of the specified thickness or diameter below 0.313".
[*6] For plate thickness over 0.7500", Mn ranged from 0.80% up to 1.20%.
[*7] ABS Sec.43 for Grade A min Yield point 34 ksi.
[*8] For 8" specimens. For 2" specimens see ASTM A516-90 & ASME SA516 Gr. 70.

To characterize steel susceptibility to cracking, transverse specimens were bent, using the 100-ton hydraulic press ‘flat-on-self’, or until crack appeared on the upper bent surface. The maximum diameter of the bend at the point of cracking for each specimen measured, and then DT_RATIO (the bend diameter / coil gage), were calculated.

Fig. 1 shows DT_RATIO performance along ingot height for both grades of steel. MCD steel shows a significantly healthier bent performance then SSK steel. In fact, 60% to 85% of MCD samples, regardless of ingots’ location were bent flat, while for SSK grade only 20% to 33% of samples showed such performance. Almost 97% of tested MCD samples tested with DT_RATIO less then 0.9, while up to 35% of tested SSK samples failed bend test with DT_RATIO > 1.0. Variation of the DT_RATION by ingot location, are more significant for the SSK grades, where samples, representing ingots’ top failed in more then 50%.

Fig.2, 3 show distribution and statistical characteristics of chemical composition and physical properties of steel. Distributions of all chemical elements and physical properties were close to the normal distribution (analyzed using χ^2 statistics). The variation and average level of all chemical elements and physical properties, for both grades of steel, analyzed by Fisher and Students’ criteria, and was identical, except Si contents, reflecting differences in deoxidation practices. Carbon varied from 0.16 % to 0.26% manganese from 0.50 % to 1.05% phosphorus from 0.003 % to 0.018% and sulfur from 0.009% to 0.033 %. Silicon in SSK grades of steel varied from 0.02% to 0.10%.

DT_Ratio by Ingot Location

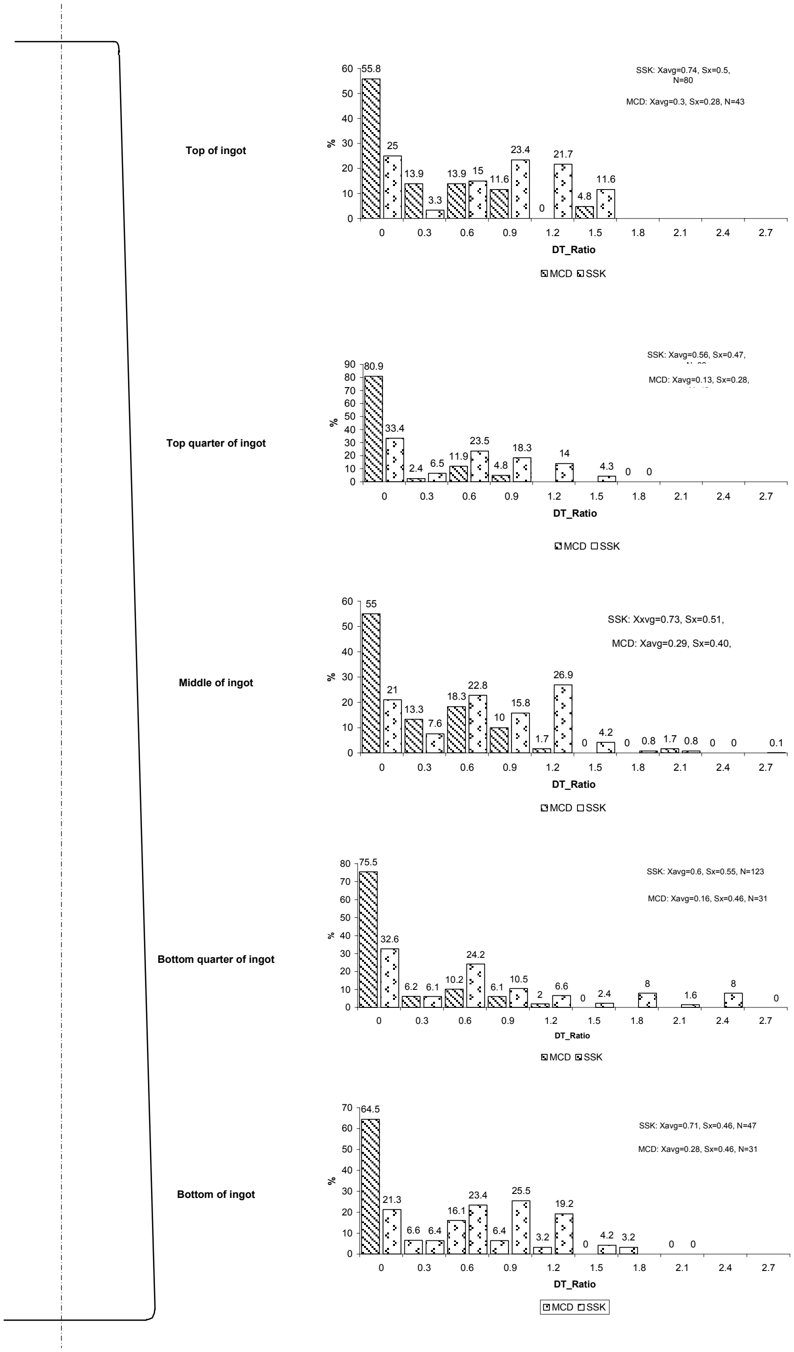
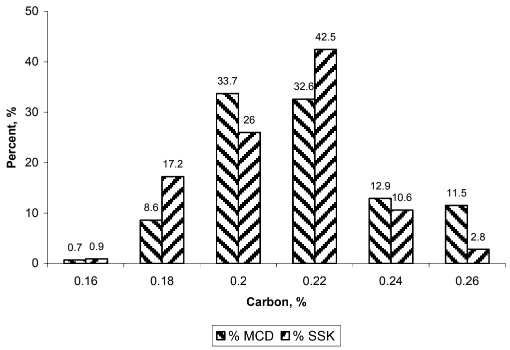
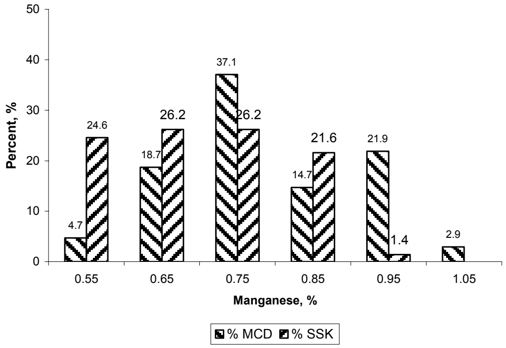
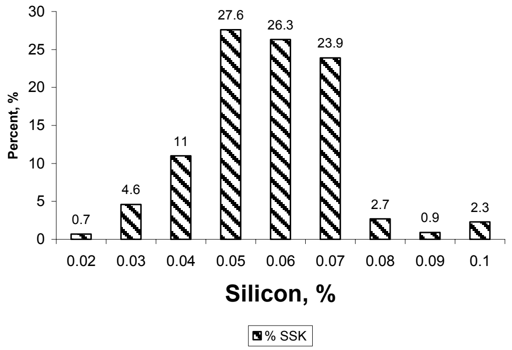


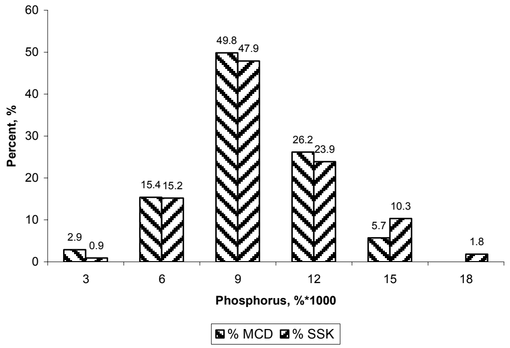
FIG 1

Chemical Composition of Steel









Steel chemistry (Statistical characteristics)

Chemical Element	Grade of steel MCD Xavg, %	 Sx, %	 SSK Xavg, %	 Sx, %
Carbon, %	0.21	0.022	0.206	0.019
Manganese, '	0.787	0.124	0.697	0.103
Silicon, %	0.005	0.002	0.058	0.014
Phosphorus, '	0.011	0.002	0.011	0.014
Sulfur, %	0.02	0.004	0.022	0.005

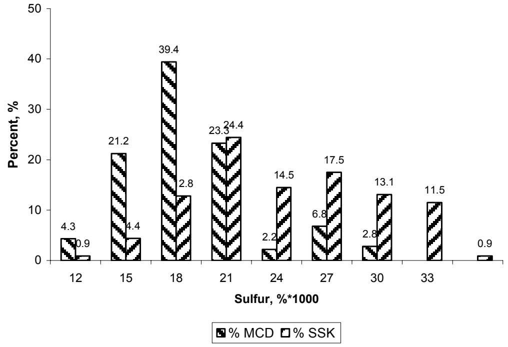


Fig. 2

Physical Properties of Steel

Physical properties
(Statistical characteristics)

ysical Propert	Grade of steel				Fishers'	Students'
	MCD		SSK		Criteria	Criteria
	Xavg	Sx	Xavg	Sx	Fc	Tc
Yield,, ksi	46.9	4.57	47.2	4.94	1.17	0.73
Tensile, ksi	68	4.25	68	4.02	1.12	0
Elongation,	23.3	2.01	23	1.86	1.17	1.85

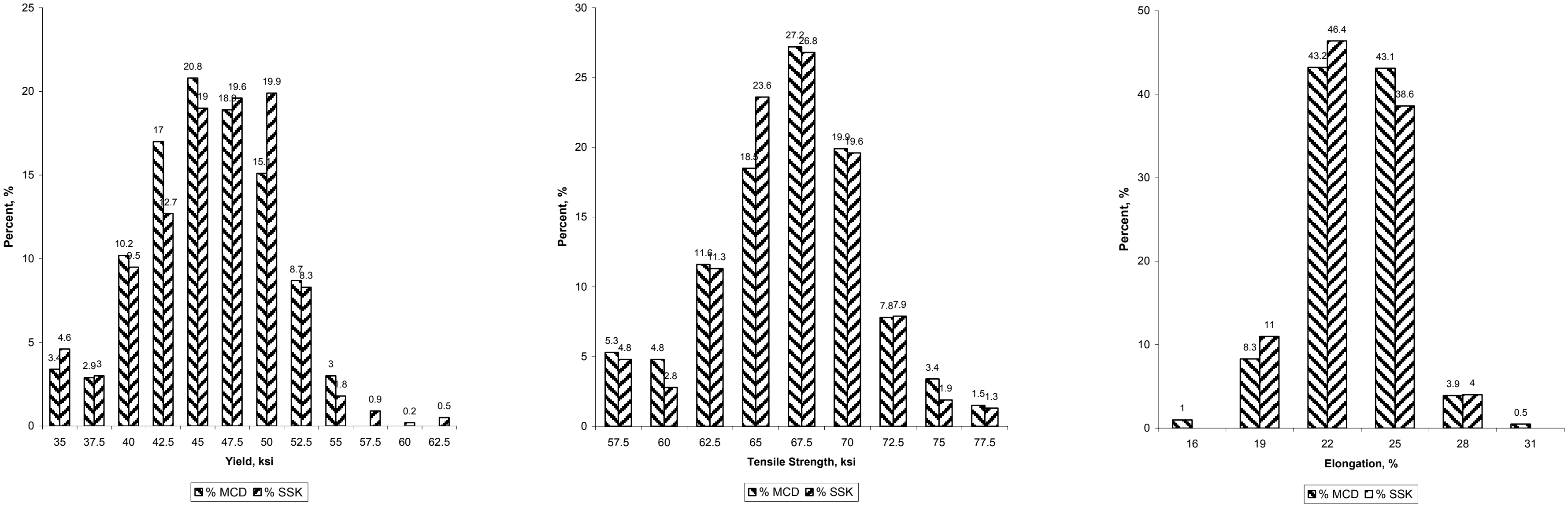


Fig. 3

The yield strength for MCD steel varied from 35 ksi to 55 ksi. For SSK grades, only 1.6 % of the test results surpassed 55 ksi. Tensile strength for both grades varied from 57.5 ksi to 77.5 ksi. Elongation varied from 16% to 31% for MCD grades and from 19% to 28% for SSK grades. The statistical characteristics for tensile test results are also shown in Fig. 3. Fisher and Student's criteria do show statistically insignificant differences in physical properties between analyzed grades of steel ($Fcr_{O.05}=1.20$; $Tcr_{O.025}=1.96$).

Steel melting and rolling parameters were among major factors, affecting breakage performance [1, 2, and 3]. Statistical analysis performed on more then fifty Q-BOP melting and rolling mill parameters collected during production of analyzed samples.

Fig. 4 – 5 shows turn down chemical composition, temperature and oxygen content in steel. Turn down carbon varied from 0.002 t to 0.05 % with the average level being 0.02 %. The average level (X_{avg}) of Mn is 0.08 % and the standard deviation (S_x) is 0.032 %. Q-BOP practice provides a very low turn down phosphorus content in steel, which does not exceed 0.015 % (X_{avg}--0.009 %). The sulfur content in steel varied from 0.008 % to 0.040 % (X_{avg}=0.021 %; S_x=0.0057 %). In 46 % of Q-BOP heats, turn down sulfur exceeded 0.020 %. Turn down nitrogen content varied to 0.010 %. In 35 % of the heats, N_2 content exceeded 0.004 %. In 97 % of the analyzed heats, turn down temperature varied from 2900 ^{0}F to 3000 ^{0}F. Turndown oxygen content in steel varied from 300 ppm to 1000 ppm (X_{avg}=568 ppm and S_x=162 ppm). Thirty percents (30.6 %) of the analyzed heats had one reblow and 9 % had more than one reblow.

Fig. 6 contains the statistical distribution of ladle additions per ton of steel. The differences in coke and high carbon FeMn additions per ton of steel for analyzed grades are insignificant. Statistically significant differences in aluminum bundle consumption for MCD and SSK practices correspond to the standard operation procedures (SOP) for these grades of steel.

Fig. 7 shows histograms of the ladle temperature and oxygen content in steel. Ladle temperature for both grades of steel varied from 2790 ^{0}F to 2890 ^{0}F. Oxygen content in the steel after ladle additions varied from 10 ppm to 130 ppm. Average oxygen content for SSK grades (51.0 ppm) was almost 20 ppm lower than for MCD grade. The Fisher's (F) and Student's (T) statistical tests were used to estimate significance in differences of average level and variation of the ladle temperature and oxygen content in MCD and SSK grades. Calculated values for ladle temperature were F_c=1.49 and T_c=3.44. For oxygen content F_c=1.30 and T_c=7.64. Critical values (tabulated values) for 5% significance level were $F_{cr0.05}$=1.52 and $T_{cr0.05}$=1.65.
Mold aluminum additions, seal time for mechanically capped grades of steel, heat weight, pouring time and pouring velocity are also shown in Fig. 7 and 8. Seal time varied from 60 to 300 seconds. Average level (X_{avg}) was a 130.7 second and standard deviation (S_x) is a 58.4 seconds. Mold aluminum additions for SSK ingots varied from 0 to 14 Lb per ingot (X_{avg}=4.74 Lb/ingot; S_x=3.48 Lb/ingot). Pouring time for 96 % ingots varied from 20 to 35 minutes (X_{avg}=23.4 minutes; $S_{x=}$5.0 minutes). Calculated pouring velocity for these ingots varied from 150 Lb/sec to 400 Lb/sec (X_{avg}--345.4 Lb/sec; S_x=64.3 Lb/sec).

Fig. 9 contains histograms of the coil gages, reduction in thickness, finishing and coiling temperatures. Coil gages varied from 0.088 inch to 0.5 inch. Coils were rolled from 4” to 9.2” thick slabs. Reduction in thickness (slab/coil thickness ratio) varied from 5 to 115 (X_{avg} = 31.8, S_x=20.2). The average finishing temperature varied from 1400 ^{0}F to 1800 ^{0}F (X_{avg}=1600 ^{0}F, S_x=57.5 ^{0}F). The average coiling temperature varied from 1000 F to 1350 F (X_{avg}=1197 ^{0}'F, S_x=65.6 ^{0}F). The finishing/coiling temperature ratio varied from 1.2 to 1.44 (X_{avg}=1.33, S_x=0.043).

Tables 3 - 4 contain Pearson correlation matrixes between DT_RATIO and analyzed technological parameters [7, 8, and 9]. Among physical properties, tensile strength and elongation show statistically significant correlation with DT_RATIO for both grades. (The correlation coefficient is statistically significant if the probability of the hypotheses that this coefficient equals to zero is less than 0.05) [7]. Coiling temperature and Carbon content in steel appeared as a most correlated with DT_RATIO among rolling and final chemical composition of steel. Steel cleanliness appeared as one of the most correlated parameters, that characterizes steel formability and susceptibility to cracking. The data also shows significant correlation between formability and ladle temperature, oxygen content in steel after ladle additions, mold aluminum consumption for SSK grades and seal time for MCD grades. The cross-correlation matrixes for the combined MCD and SSK grades of steel show strong correlation between formability and the physical properties, steel cleanliness, combination of the steel chemistry with finishing and coiling temperatures and pouring parameters.

The SAS GLM ® backward stepwise elimination procedure was used to perform linear regression modeling of the DT_RATIO, depending on analyzed parameters [7]. Below is first and last of eighteen steps' (after the elimination of all insignificant parameters) SAS GLM regression procedure output for the DT_RATIO for MCD and SSK grades.

The final multiregression coefficient equals 0.612 for MCD and 0.671 for SSK grades. Type one squared partial correlation coefficients show the percent of DT_RATIO variability that could be explained by the variability of the analyzed parameters. The final regression equation for the MCD grade explains up to 37.4% of the DT_RATIO variability. Among steel teeming parameters, which determines up to 26.3% of the DT_RATIO variability, major effect belong to the pouring velocity - 10.4 %, seal time - 8.56 % and mold aluminum consumption – 7.4 %. Turn down oxygen content in steel, coiling temperature and final chemical composition of steel also affect the DT-RATIO variability. However, this effect is much lower and varied from 1.0% to 4.5%.

Analysis of the regression equation for MCD grade suggests, that fixing all other parameters at the average level, for each coiling temperature increase of 50 ^{o}F, the DT_RATIO reduced by an average of 0.12. In addition, for each finishing temperature reduction of 50 ^{o}F, there is a reduction of the DT_RATIO by an average of 0.08. The optimal combination of the finishing and coiling temperatures could be used to compensate the negative effect on steel formability by the bad combination of steel melting, treating and teeming parameters. The best formability for MCD grades could be achieved in combination of the finishing temperature ranging from 1450 ^{o}F to 1600 ^{o}F and coiling temperature ranging from 1150 ^{o}F to 1350 ^{o}F. The finishing/coiling temperature ratio should not exceed 1.35. Increasing the seal time by 30 sec increments improves the DT_RATIO by an average of 0.04. The best formability performance achieved when the ladle oxygen content in the steel is less than 70 ppm, the temperature less than 2850 ^{o}F and the seal time surpassed 150 - 180 sec.

Each additional increase of 0.005 % in the sulfur content in the MCD steel increases the DT_RATIO by an average of 0.06. The effect of the carbon, manganese, phosphorus and nitrogen content on the steel formability is much lower than from the parameters discussed above. The cross-correlation effect between these elements with turn down parameters and ladle additions require additional study. The effect from the rimming activity, mold additions, ingot crystallization and transit time, soaking pits and rolling mill parameters on the steel formability was not analyzed in this study.

For SSK grade 45% of the variability of DT_RATIO, derived from the variability of parameters, included in the final regression equation. Chemical composition of steel, reduction in gages and coiling temperature were determined to be the most significant part of the DT_RATIO variability (30.5 %). The variability of the coke and FeSi in ladle additions, ladle temperature and mold aluminum affected ~ 16% of the DT_RATIO variability. Statistical analysis shows, that light SSK gages (less than 1/8") are more sensitive for cold cracking than heavy gages. However, this effect could result as a cross-correlation effect between sheets gages, finishing and coiling temperatures, and require special study. For each coiling temperature increase of 50 F, the DT__RATIO reduced by an average of 0.07. The coiling temperature for SSK grades (depending of the gage) varied from 1150 ^{o}F to 1350 ^{o}F. Each additional increase of 0.01% in the carbon content increases the DT_RATIO by an average of 0.13.

Each additional increase of 0.005% in the phosphorus, sulfur, silicon and nitrogen content in steel, increases DT_RATIO by an average from 0.04 for silicon and sulfur, to 0.50 for nitrogen. An increase of 0.05% in the manganese content in steel reduces the DT__RATIO by an average of 0.07. Each additional pound of aluminum addition per mold reduced DT_RATIO by an average of 0.05. The cross-correlation effect between mold Al consumption and ladle oxygen content in steel require special study. The effect from the ingot transit and crystallization times, soaking pits and rolling mill parameters on steel formability did not analyzed.

Table 3

Pearson Correlation Matrix between DT_RATIO and Physical Properties of Steel

Grade of steel	Parameter	N	Mean	Standard Deviation	Min	Max	DT_RATIO	Yield	Tensile	Elongation
MCD	DT_RATIO	225	0.2346	0.380	0	1.976	1	0.1432	0.2532	-0.1537
	Yield	199	471.1	45.7	360.0	572.0		1	0.7111	-0.1211
	Tensile	199	680.7	42.9	580.0	797.0			1	-0.0491
	Elongation	199	23.3	2.0	17.0	31.0				1
SSK	DT_RATIO	442	0.6598	0.511	0	3.2	1	0.3108	0.3235	-0.0747
	Yield	427	471.4	49.2	360.0	642.0		1	0.7311	-0.1027
	Tensile	427	679.9	40.0	580.0	799.0			1	-0.0113
	Elongation	423	23.0	1.9	20.0	29.0				1

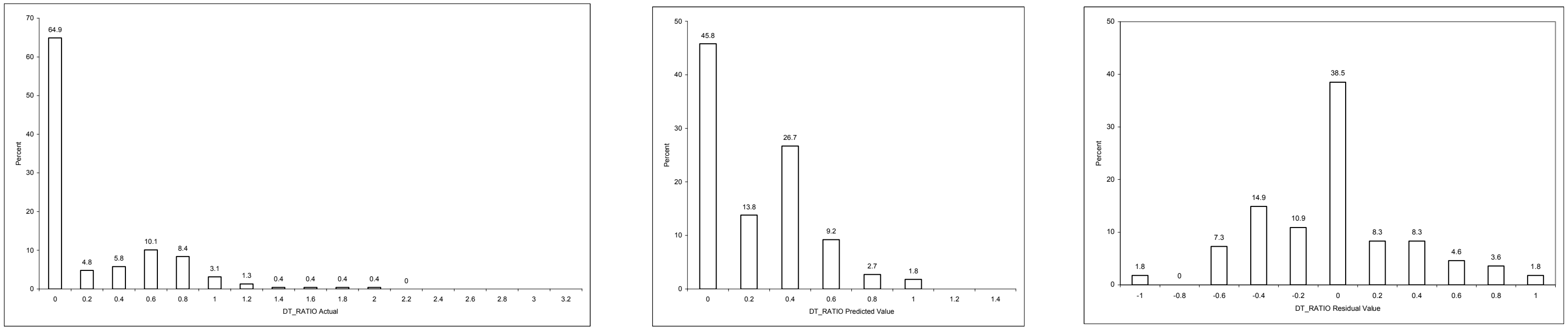
Table 4

Pearson Correlation Matrix between DT_RATIO and Chemical Composition and Rolling Parameters

Parameter	DT_RATIO	Coil Gage	Coiling to Finishing Temp. Ratio	Finishing Temperature	Coiling Temperature	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Nitrogen
DT_RATIO	1	-0.0076	0.0654	0.0786	-0.1344	0.1593	-0.0117	0.0078	0.1180	0.0648	0.0370
Coil Gage		1	-0.7744	0.6351	0.7631	0.5721	0.4876	0.0583	0.0262	0.0109	0.1389
Coiling to Finishing Temperature Ratio			1	-0.2409	-0.4727	-0.4326	-0.2981	-0.0715	-0.0134	0.1030	0.0308
Finishing Temperature				1	0.7640	0.4672	0.4391	0.0562	-0.0339	0.0877	0.2449
Coiling Temperature					1	0.4550	0.3869	0.0577	-0.1603	0.0412	0.1544
Carbon						1	0.3962	0.1238	0.0509	-0.1172	0.0874
Manganese							1	0.0924	0.1382	0.3546	-0.0520
Silicon								1	0.1017	0.0621	0.0055
Phosphorus									1	0.2837	-0.2398
Sulfur										1	-0.2446
Nitrogen											1

Final Regressional Equition for MCD Steel (Based on technological Parameters)

DT_RATIO=14.872+2.759*Mn-79.179*P+11.49*S-103.3*N_2+0.005733*T_RATIO+0.001624*AVG_FT-0.002423*AVG_CT-0.006032*TD_TMP+0.001593*TD_O_{2ppm}+4.9485*TD_Mn +0.2839*COKE_T-0.056322*NCFeMn_T+0.002801*LAD_O_{2ppm}+0.002070*POURVLS-0.001209*SEALTIME+0.2814*MOLD_Al; R=0.612; R^2=0.3747; ROOT_MSE=0.3177



Final Regressional Equition for SSK Steel (Based on technological Parameters)

DT_RATIO=21.3587+13.1486*C-1.4627*Mn+38.1349*P+6.6611*S+4.5758*Si+97.082*N_2+0.02232*T_RATIO-0.001297*AVG_CT-0.1388*REBLOW-47.9397*TD_P-0.3798*COKE_T-0.08506*FeSi_T-0.00661*LAD_TMP-0.01229*HEAT_WT+0.03576*POURTIME+0.002691*POURVLS-0.04921*MOLD_Al; R=0.671; R^2=0.45; ROOT_MSE=0.38

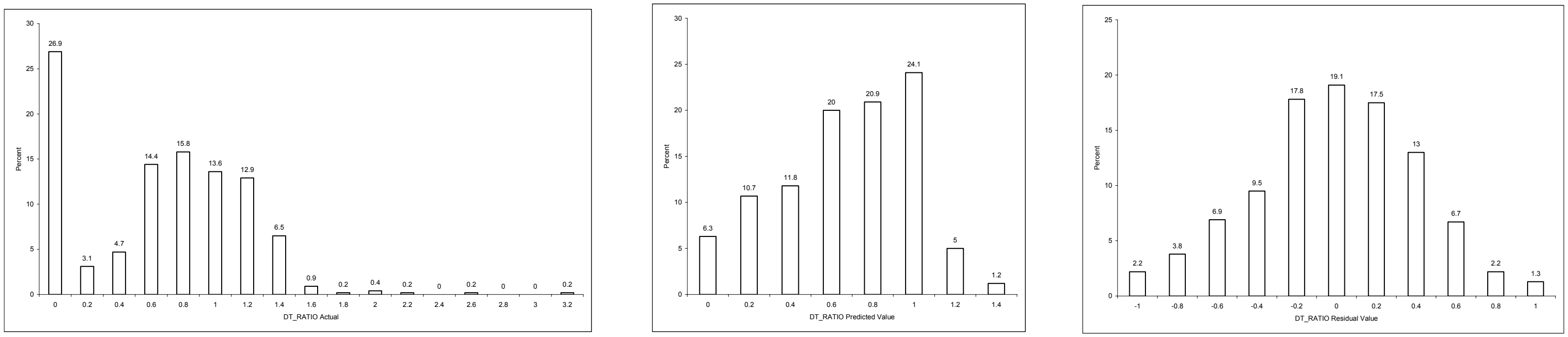
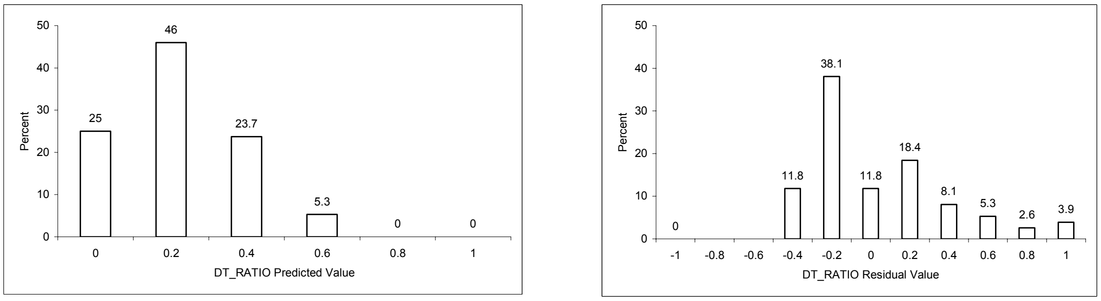


Fig 4

Final Regressional Equition for MCD Steel (Based on Physical Test Results)

DT_RATIO=-0.37-1.2822*GAGE-0.004539*YIELD+0.005369*TENSILE+0.153*DIRT
R=0.462; R^2=0.2135; ROOT_MSE=0.3609



Final Regressional Equition for SSK Steel (Based on Physical Test Results)

DT_RATIO=-0.2932+14.7882*S-1.0191*GAGE+0.003681*TENSILE+0.1184*DIRT
R=0.438; R^2=0.1922; ROOT_MSE=0.4188

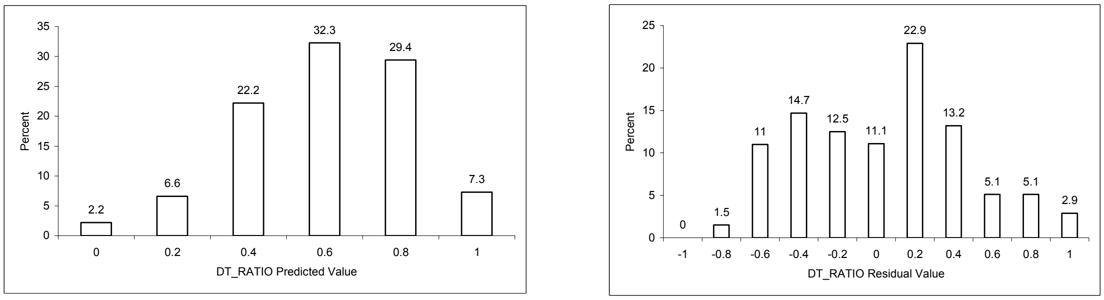


Fig. 5

Fig. 4 and 5 show final regression equations and distribution of actual, predicted and residual values of the DT_RATIO for MCD and SSK grades of steel. Statistically significant correlation between DT_RATIO and analyzed parameters, and good correspondence with practical knowledge, of how steelmaking parameters affect steel formability, suggests practical applicability of the developed statistical models [1, 10]. Models were implemented into process control system to predict steel susceptibility of cracking, depending on technological parameters.

CONCLUSIONS

Over 70 parameters based on 178 Q-BOP melted medium carbon MCD and SSK heats (639 coils), shipped as coils or plates, processed through the heavy gage shear line (HGSL) or Temper Mill, were statistically analyzed to determine steelmaking factors that affect sheet susceptibility to cracking. The "hard way" (transverse according to the rolling direction) specimens from the outside, inside and middle wrap of the processed coils were bend, and DT_RATIO (bend diameter/coil gage ratio) used to characterize steel formability.

The SSK grades are more sensitive for cracking than MCD grades. Over seventy (70.3%) percents of variability of the DT_RATIO on MCD grades, resulted by variation of the ingot pouring practices. For SSK grades 67.5% of variability of the DT_RATIO determined by the variation of the chemical composition of steel, reduction in gages and coiling temperature. The light SSK gages (less than 1/8") are more sensitive for cold cracking than heavier gages.

The optimal combination of the finishing and coiling temperature could be effectively used to compensate negative effect on steel formability of bad combination of melting, ladle treating and teeming parameters for both grades.

The tensile test results and cleanliness testing, in combination with steel chemistry, could be used to predict steel's susceptibility to cracking.

Implementation of developed regression models through the MIC (Metallurgical Index Code) process control system, allow separation of heats with high susceptibility to cracking from production line to improve steel quality and rejection rate.

Appendix 1
CONVENTIONAL DESIGNATIONS

1. Q-BOP / Steel Melting and Pouring Parameters:

* ORD_WGT - Ordered steel weight, Lb;
* HMWEIGHT - Hot metal weight, Lb;
* YIELDWT = HMWEIGHT/ORD_WGT*100, %;
* TEMP - Hot metal temperature, F;
* HM_Mn, HM_Si, HM_P, HM_S - Hot metal chemical composition, %;
* BLOW_SEC - Blowing time, sec;
* O2PTON - Oxygen consumption per ordered ton of steel, scf/ton;
* SPTON - Natural gas consumption per ordered ton of steel scf/ton;
* LINETON - Lime consumption per ordered ton of steel, Lb/ton;
* DOLOPTON - Dolomite consumption per ordered ton of steel, Lb/ton;
* TD_TMP - Turn down temperature, F;
* TD_O2PPM - Turn down oxygen content in steel, ppm;
* TD_C, TD_Mn, TD_ P, TD__S, TD_N_2 - Turn down chemistry, %;
* CaO, MgO, P_20_5, SULFUR, Al_2O_3, MnO, Fe, Fe_2O_3 - Slag chemistry, %;
* BAS1=(CaO+MgO)/(SiO2+ P_20_5) - Characteristic of basicity;
* BAS2=CaO/(SiO_2+ P_20_5) - Characteristic of basicity;
* HCFeMn, ALBAR, COKE, FeSi - Ladle additions, Lb;
* HCFeMn_T, AlBAR_T, COKE_T, FeSi_T - Ladle additions per ton of steel, Lb/ton;
* LAD_TMP - Ladle temperature, F;
* LAD_O2PPM - Ladle oxygen content in steel, ppm;
* LAD_C, LAD_Mn, LAD_P, LAD_S, LAD_N_2 - Ladle chemistry, %;
* POURTIME - Pouring time, min;
* HEAT_WT - Heat weight, ton;
* POURVLS=2000*HEAT_WT/(60*POURTIME) - Pouring velocity, Lb/sec.

2. Rolling Mill Parameters:

* CARBON, MANG, SILICON, PHOS, SULF, CU, Ni, Cr, Mo, COLUMB, VAN, NITRO - Final steel chemistry, %;
* SLB_THK, SLAB_WID - Slab thickness and width, inch;
* GAGE, WIDTH - Coil's thickness and width, inch;
* T_RATIO=SLB_THK/GAGE - Reduction;
* AVG_FT, FT_LOW, FT_MAX - average, minimum and maximum rolling temperature, F;
* AVG_CT, MN_CT, MX_CT - average, minimum and maximum coiling temperature, F.

3. Tensile Test Results

* YIELD, TENSILE, ELONG - Tensile test results, psi; or % for elongation;
* RADIUS, DIANETER - Bend test results, inch;
* DT_RATIO = DIAMZTER/GAGE - Characteristic of bendability;
* DIRT5R, RIRT5L, DIRT - Steel cleanliness measurement.

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