EVALUATION OF THE PROPERTIES OF S235JR STRUCTURAL CARBON STEEL IN LEBANON

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ABSTRACT

The chemical and mechanical properties of S235JR structural low carbon mild steel were tested and reported for specimens collected from the Lebanese steel market. European and American standards were presented as references and compared with the achieved results. Discussion was conducted to show the similarities and differences between S235JR steel samples and standard requirements. Some of the reasons for such differences were discussed.

A database was furnished through this work for the public and mainly for the Lebanese Standard Organization LIBNOR to easily adopt and implement a standard that has been tested in Lebanon concerning the hot rolled low carbon structural steels.

Keywords: S235JR, structural steel, carbon steel, Lebanon

INTRODUCTION

Steel has become an essential factor in our every-day life. In well established manufacturing and industrial countries steel is classified and ordered in a very clear and organized way. This is due to the quality assurance procedures carried out in such industrial countries mainly in which steel is made. In Lebanon, the situation is totally different since the import of steel is managed by commercially oriented companies which just started to get familiar with standards and quality control systems for steel and other products. This is due to the fact that Lebanon is a non-steel-manufacturing country. Over and above, no serious development in the standardization and quality assurance fields was carried out due to the crisis, which took place at the end of the past century.

Thanks to the economic development and a flourishing construction industry during the past decade, a considerable effort has been made to change this situation in Lebanon.

Quality assurance courses have been implemented at most universities and institutions (public and private) and the focus has shifted to adopting new and updated, tested, and practical standards.

S235JR (previously designated St 37-2 or E24-2) is classified as low carbon mild steel used in most steel structural constructions in Lebanon. This kind of steel is very popular and has good ductile properties as well as excellent weldability. Hundreds of tons of S235JR steel are used in numerous applications: for example, the fabrication of water vessels and shelters (Hangars). S235JR steel is produced in many shapes and thickness such as steel plates, sheets, strips, angles and different other geometric shapes.

The main objective of this study is to provide theoretical and experimental data on the main chemical and mechanical properties of the above-mentioned steel.

COMPOSITION AND MAIN PROPERTIES OF S235JR STEEL

Steel Designation

S235JR is a European designation for steel that is better known in Lebanon as St 37-2 according to German standards (DIN), or as E 24-2 according to French standards NF (AFNOR). As for the equivalence in American standards, this steel may be referred to as ASTM A 570 grade 36 (ASTM 570/A 570 M-98, 2000) when sheets or strips of less than 6mm are considered, or to ASTM A 36 Grade 36 (ASTM A36/A 36 M-93a, 1997), or ASTM A 709 Grade 36 (ASTM 709/A 709 M93-a, 1997) when considering other standard shapes and sheet thickness. Table 1 shows a list of corresponding former European designations for this type of steel.

S235JR is a hot rolled non-alloy low carbon structural steel. This material is intended for structural purposes where mechanical test values are required. The calculated mass of this steel is determined using a volumetric mass of 7.85 kg/dm^3.

For the quality JR, the impact strength is not checked out unless specifically required, the method of deoxidation is optional and the nominal thickness is limited to 25 mm. Where applicable, an indication for the deoxidation method is as follows (BS EN 10025, 1993):

a) G1 for rimming steel.
b) G2 for rimming not permitted.

In the edition of ASTM standard 2000, ASTM A 570 Grade 36 steel is considered for two types, type 1 and type 2. Both types have a similar yield strength Re (250 MPa) but of different tensile strength Rm. Type 1 has a minimum required tensile strength Rm of 365 MPa, while type 2 has a permitted tensile strength range between 400- 550 MPa.

S235JR steel is also designated in other related European standards such as (EN 10027-1, 1993; EN10027-2, 1993; ECISS IC-10, 1993) or designation codes (Sollac, 1994; Designation des aciers selon nouvelle norme NF EN 10027-1 et ECISS IC-10, 1994). Such references are mainly concerned with the classification of carbon steels, symbols, and numerical systems.

TABLE 1
List of Corresponding Former Designations of S235JR Steel (BS EN 10025, 1993)

Designation According to	EN 10027-1 & ECISS IC 10	S235JR	S235JRG1	S235JRG2	S235JO	S235J2G3	S235J2G4
	EN 10027-2	1.0037	1.0036	1.0038	1.0114	1.0116	1.0117
Equivalent former designation in	EN 10025: 1990	Fe 360 B	Fe 360 BFU	Fe 360 BFN	Fe 360 C	Fe 360 D1	Fe 360 D2
	Germany	St 37-2	USt 37-2	RSt 37-2	St 37-3 U	St 37-3 N	-
	France	E 24-2	-	-	E 24-3	E 24-4	-
	United Kingdom	-	-	40-B	40-C	40-D	-
	Spain	-	AE 235 B-FU	AE 235 B-FN	AE 235 C	AE 235 D	-
	Italy	Fe 360 B	-	-	Fe 360 C	Fe 360 D	-
	Belgium	AE 235-B	-	-	AE 235-C	AE 235-D	-
	Sweden	13 11-00	-	13 12-00	-	-	-
	Portugal	Fe 360-B	-	-	Fe 360 C	Fe 360 D	-
	Austria	-	USt 360 B	RSt 360 B	St 360 C & St 360 CE	St 360 D	
	Norway	NS 12 120	NS 12 122	NS 12 123	NS 12 124	NS 12 124	-

Chemical Composition

Chemical composition according to EN 10025:1993 (BS EN 10025, 1993)

The chemical composition of S235JR is presented in Table 2 as the ladle analysis for long and flat products and the product analysis in % weight. Product analysis is to be taken into consideration when dealing with purchase orders.

A maximum Carbon Equivalent Value CEV, based on the ladle analysis is determined using the following formula: (CEV max. for $t \leq 40$ mm is 0.35 %)

$$CEV = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$$ (BS EN 10025, 1993)

TABLE 2
Chemical Composition of S235JR Steel (BS EN 10025, 1993)

Analysis	C % max for nominal product thickness t			Mn % max	Si % max	P % max	S % max	N % max
	t≤16 mm	16<t≤40 mm	t>40 mm					
Product analysis	0.21	0.25	-	1.5	-	0.055	0.055	0.011
Ladle analysis	0.17	0.20	-	1.40	-	0.045	0.045	0.009

Chemical composition according to ASTM A 570 Grade 36
(ASTM 570/A 570 M-98, 2000)

The chemical composition of S235JR or its equivalent in ASTM standards is presented in Table 3 for the chemical requirements and in Table 4 for limits on additional elements for both type 1 and type 2 of Grade 36.

TABLE 3
Chemical Composition of ASTM A 570 Steel Grade 36 Type 1 & 2
(ASTM 570/A 570 M-98, 2000)

Type	C % Wt. max	Mn % Wt. max	Si % Wt. max	P % Wt. max	S % Wt. max	Al % Wt.	Cu % Wt. min **
Type 1	0.25	0.90	*	0.035	0.04	*	0.20
Type 2	0.25	1.35	0.40	0.035	0.04	*	0.20

* No requirement, but the analysis shall be reported.
** When Copper is specified min. 0.20 %.

TABLE 4
Limits of Additional Elements of ASTM A 570 Steel Grade 36 Type 1 & 2
(ASTM 570/A 570 M-98, 2000)

Analysis *	Copper % max	Nickel % max	Chromium % max	Molybdenum % max	Vanadium % max	Columbium % max
Heat	0.20	0.20	0.15	0.06	0.008	0.008
Product	0.23	0.23	0.19	0.07	0.018	0.018

* For details of the sum of the limitations please refer to ASTM A 570-98 p. 315 (ASTM 570/A 570 M-98, 2000).

Mechanical Properties OF S235JR Steel

Mechanical properties according to EN 10025:1993 (BS EN 10025, 1993)

The mechanical properties of S235JR are presented in Table 5 as the minimum values required for the yield strength, tensile strength as well as for the elongation. These values are also classified according to different thickness of steel sheets.

TABLE 5
Mechanical Properties of S235JR Steel (BS EN 10025, 1993)

Minimum yield strength R_{eH} [MPa] nominal thickness t [mm]		Minimum tensile strength R_m [MPa] nominal thickness t [mm]		Minimum percent elongation [%]					
				L_o = 80 mm					L_o = 5.65√So
				Nominal thickness t [mm]					
t≤16	16<t≤40	t<3	3≤t≤100	t≤1	1<t≤1.5	1.5<t≤2	2<t≤2.5	2.5<t<3	3≤t≤40
235	225	360-510	340-470	17	18	19	20	21	26

Mechanical properties according to ASTM A 570 Grade 36 (ASTM 570/A 570 M-98, 2000)

The mechanical properties of S235JR or its equivalent in ASTM standards is presented in the following Table 6 for both types of steels ASTM570 Grade 36 type 1 and type 2. These values are considered as the tensile requirements for the above-mentioned steel.

TABLE 6
Mechanical Properties of S235JR Steel (ASTM 570/A 570 M-98, 2000)

Steel type	Minimum yield strength [MPa]	Tensile strength [MPa]	Minimum percent elongation [%]			
			In 50 mm			In 200 mm
			Nominal thickness t [mm]			
			0.65<t<1.6	1.6<t<2.5	2.5<t<6.0	2.5<t<6.0
Type 1	250	Min. 365	17.0	21.0	22.0	17.0
Type 2	250	400-550	16.0	20.0	21.0	16.0

Weldability of S235JR Steel

The weldability of carbon steels is affected by many factors such as the carbon content, the Carbon Equivalent Value CEV, the dimensions and shape of the product, as well as the manufacturing and service conditions.

Since S235JR steel is a low carbon steel with a carbon content C< 0.35 %, and of maximum Carbon Equivalent Value permitted of 0.35 % which allows no special treatment before or after welding (CEV < 0.45 %), it is considered to have excellent weldability. However, S235JR killed steels are preferable to rimmed steels particularly if segregation zones could be encountered during welding (AWS D1.1-96, 1996).

According to AWS D1.1-96 (AWS D1.1-96, 1996), S235JR (ASTM A36 Grade 36, ASTM A570 Grade 36, ASTM A709 Grade 36) steel lies in Group I of Table 3.1 prequalified base metal-filler metal combinations for matching strength, which in turn permits S235JR to have a wide range of welding techniques such as Shielded Metal Arc Welding (SMAW), Submerged Arc Welding (SAW), Gas Metal Arc Welding (GMAW), and other welding techniques with electrodes covered by AWS A5.1 or A5.5 (low-hydrogen electrodes and other non-low hydrogen electrodes) as well as AWS A 5.7 or A5.23 and AWS A5.18 and other types of electrodes suitable for the corresponding welding technique.

On the other hand AWS D1.1-96 (AWS D1.1-96, 1996) classifies S235JR (ASTM A36, ASTM A570 Grade 36, ASTM A709 Grade 36) in Categories A and B in Table 3.2 prequalified minimum preheat and interpass temperature as follows:

TABLE 7

Prequalified Minimum Preheat and Interpass Temperature (AWS D1.1-96, 1996)

Welding process	Thickness of thickest part at point of welding	Minimum preheat and interpass temperature
	[mm]	[^{o}C]
Shielded metal arc welding with other than low-hydrogen electrodes	3-19 included	None
	Over 19 thru 38.1 incl.	66
	Over 38.1 thru 63.5 incl.	107
	Over 63.5	150
Shielded metal arc welding with low-hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	3-19 included	None
	Over 19 thru 38.1 incl.	10
	Over 38.1 thru 63.5 incl.	66
	Over 63.5	107

Formability of S235JR Steel

Hot formability of S235JR steel

Only products ordered and supplied in the normalized or normalized rolled condition shall comply with the above mechanical properties.

Cold formability of S235JR steel

According to EN 10025:1993, carbon steels with qualities suitable for cold forming shall be designated by the symbol C when ordering (BS EN 10025, 1993), as for S235JRC.

Flangeability of S235JR steel

If specified at the time of enquiry and order, plate, sheet, strip and wide flats made from S235JRC with nominal thickness $t \leq 20$ mm shall be suitable for flanging without cracking (BS EN 10025, 1993).

Roll forming of S235JR steel

Plate and strip made from S235JRC with nominal thickness $t \leq 8$ mm shall be suitable for the production of sections by cold rolling (BS EN 10025, 1993).

Drawing of bars of S235JR steel

If specified at the time of enquiry and order, bars made from S235JRC steel shall be suitable for cold drawing (BS EN 10025, 1993).

MATERIALS AND METHODS

Specimens of S235JR steel were prepared into a rectangular shape (40X50 mm) as to be tested by the electron emission method using an Optical Emission Spectrophotometer available at the Industrial Research Institute in Beirut. This method is used for metal chemical analysis in alloys while they are in the solid state. This gives the advantage of avoiding dissolution of metals. Alloys of iron base, copper base, nickel base, aluminum base, and lead base can be analyzed for over 15 elements of their components and in different concentrations. Table 8 contains a summery of the chemical analysis results as well as the corresponding Carbon Equivalent Values for each specimen according to its designation after collection. The calibration certificate number of the spectrophotometer is EAED-0011 dated June 1999. The collection of specimens was done from different sources offering S235JR or equivalent in the Lebanese steel market. The designation contains the thickness of the specimen as well as its collection classification code and type.

Two required standard mechanical tests were conducted on each specimen. For the purpose of comparison, more than one specimen was sometimes prepared from each collected sample of S235JR steel. Standard tension test (ASTM A 370-97a, 2000; ASTM E 8M-95, 1995) and standard bend test (ASTM E 290-92, 1995) were conducted at the laboratories of the Industrial Research Institute in Beirut. The calibration certificate number of the tensile test machine is 20010208 dated 07/02/2001. Results of the tensile and bend tests are documented in Table 9. Contraction values are presented as the difference in cross-sectional area for the purpose of comparing lateral deformation in the specimens.

RESULTS AND DISCUSSION

Chemical analysis

The chemical analysis results shown in Table 8 indicate acceptable results for all existing elements and Carbon Equivalent Values except those shown for copper. Comparison of the chemical analysis results of the major elements with the standard requirements in Tables 2, 3, and 4 is carried out as follows:

1. Carbon content: (C < 0.21 % S235JR EN 10025:93, C < 0.25 % ASTM A 570-98 Gr. 36 Type 1 & 2). The carbon content is one of the major factors affecting the mechanical properties of carbon steels. In the collected specimens, the carbon content ranged from 0.04-0.19 %. Lower carbon content may cause a drop in the yield and tensile strength. This effect will be shown later when discussing the mechanical properties results.

2. Manganese content: (Mn < 1.5 % S235JR EN 10025:93, Mn < 0.9 % for type 1, and Mn < 1.35 % for type 2 ASTM A 570-98 Gr. 36). In the collected specimens, the manganese content ranged from 0.25-0.54 %. Manganese is added to most plain carbon steels to combine with sulfur and produce soft manganese sulfides. This addition prevents the formation of iron sulfide, which coats grain boundaries and impart a brittleness to the metal.

3. Phosphorus and Sulfur contents: (P < 0.055 %, S < 0.055 % S235JR EN 10025:93, P < 0.035 %, S < 0.04 % ASTM A 570-98 Gr. 36 Type 1 & 2). In the collected specimens, phosphorus ranged from 0.011-0.025 %, while sulfur ranged from 0.003-0.024 %. Both elements are usually not desired in steel because of their negative effects. For this reason they are considered as impurities.

4. Silicon content: (not specified in S235JR EN 10025:93, Si < 0.4 % ASTM A 570-98 Gr. 36 Type 1 & 2). In the collected specimens, the silicon content ranged from 0.001-0.150 %. In small amounts, silicon increases the strength properties of steel with little companion loss of ductility.

5. Copper content: (0.25 % < Cu < 0.4 % S235JR EN 10025:93, Cu > 0.2 % ASTM A 570-98 Gr. 36 Type 1 & 2). In the collected specimens, the cupper content ranged from 0.01-0.08 %. Low carbon sheet steels and structural steels often contain a copper addition to enhance corrosion resistance, but surface quality and hot working behavior tend to be negatively effected somewhat.

6. Nickel and Chromium contents: (not specified in S235JR EN 10025:93, Ni < 0.23 %, Cr < 0.19 % ASTM A 570-98 Gr. 36 Type 1 & 2). In the collected specimens, the nickel content ranged from 0.018-0.052 % while chromium ranged from 0.01-0.023 %. Nickel and chromium are present in such small quantities to be considered as impurities.

TABLE 8
Chemical Analysis of S235JR Steel

Specimen No	Type	C [%] ± 0.01	Mn [%] ± 0.01	P [%] ± 0.001	S [%] ± 0.001	Si [%] ± 0.001	Cu [%] ± 0.001	Ni [%]± 0.001	Cr [%] ± 0.001	Co [%] ± 0.001	V [%] ± 0.001	Al [%] Al<0.001 ± 0.001	CEV [%]
T2	Plate	0.09	0.27	0.011	0.016	0.001	0.015	0.027	0.001	0.036	0.001	0.001	0.138
T3	Plate	0.06	0.31	0.011	0.008	0.001	0.031	0.036	0.001	0.039	0.001	0.001	0.117
D2	Plate	0.06	0.33	0.017	0.017	0.001	0.045	0.028	0.014	0.053	0.001	0.001	0.123
D3	Plate	0.04	0.30	0.013	0.007	0.001	0.031	0.033	0.001	0.044	0.001	0.001	0.095
D6	Plate	0.05	0.34	0.014	0.012	0.001	0.047	0.052	0.023	0.038	0.001	0.001	0.118
A2	Plate	0.10	0.31	0.025	0.019	0.001	0.039	0.027	0.003	0.046	0.001	0.001	0.157
A5	Angle	0.19	0.46	0.019	0.024	0.041	0.040	0.031	0.004	0.036	0.001	0.001	0.272
A6	Angle	0.18	0.46	0.021	0.018	0.048	0.045	0.030	0.003	0.036	0.001	0.001	0.262
A8	Angle	0.17	0.44	0.021	0.022	0.016	0.052	0.029	0.001	0.036	0.001	0.001	0.249
Z4	Plate	0.11	0.54	0.020	0.007	0.120	0.018	0.031	0.001	0.036	0.001	0.001	0.204
Z5	Plate	0.10	0.25	0.019	0.004	0.066	0.053	0.019	0.001	0.036	0.001	0.001	0.147
Z6	Plate	0.10	0.54	0.022	0.003	0.001	0.010	0.026	0.001	0.036	0.001	0.001	0.193
Z7	Angle	0.11	0.45	0.021	0.007	0.118	0.080	0.032	0.008	0.036	0.001	0.001	0.194
Z	Channel	0.12	0.45	0.020	0.021	0.026	0.017	0.018	0.001	0.036	0.001	0.001	0.198
S2	Plate	0.07	0.27	0.013	0.011	0.001	0.035	0.021	0.001	0.048	0.001	0.001	0.119
S3	Plate	0.04	0.29	0.012	0.008	0.001	0.029	0.031	0.001	0.040	0.001	0.001	0.093
S4	Plate	0.10	0.54	0.020	0.008	0.150	0.017	0.027	0.001	0.044	0.001	0.001	0.193

Mechanical properties

The mechanical properties results summarized in Table 9 showed a number of unacceptable results for many specimens where either the yield or tensile strengths and even in some cases both failed to meet with the requirements of EN or ASTM and sometimes both standards. All of those nonconforming results are concerned with sheets (plates). However, the elongation and bend test results came to meet the requirements of the EN standard. The Comparison of the mechanical test results with the standard requirements in Tables 5, and 6 is carried out as follows:

1. Yield Strength: (Re > 235 MPa S235JR EN 10025:93, Re > 250 MPa ASTM A 570-98 Gr. 36 Type 1 & 2). Specimens D2-III, D6-I, and D6-II showed as illustrated on Figure 1 unacceptable yield strength results when compared to the requirements of both the EN and ASTM standards, while specimen S4-II failed to meet the requirements of ASTM only. The yield strength of the collected specimens varied from 195 – 328 MPa and the average of the passing specimens is 284 MPa. As mentioned above the nonconforming results are concerned only with sheets.

2. Tensile Strength: (t < 3 mm: 360 MPa < Rm < 510 MPa, t ≥ 3 mm: 340 MPa < Rm < 470 MPa S235JR EN 10025:93, Rm > 365 MPa for type 1, 400 MPa < Rm < 550 MPa for type 2 ASTM A 570-98 Gr. 36). Specimens T2, D2-III, D6-I, and D6-II showed as illustrated on Figure 2 unacceptable yield strength results when compared to the requirements of both the EN and ASTM standards, while specimens T3, D3-IV, D3-V, S3-I, and S3-II failed as shown on Figure 3 to meet the requirements of ASTM only. The tensile strength of the collected specimens varied from 291 – 440 MPa and the average of the passing specimens is 395 MPa and 402 MPa according to EN and ASTM respectively. The nonconforming results are concerned only with sheets.

3. Comparison of tensile properties: In what is discussed above it is clear that when selecting carbon steels it is also important to assure the required tensile properties. Steels with quite different chemical composition can have almost identical mechanical property ratios when heat-treated properly (De Garmo *et al*., 1990). This means that different alloyed steels will create a straight-line representation of their mechanical properties. In other words, steels of the same chemical composition will have the same mechanical property ratio. Figure 4 shows the tensile strength versus the yield strength relation of S235JR collected specimens. It can be clearly seen that the tensile-yield strength ratio of the specimens meeting the requirements of the standards are concentrated in the location of accepted range while those not meeting standard requirements are out of range and are dispersed around.

Comparison is made in Figure 5 and Figure 6 where the tensile strength versus the elongation results and the tensile strength versus the contraction (reduction in cross sectional area) results are plotted respectively to support the discussion above. Again the specimens failing to meet with the standard requirements were clearly observed to be out of range.

This leads to the conclusion that, the reason for the specimens to get out of the tensile range, even if their chemical composition is within the required range, may be referred to the improper heat treatment in this case the hot rolling of the steel sheets. Note that the failing specimens are all of the sheet (plate) type where hot rolling is performed. Angles and other type are not hot rolled as sheets.

TABLE 9
Mechanical Properties of S235JR steel

Specimen No	Type	Dimensions in parallel length				Yield strength	Tensile strength	Elongation	Contraction	Bending
		Initial width Wo [mm]	Final width Wf [mm]	Initial thickness t_o [mm]	Final thickness t_f [mm]	at 0.2 % offset [MPa] ± 0.6 %	[MPa] ± 0.6 %	5.65 √Section [%]	[%]	Results at 180°
T2	Plate	29.10	21.95	1.70	1.21	274	291	35.0	-46.3	No cracks
T3	Plate	29.10	21.65	3.00	2.05	266	363	48.0	-49.2	No cracks
D2-III	Plate	29.08	22.85	1.65	1.26	220	321	53.5	-40.0	No cracks
D2-IV	Plate	41.00	32.60	2.00	1.55	300	373	36.0	-38.4	No cracks
D2-V	Plate	41.00	32.25	2.00	1.60	309	430	40.0	-37.1	No cracks
D3-III	Plate	29.03	21.00	2.93	2.05	267	373	44.2	-49.4	No cracks
D3-IV	Plate	41.00	30.60	3.00	2.05	328	347	40.0	-49.0	No cracks
D3-V	Plate	41.00	32.60	3.00	2.25	265	360	41.6	-40.4	No cracks
D6-I	Plate	30.00	21.12	6.00	3.30	195	321	36.0	-61.3	No cracks
D6-II	Plate	30.00	21.55	6.00	3.85	229	324	36.0	-53.9	No cracks
A2-IV	Plate	50.00	40.90	2.00	1.50	322	437	41.8	-38.7	No cracks
A2-V	Plate	50.00	40.35	2.00	1.40	328	439	41.8	-43.5	No cracks
A5-I	Angle	31.00	22.84	5.00	3.55	254	425	34.2	-47.7	No cracks
A5-II	Angle	30.00	23.35	5.00	2.98	298	440	34.2	-53.6	No cracks
A6-I	Angle	30.00	22.45	6.00	3.10	285	426	37.1	-61.3	No cracks
A6-II	Angle	30.00	23.53	6.00	3.56	276	428	34.2	-53.5	No cracks

Continued

Specimen No	Type	Dimensions in parallel length				Yield strength	Tensile strength	Elongation	Contraction	Bending
		Initial width Wo [mm]	Final width Wf [mm]	Initial thickness t_o [mm]	Final thickness t_f [mm]	at 0.2 % offset [MPa] ± 0.6 %	[MPa] ± 0.6 %	5.65 √Section [%]	[%]	Results at 180°
A8-I	Angle	30.00	21.45	8.00	5.04	271	407	36.6	-55.0	No cracks
A8-II	Angle	30.00	20.80	8.00	4.25	283	405	35.5	-63.2	No cracks
Z4-IV	Plate	40.00	29.95	4.00	2.75	250	387	38.5	-48.5	No cracks
Z4-V	Plate	40.00	29.65	4.00	2.75	254	384	40.0	-49.0	No cracks
Z5	Plate	30.00	20.78	5.00	2.08	308	398	35.7	-71.2	No cracks
Z6-I	Plate	30.00	20.25	6.00	2.55	283	387	33.3	-71.3	No cracks
Z6-II	Plate	30.00	20.11	6.00	2.66	274	384	36.0	-70.3	No cracks
Z7-I	Angle	30.00	21.48	7.00	3.80	300	407	33.7	-61.1	No cracks
Z7-II	Angle	30.00	22.15	7.00	4.30	304	408	33.7	-54.6	No cracks
Z	Channel	30.00	22.40	4.00	2.88	278	391	27.0	-46.2	No cracks
S2-I	Plate	30.00	21.95	2.00	1.40	306	381	45.0	-48.8	No cracks
S2-II	Plate	30.00	23.40	2.00	1.51	330	391	45.0	-41.1	No cracks
S3-I	Plate	30.00	22.55	3.00	1.65	265	363	46.0	-58.7	No cracks
S3-II	Plate	30.00	22.25	3.00	1.90	259	358	46.0	-53.0	No cracks
S4-I	Plate	30.00	20.85	4.00	2.38	259	390	35.0	-58.6	No cracks
S4-II	Plate	30.00	20.99	4.00	2.23	244	385	36.6	-61.0	No cracks

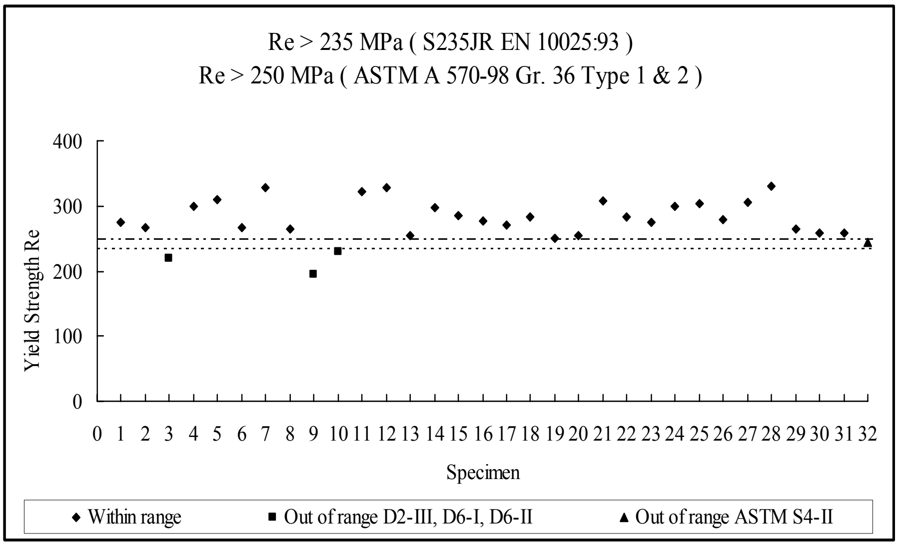

Figure 1. Yield Strength Re [MPa] of S235JR steel specimens compared to EN 10025:93 and ASTM A 570-98 Gr. 36.

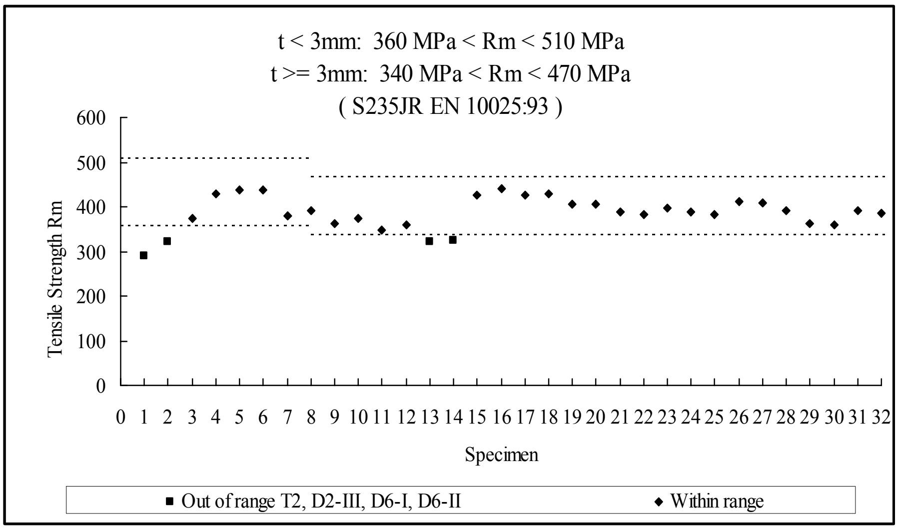

Figure 2. Tensile Strength Rm [MPa] of S235JR steel specimens compared to EN 10025:93.

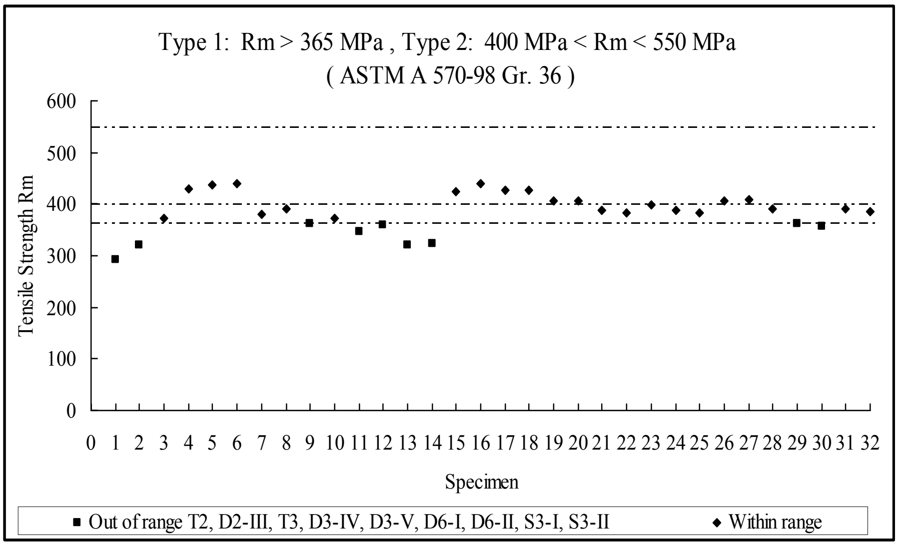

Figure 3. Tensile Strength Rm [MPa] of S235JR steel specimens compared to ASTM A 570-98 Gr. 36.

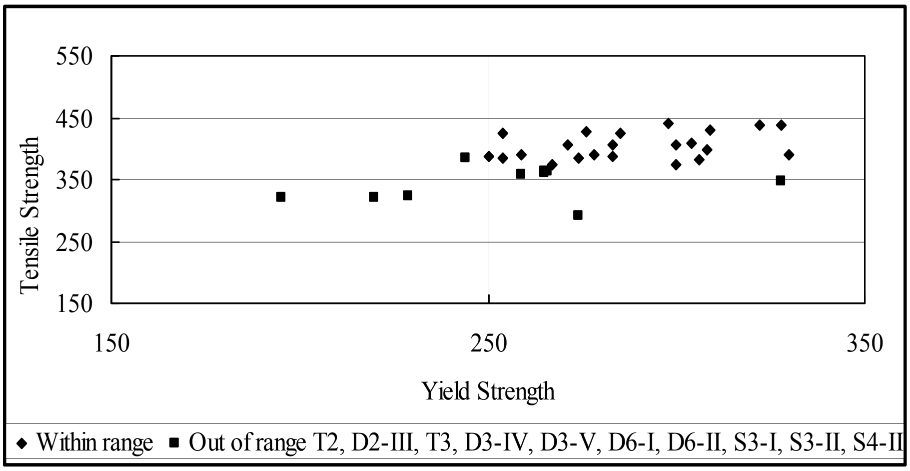

Figure 4. Tensile Strength [MPa] versus Yield Strength [MPa] of S235JR steel specimens.

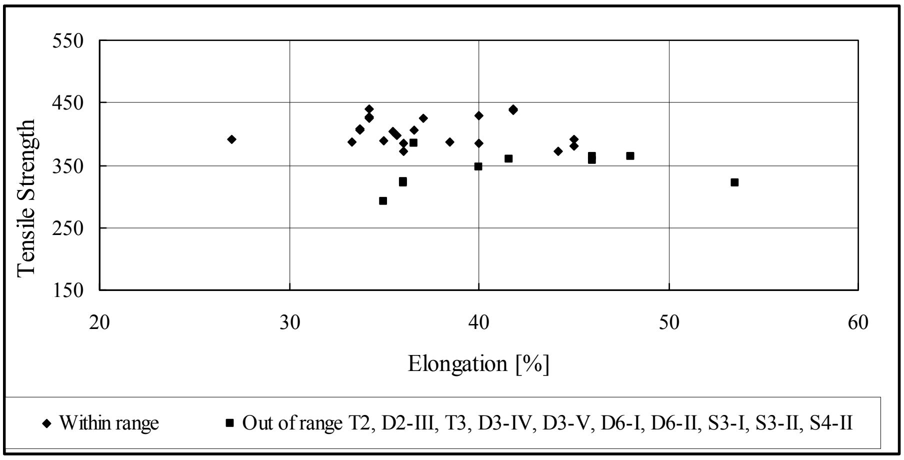

Figure 5. Tensile Strength [MPa] versus Elongation [%] of S235JR steel specimens.

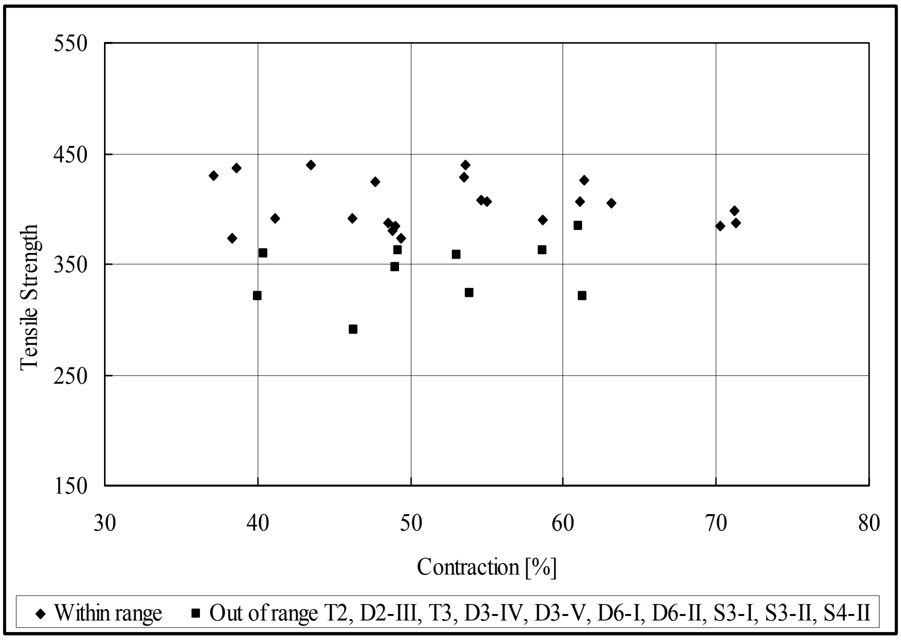

Figure 6. Tensile Strength [MPa] versus Contraction [%] of S235JR steel specimens.

4. Comparison of the elongation: Ranging from a minimum of 27 % to a maximum of 53 %, all the elongation results of the specimens are acceptable as for the EN and ASTM standards as seen in Table 9. But there exists some elongation results, such as in specimen D2-III (53 %) being 3 times the minimum elongation required by the standards, which may cause some problems being so ductile. This may confirm the fact that this particular specimen has both low and unacceptable yield and tensile strength respectively (220, 321 MPa).

5. Comparison of the contraction: The contraction results (reduction in cross sectional area) Table 9, fluctuating between 37 % and 71 %, show approximately a double difference in lateral deformation which in turn may reflect the fact that improper heat treatment has been conducted.

Comparison of two or more specimens made from same sample

D2-III, D2-IV and D2-V are specimens made from the same sheet. The tensile results show a significant difference in their yield strength Re (220, 300 and 309 MPa respectively) tensile strength Rm (321, 373 and 430 MPa respectively) giving a tensile / yield strength ratio of (1.46, 1.24, 1.39 respectively) and elongation (53%, 36 % and 40 % respectively). This difference in yield and tensile strength accompanied by the difference in the elongation could cause serious problems to the steel structure design supporting stresses as well as being a clear indicator of the improper heat treatment of the steel sheets.

Specimens D3-III, D3-IV and D3-V gave also different results like in their yield strength Re (267, 328 and 265 MPa respectively) if we take in consideration that they are made from the same samples and mainly that there exist a little difference in their tensile strength Rm (373, 347 and 360 MPa respectively) and in the elongation (44%, 40 % and 42 % respectively). This significant difference in the yield strength may cause huge problems in the design calculations of steel structures. One main reason for this difference could be the absence of the homogeneity in this steel plate that in turn is referred to the improper heat treatment.

CONCLUSIONS

The following conclusions were obtained:

1) The Lebanese steel market contains large and sufficient quantities of S235JR steel imported from different countries, but they are not properly identified and designated.

2) The chemical composition of the available S235JR steel in Lebanon fits in general with the requirements of European EN and American standards ASTM, while the tensile mechanical properties are in some cases unacceptable below the required limits of the above-mentioned standards. Even the satisfying samples gave dispersed results. This is referred to the improper heat treatment (normalizing and rolling) of the fabricated steel.

3) The difference in the tensile properties of S235JR samples may cause severe damages and failures. In this case the steel structure designer when choosing S235JR steel for a certain

structure is forced to consider a higher safety factor resulting in larger cross-sections which in turn results in great economic losses. The ignorance of such differences may result in deflection or even failure of the structure causing material and life losses.

4) The absence of implementing Lebanese standards for structural steels resulted in a big mess in the steel market. The dealer on one hand has no clear standard to show the order and purchase procedures forcing him to rely on the mill certificates sent by the manufacturer. Dealers are using these mill certificates for any heat number and not the corresponding one.

5) After implementing Lebanese standards adopted by LIBNOR for the purpose of ordering and purchase, a third party governmental professional and capable authority in this case the Industrial Research Institute IRI or another nongovernmental authority authorized by the IRI has to perform the required delivery and acceptance procedures required by the standard or related standards.

6) As for the time being and until Lebanese standards concerning carbon hot rolled steels will be available it is strongly recommended to use EN standards (since the major import sources are European) and to apply severe sampling and testing procedures before or after the delivery of steel to the consumer.

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