Al-Farouk journal of sciences
Volume (2), Issue (4) (Spt, 2026)
ISSN: 3135-2359

مجلة الفاروق للعلوم
المجلد (2) العدد 4 سبتمبر 2026
ردمد: 3135-2359

Comparative Evaluation of the Mechanical Properties and Chemical Composition of Reinforcing Steel Bars Produced by Libyan Mills

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Received: 03/8/2026 Revised: 17/8/2026 Accepted: 05/9/2026 Publication: 05/11/2026

Abstract. The quality of reinforcing steel largely determines the safety and durability of reinforced-concrete structures, yet the increasing number of private rolling mills in Libya has raised questions about consistency with accepted specifications. This study evaluates and compares 12 mm reinforcing bars from two Libyan producers, Sidi Al-Sayeh (SS) and Misurata Iron and Steel (MR). Hardness, tensile behaviour (three specimens per mill), dye-penetrant inspection, radiography and handheld X-ray fluorescence (XRF) analysis were carried out. Hardness was 114 HB (SS) and 124 HB (MR). Mean yield strength was 389 ± 4 MPa (SS) and 338 ± 29 MPa (MR), and mean tensile strength was 565 ± 8 MPa and 495 ± 40 MPa, respectively; both fall inside the indicative ranges for normal-strength bars (250–400 MPa and 400–600 MPa). Elongation, however, was only 7.4 % (SS) and 5.4 % (MR), well below the 12 % minimum, and the SS hardness lies slightly below the 120 HB lower bound. Dye penetrant revealed small surface indications in both bars (more pronounced in SS), while radiography showed no internal flaws. The XRF analyses indicated 98.02 % (SS) and 98.77 % (MR) iron with minor differences in Mn, Cr and Co; carbon and sulphur could not be quantified. Both products therefore satisfy the strength criteria but show limited ductility. Larger sampling, full chemical analysis by optical emission spectrometry and testing of unmodified bar diameters are recommended.

Keywords: *reinforcing steel; rebar; tensile strength; hardness; ductility; XRF; Libya; quality assessment*

1. Introduction

Iron and its alloys are the most widely used metals in engineering, and reinforcing steel bars (rebar) are among their most important applications in construction. Embedded in concrete, rebar compensates for the low tensile capacity of the concrete and helps structural members resist tension, bending, torsion and shear [2]. Any deficiency in the bars can therefore compromise the safety of the whole structure.

Competition in the Libyan market between public and private producers has led to the establishment of several new private rebar mills. Differences in product quality and conformity with standard specifications have consequently become a concern for researchers because of their economic implications for producers and consumers alike [1]. Tensile and yield strength, elongation, hardness and the proportions of certain alloying elements all play an important role in determining the efficiency of reinforcing steel. Material testing supplies the technical data needed to judge whether a product is suitable for a project and complies with the project specifications and the design code [1], [3].

The objective of this paper is to characterise and compare 12 mm reinforcing bars from two Libyan mills, Sidi Al-Sayeh (SS) and Misurata Iron and Steel (MR), through mechanical testing

(hardness and tension), non-destructive examination (dye penetrant and radiography) and chemical analysis, and to assess the results against indicative requirements for normal-strength reinforcing steel. The remainder of the paper describes the materials and methods (Section 2), presents the results (Section 3), discusses compliance, between-mill differences and limitations (Section 4), and closes with conclusions and recommendations (Section 5).

2. Materials and Methods

2.1 Materials and specimen preparation

Reinforcing bars of nominal diameter 12 mm were collected from the two producers (Fig. 1). The laboratory testing machine could not accommodate 12 mm bars; the bars were therefore filed down to a diameter of 10 mm and a length of 50 mm for the tensile tests. Three tensile specimens were tested per mill. Specimens are designated SS-1 to SS-3 and MR-1 to MR-3.



Fig. 1. Bar samples after dye-penetrant treatment: sample 1 is from Sidi Al-Sayeh (SS) and sample 2 is from Misurata (MR).

2.2 Hardness

Hardness was measured with a Proceq Equotip portable hardness tester. Each reading was repeated three times on the specimen surface, and the result is expressed on the Brinell scale (HB). Indicative hardness ranges for reinforcing steel are 120–180 HB for normal-strength bars and 180–250 HB for high-strength bars (Table 1).

2.3 Tensile test

Tensile tests were performed in a universal testing machine (UTM) equipped with gripping jaws, a load cell, a displacement/extension measuring system and a data-acquisition unit. Each specimen was clamped at both ends and loaded gradually while force and stroke were recorded continuously; the yield point and the peak (maximum) force were then identified from the force–stroke curve. Engineering stress was obtained from

$$R_i = F_i / A_0, \quad A_0 = \pi d^2 / 4 = 78.5 \text{ mm}^2 \tag{1}$$

where F_i is the yield force (giving the yield strength R_e) or the peak force (giving the tensile strength R_m) and d = 10 mm is the specimen diameter. Elongation values are those recorded in the original test report. Specimen-level results are given as mean ± sample standard deviation (n = 3), and the between-mill difference was examined with Welch's two-sample t-test.

2.4 Dye-penetrant inspection and radiography

Dye-penetrant testing exploits the ability of a low-viscosity liquid to enter fine surface-breaking cracks and pores. The specimen surface was cleaned to remove dirt, oil, grease and rust; the coloured penetrant was applied evenly and left to dwell; the excess was removed with a suitable cleaner; and a developer was applied to draw the penetrant out of any discontinuities and render them visible against the metal. The test was applied to the cut cross-sections of both

specimens. In addition, an X-ray radiograph of the two specimens was taken to check for internal inclusions, voids or distortion.

2.5 Chemical analysis

The chemical composition was determined with a handheld XRF analyser (Oxford Instruments/Hitachi X-MET 7000). The specimen surfaces were cleaned and smoothed before measurement. The analyser automatically matched both spectra to a library alloy (SA 210 Gr C) and displayed the library's composition limits; these limits belong to that alloy and are not requirements for reinforcing steel. Handheld XRF does not quantify carbon or sulphur, so a complete reinforcing-steel analysis (including carbon equivalent) was not obtained.

2.6 Reference requirements

Measured values were compared with the indicative requirements for normal- and high-strength reinforcing steel summarised in Table 1. These values were compiled in the source project from engineering practice and international standards and are described there as approximate; the official Libyan standard text was not available for this study.

Table 1. Indicative requirements for reinforcing steel used in Libya (compiled from the source project).

Property	Unit	Normal strength	High strength
Tensile strength, Rm	MPa	400–600	500–700
Yield strength, Re	MPa	250–400	400–500
Elongation	%	≥ 12	≥ 14
Hardness	HB	120–180	180–250
Iron, Fe	%	98.0	99.0
Manganese, Mn	%	0.05	0.15
Cobalt, Co	%	0.01	0.5
Chromium, Cr	%	0.10	0.30

Note: the source lists the Mn, Co and Cr values without stating whether they are minimum or maximum limits; they are therefore treated as indicative levels only.

3. Results

3.1 Tensile properties

The force–stroke curves (Fig. 2) show a clear yield point followed by strain hardening to a peak force and then necking. The SS specimens give almost coincident curves, with yield forces of 30.2–30.9 kN and peak forces of 44.0–45.1 kN. The MR specimens are noticeably more scattered, with yield forces of 24.1–28.7 kN and peak forces of 35.6–41.9 kN. Converted to stress with Eq. (1), the specimen-level results are listed in Table 2.

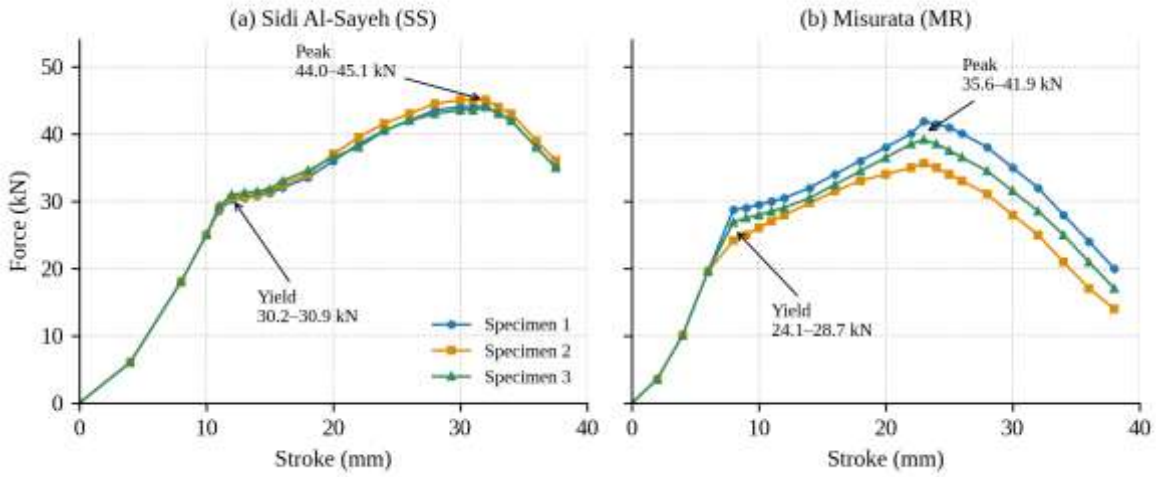


Fig. 2. Force–stroke curves of the three tensile specimens from (a) Sidi Al-Sayeh and (b) Misurata. Curves were re-plotted from the recorded force readings in the original test report.

Table 2. Specimen-level tensile results (d = 10 mm, A0 = 78.5 mm²).

Mill / specimen	Yield force (kN)	Re (MPa)	Peak force (kN)	Rm (MPa)	Rm / Re
SS-1	30.24	385.0	44.07	561.1	1.46
SS-2	30.53	388.7	45.09	574.1	1.48
SS-3	30.93	393.8	43.98	560.0	1.42
SS mean ± SD	30.57 ± 0.35	**389.2 ± 4.4**	44.38 ± 0.61	**565.1 ± 7.8**	1.45
MR-1	28.71	365.5	41.86	533.0	1.46
MR-2	24.13	307.2	35.63	453.7	1.48
MR-3	26.87	342.1	39.13	498.2	1.46
MR mean ± SD	26.57 ± 2.30	**338.3 ± 29.3**	38.87 ± 3.12	**495.0 ± 39.8**	1.46

Re: yield strength; Rm: tensile strength (maximum force divided by A0). SD: sample standard deviation (n = 3).

SS bars showed higher mean yield (389 vs 338 MPa, +15 %) and tensile strength (565 vs 495 MPa, +14 %) than MR bars, together with a much smaller scatter (coefficients of variation of 1.1–1.4 % against 8.0–8.7 %). With only three specimens per mill, however, the differences are suggestive rather than conclusive (Welch's t-test: $p = 0.09$ for Re and $p = 0.09$ for Rm). The ratio Rm/Re is virtually identical for both mills (about 1.45). All mean strengths fall inside the indicative normal-strength ranges (Fig. 3), the SS yield strength lying close to the upper end of its range.

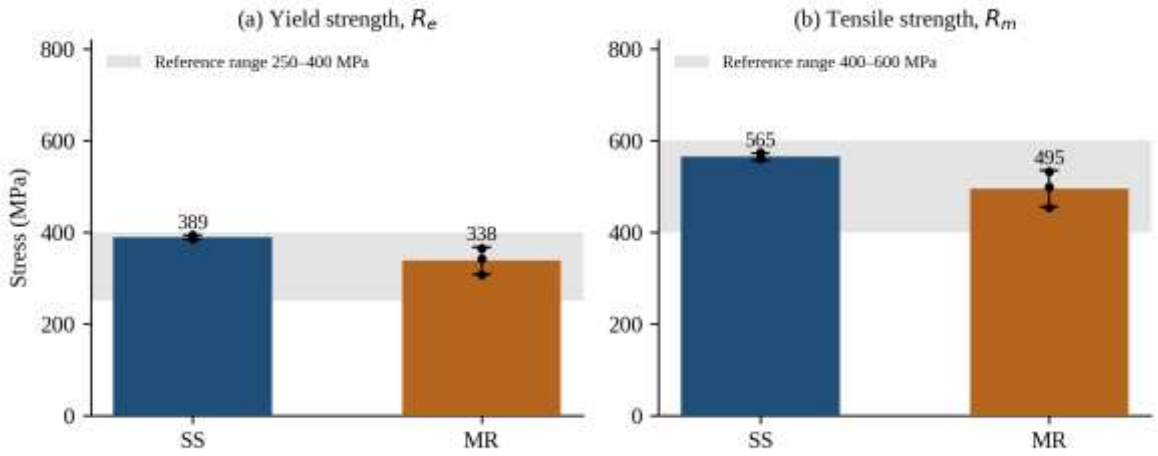


Fig. 3. Mean (a) yield strength and (b) tensile strength of the two mills. Error bars show ±1 SD; dots are individual specimens; the grey band is the indicative normal-strength range.

3.2 Hardness and elongation

The portable hardness tester gave 114 HB for SS and 124 HB for MR. The MR value lies just inside the 120–180 HB range for normal-strength bars, whereas the SS value is slightly below its lower bound (Fig. 4a). The recorded elongation was 7.4 % for SS and 5.4 % for MR, both well below the 12 % minimum for normal-strength bars (Fig. 4b).

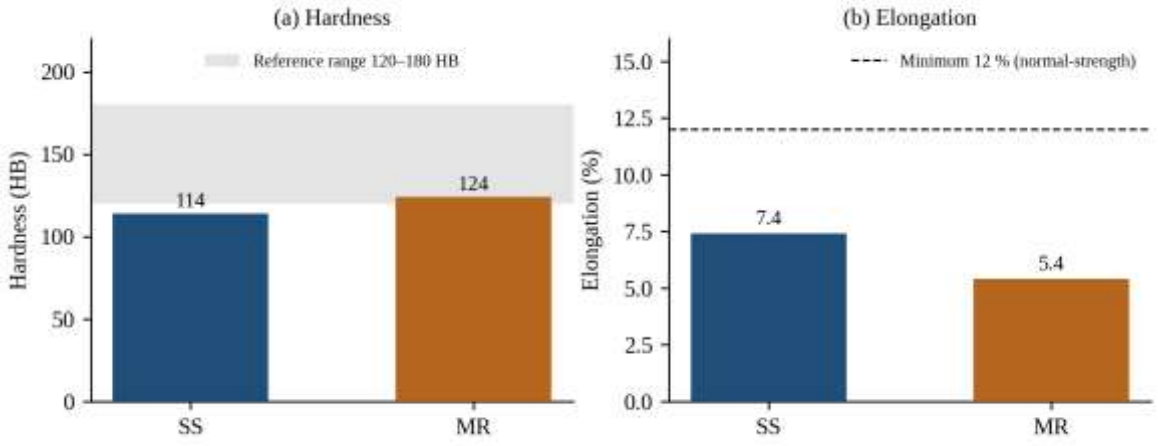


Fig. 4. (a) Hardness and (b) elongation of the two mills compared with the indicative requirements.

3.3 Surface and internal soundness

Dye-penetrant inspection revealed small surface indications along the periphery of the cross-sections of both bars (Fig. 5). The indications were more pronounced in SS than in MR. The radiograph (Fig. 6) showed no internal inclusions, voids or distortion in either specimen.



Fig. 5. Dye-penetrant inspection of the cross-sections: (a) Sidi Al-Sayeh (SS) and (b) Misurata (MR). Retained penetrant appears pink.

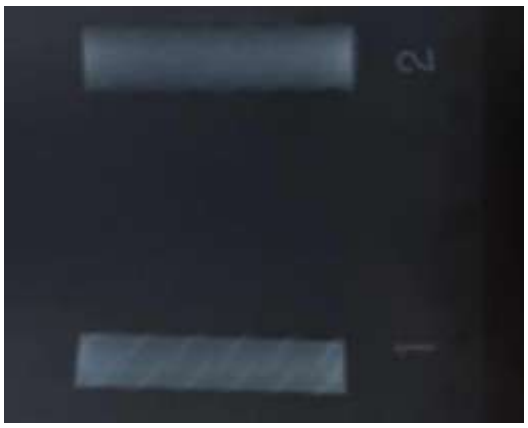


Fig. 6. Radiograph of specimen 1 (SS) and specimen 2 (MR) (image rotated 90°); no internal defects are visible.

3.4 Chemical composition

Table 3 lists the elements detected by XRF. Iron content was 98.02 % in SS and 98.77 % in MR. Manganese was higher in MR (0.52 % vs 0.40 %), whereas chromium was higher in SS (0.34 % vs 0.13 %). Cobalt was 0.67 % in SS and 0.52 % in MR. Titanium, copper and phosphorus (0.21 %, 0.17 % and 0.15 %) were reported only for SS, while MR showed 0.06 % antimony and no phosphorus (Fig. 7).

Table 3. Chemical composition of the two bars by handheld XRF (wt %, ± instrument-reported uncertainty).

Element	SS (wt %)	± (SS)	MR (wt %)	± (MR)
Iron (Fe)	98.02	0.294	98.77	0.269
Manganese (Mn)	0.40	0.035	0.52	0.036
Cobalt (Co)	0.67	0.063	0.52	0.057
Chromium (Cr)	0.34	0.018	0.13	0.013
Titanium (Ti)	0.21	0.024	n.d.	–
Copper (Cu)	0.17	0.025	n.d.	–
Phosphorus (P)	0.15	0.044	0.00	0.000
Palladium (Pd)	0.06	0.017	n.d.	–
Antimony (Sb)	n.d.	–	0.06	0.019

n.d.: not detected/not reported. Elements displayed as 0.00 wt % are omitted except P. Carbon and sulphur are not quantified by this technique. Pd and Sb are not expected constituents of reinforcing steel and, like the relatively high Co, may reflect spectral overlap in the handheld analyser.

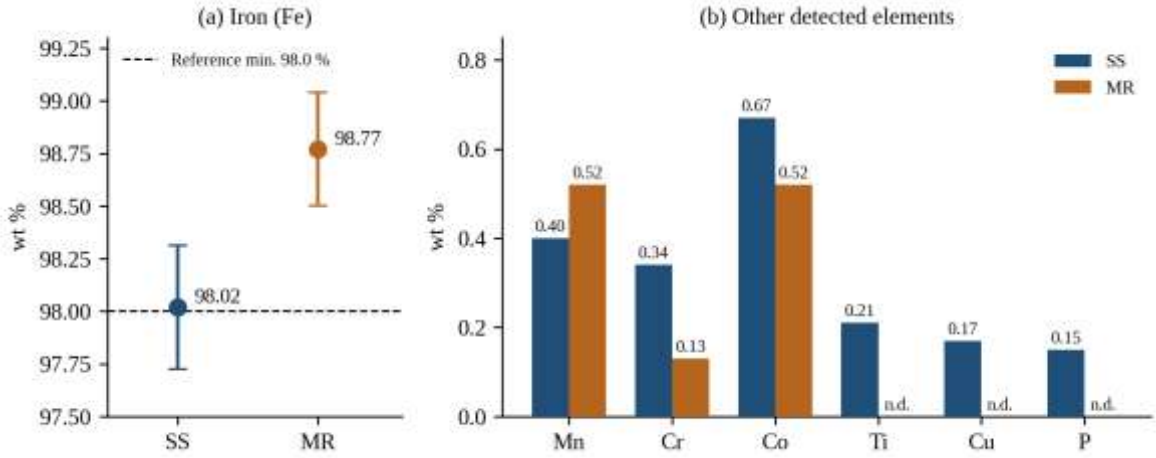


Fig. 7. Chemical composition by XRF: (a) iron content with instrument uncertainty and the 98.0 % indicative minimum; (b) other detected elements (n.d.: not detected).

4. Discussion

4.1 Conformity with the indicative requirements

Both mills produced bars whose mean yield and tensile strengths lie within the normal-strength ranges of Table 1 (Fig. 3). The bars do not, however, reach the high-strength class: the yield strength of SS (389 MPa) is below the 400 MPa lower bound for that class. Hardness is consistent with this picture, with MR at 124 HB near the bottom of the normal-strength range and SS at 114 HB marginally below it. The XRF iron contents of 98.02 % (SS) and 98.77 % (MR) satisfy the 98.0 % indicative minimum, although the SS value is within the instrument uncertainty (±0.29 %) of that limit. Because the Mn, Co and Cr entries in Table 1 are not defined as minima or maxima, and because carbon and sulphur were not measured, conformity of the chemical composition cannot be confirmed from these data.

4.2 Ductility

The most significant finding is the low elongation of both products (7.4 % and 5.4 %, against a 12 % minimum). Low elongation means reduced ductility: the bar has less capacity to deform before rupture, is more prone to sudden failure with little warning, and is less suitable where dynamic or seismic actions are expected. The elongation values should nevertheless be treated as indicative. They are those recorded in the test report, the way they were derived from the stroke-based records is not documented, and the specimens were machined from 12 mm to 10 mm bars, which removes the outer layer and ribs and can change the measured response. Separately, the SS analysis reports 0.15 % phosphorus; if confirmed by a more reliable technique, an elevated phosphorus level would be consistent with reduced ductility, but handheld XRF is not well suited to light elements and the value requires verification.

4.3 Comparison between the two mills

SS bars were stronger and markedly more uniform in tension than MR bars, with similar Rm/Re ratios, whereas MR bars were somewhat harder (124 vs 114 HB), showed fewer surface indications, and had a higher manganese content. That the harder bar has the lower strength is not necessarily contradictory: the hardness reading was taken on the as-received surface of a 12 mm bar, while the tensile specimens were machined, so the two tests sample different parts of the cross-section. Bar-to-bar variation in the MR tensile results (Re from 307 to 366 MPa) points to less consistent production, which is relevant for quality control even though the mean values remain within range.

4.4 Limitations

- Only three tensile specimens per mill, from a single sampling, were tested; mill-to-mill differences cannot be generalised, and the Welch tests are not significant at the 5 % level.
- Tensile specimens were reduced from 12 mm to 10 mm, which departs from standard testing of as-rolled bars.
- Hardness was measured with a portable rebound-type tester and reported in HB; no individual readings or conversion details are available, and only one value per mill is reported.
- Handheld XRF cannot quantify carbon and sulphur, and several reported elements (Co, Pd, Sb) are unusual for reinforcing steel; optical emission spectrometry is needed for a reliable analysis.
- The reference ranges are indicative values rather than the official Libyan standard, and dye penetrant and radiography were used qualitatively.

5. Conclusions and Recommendations

The following conclusions are drawn from the tests on 12 mm reinforcing bars from the Sidi Al-Sayeh and Misurata mills:

1. Mean yield and tensile strengths were 389 ± 4 MPa and 565 ± 8 MPa for SS and 338 ± 29 MPa and 495 ± 40 MPa for MR, all within the indicative normal-strength ranges. SS bars were stronger and more consistent, although with n = 3 the difference is not statistically conclusive.
2. Elongation (7.4 % for SS and 5.4 % for MR) is well below the 12 % minimum, indicating limited ductility in both products.

3. Hardness was 114 HB (SS, slightly below the 120 HB lower bound) and 124 HB (MR, just within range).
4. Small surface indications were found in both bars, more pronounced in SS, while radiography showed no internal defects.
5. XRF showed 98.02 % (SS) and 98.77 % (MR) iron with small differences in Mn, Cr and Co; a complete chemical analysis including carbon and sulphur is still required.

Recommendations. Mills should concentrate on improving ductility and strength consistency, reduce surface defects and run regular, comprehensive chemical analyses. Producers and engineers should rely on accredited laboratories, and site engineers should inspect and test bars on delivery rather than select on price alone. Future work should test more samples from more mills, additional diameters (for example 14 and 16 mm) and high-strength grades on unmodified bars, use optical emission spectrometry, and study the influence of Libyan environmental conditions. Upgrading testing laboratories in Libya would further improve the reliability of such evaluations.

References

[1] A. Al-Zayani, M. Shamata and S. Al-Mnefi, “A study and comparison of the mechanical properties of reinforcing steel types in Libyan factories” (in Arabic), Bani Walid University Journal, 2023, p. 297.

[2] A. M. M. Mahdi and M. Amin, “Properties of Engineering Materials” (in Arabic), 2020.

[3] F. Mishkaf, “Reinforcing steel tests” (in Arabic), Arageek Encyclopedia, 2021.

[4] A. S. K. Kanz, “A study and comparison of the properties of reinforcing steel in Libyan mills” (in Arabic), B.Sc. graduation project, Department of Civil Engineering, Faculty of Engineering, University of Zawia, Autumn 2024 (supervisor: A. Al-Hashmi).