Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2023, 10(11):100-107

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Comparative Evaluation of the Adhesion Properties of Steel Bars for Reinforced Concrete used in Constructions in Senegal

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Abstract The aim of this paper is to study the geometrical characteristics of steel bar ribs used in constructions in Senegal. The study concerns four (04) types of steel used in the construction sector. Type 1 (E1), 2 (E2) and 3 (E3) steels are produced by locally based companies and type 4 (E4) steels, control bars, are imported from France. For the study, the height, spacing and inclination of the ribs were measured. To specify the spacing of the ribs and their inclinations, for each type of bar studied, the two-dimensional impression technique combined with the Autocad software was used. A digital caliper was used to determine the rib heights. The results showed that 66% of locally manufactured steels do not have latch heights that meet the requirements of the standard. The minimum values of 0.24 mm, 0.30 mm and 0.36 mm respectively for steels with nominal diameters of 8 mm, 10 mm and 12 mm are not met. The results also indicate that the latch heights, spacings and inclinations of steels imported from France (E4) and locally manufactured steels of type E3 comply with the standard. Therefore, locally produced steels are not necessarily suitable for use in reinforced concrete structures.

Keywords Local manufacturing, Eurocode, steel-concrete connection, ribs, interface

1. Introduction

The quality of the materials used to build the structures is of crucial importance to ensure the stability and safety of the structures [1]. In Senegal, as in several countries, steel bars are key elements in the construction of reinforced concrete structures. However, it is essential to ensure that these steel bars meet quality and compliance standards to ensure the stability of buildings.

When a reinforced concrete part is stressed. the concrete very quickly reaches its tensile limit in the tense areas. the reinforcement takes over [2-3]. The interface between the two materials (concrete and steel) must ensure that the forces are transmitted without slipping the reinforcement in the concrete sheath. Indeed. the transfer of forces from concrete to steel is a combination of adhesion. mechanical interaction and friction effects as shown in Figures 1.a. 1.b and 1.c respectively [4].

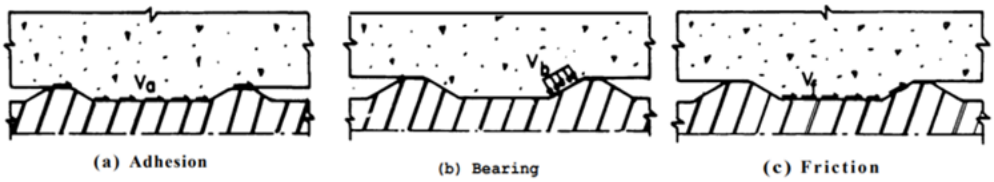


Figure 1: Effort Transfer Mechanisms - ACI 408.2R-92 [4].

Thus, good adhesion between steel and concrete is required for reinforced concrete structural elements.

The geometrical characteristics of the ribs, the high-adhesion bars, play an essential role in a good adhesion between the steel and the concrete. Steels compatible with the use of Eurocodes, for the design of reinforced concrete structural elements, must have specific geometrical characteristics [5]. Article 7.4 of standard NF EN 10080 states that the requirements relating to the adhesion characteristics of reinforced concrete steels with ribs and cavities must be based on the geometry of the surface. However, beam test and pull-out test can be used to determine the adhesion characteristics of steels for reinforced concrete.

In Senegal, the standards applicable in France are used for the realization of constructions. Currently, companies producing steel for reinforced concrete are located locally. However, there is not yet an independent body responsible for certifying building materials before use.

Thus, at the time of the work, the construction actors have no guarantee on the conformity of the characteristics of the materials with the calculation hypotheses during the design. The final report of a technical commission of May 2021 [6], following building collapses in Senegal, under the direction of the Ministry of Urban Planning, Housing and Public Hygiene, indicates that the poor quality of materials is one of the causes of building collapse in Senegal. Indeed, for the safety and durability of reinforced concrete structures, it is essential to use quality materials. The geometrical characteristics of the bars, including the height, spacing and inclination of the ribs, are essential parameters for characterizing the adhesion between steel and concrete.

Research has been carried out on the configuration of the ribs at the bars for better adhesion between the steel and the concrete. After their work on 17 configurations of steel bar ribs, Clark et al. [7-8] proposed, for steels with a diameter less than or equal to 13 mm, an average spacing between dimensions equal to 70% of the diameter and a height equal to 4% of the diameter. For bars with a diameter of 16 mm, the heights should be between 4.5% and 5% of the diameter.

In discussing the influence of the angle of the ribs, Lutz and Gergeley [9] observed that angles between 40° and 105° are adequate to prevent any relative movement between the interface of the steel bar and the concrete.

As part of the research work carried out by Hamad [10], different geometrical configurations of the ribs have been analyzed. This included the variation in the spacing between the ribs, which was between 35% and 60% of the diameter, the height of the ribs, ranging from 5% to 12.5% of the diameter, as well as the slope of the rib face with values varying from 30° to 90°. Analysis of the results of this study revealed that the configuration that showed the best performance was the one characterized by a viewing angle of 60° to the coast, a spacing of 50% and a rib height of 10% of the bar diameter.

Makni and Daoud [11] used the impression technique in their research to determine the thickness and inclination of steel bar ribs from Tunisia, France and Brazil. The results obtained are comparable to those obtained with a more sophisticated three-dimensional laser scanner technique.

Following building collapses in Nigeria, researchers have concluded that one of the main causes is that the properties of some steel bars used in construction do not comply with standards [12-19].

This research shows the importance of having standard-compliant steels during construction work. In Senegal, at the time of the construction of reinforced concrete structures, construction actors have no information on the conformity of the adhesion characteristics of steels. These parameters are essential for the operation of reinforced concrete structural elements. To date, no scientific study has evaluated the conformity of the geometrical characteristics of the ribs, for good adhesion with concrete, of the reinforcement used in the construction sector in Senegal with Eurocode 2.

The aim of our work is to evaluate the geometrical characteristics (height, spacing and angle of inclination of the ribs), relating to the adhesion, of steel bars for reinforced concrete used for constructions in Senegal and to verify their compliance with the requirements of the NF EN 10080 standard.

The geometrical characteristics of the bars studied concern the height, spacing and angle of inclination of the ribs and the possible height of the ribs. Figure 2 shows a steel bar with ribs with their height (h), angle of inclination (β) and spacing (c).

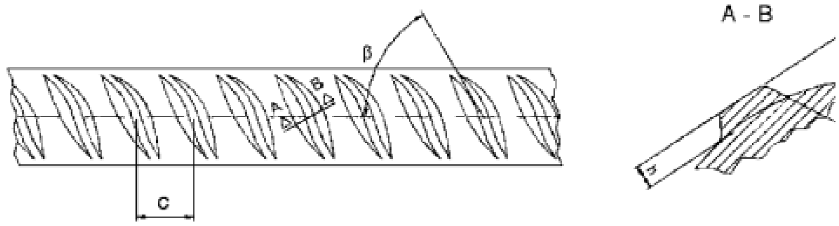


Figure 2: Geometrical characteristics of the ribs - height (h), angle of inclination (β) and spacing (c) [5].

In this article, the geometric characteristics of locally manufactured steel bar ribs imported from France are presented.

2. Materials and Methods

At the time of the work, a large number of companies buy the steels directly from retail suppliers. To obtain information on the characteristics of the steels actually used in constructions, our samples were obtained directly from the suppliers. So-called local reinforced concrete steels are sometimes identifiable by the initials of the local producing company. For our work, three (03) types of locally manufactured steels and one (01) type of steel imported from France, which serves as a control material, are studied. To ensure anonymity, the steels are designated as shown in Figure 3.

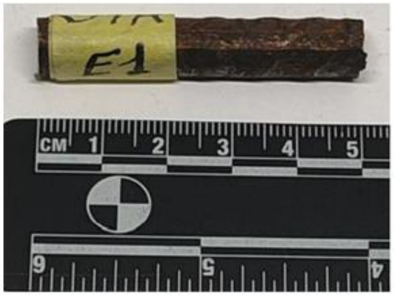
E1 – Type 1 - local manufacture 	E2 – Type 2 - local manufacture 
E3 – Type 3 – local manufacture 	E4 – Type 4 – Imp. From France 

Figure 3: Naming of the steel bars studied [20]

The study of the geometrical characteristics of the ribs at the level of the steels was carried out on bars with diameters of 8 mm, 10 mm and 12 mm for each type.

For each type and for all the diameters studied, a bar length of 10 cm is studied. Before measuring the geometrical characteristics of the ribs, all the bars are cleaned with sandpaper to remove impurities.

The height of the ribs is measured directly at the bars with a digital caliper (Figure 4).

Figure 4: Digital calipers for measuring rib height

For the determination of the spacings and angles of inclination of the ribs, the two-dimensional impression technique is adopted. It is a technique that is used by mechanics to determine the number of threads and their pitch for augers in particular and threaded pins in general. The principle of this technique is based on tracing the imprint of the protruding parts of a revolving part.

The bars are soaked in a dye solution (Figure 5), to mark the ribs.

Figure 5: Dye solution for measuring rib spacing and tilt angle

The bar is then rolled on a blank sheet of paper in order to trace the development of the vertical generator cylinder of the bar as shown in Figure 6.

Figure 6: Bar rolled on white paper

To determine the spacing and inclination at the ribs, the sheets of paper with the impressions are scanned using a scanner. Then, Autocad software was used to make the measurements. The scale was adjusted before the measurements were made.

3. Results and Discussion

In this section, the results obtained at the end of the measurements are presented and discussed. The results obtained are compared with the technical specifications for the adhesion conditions between steel and concrete of the French standard NF EN 10080 [5]. Tables 1, 2 and 3 show the results of the measurements of the geometrical characteristics of the ribs measured at the level of type E1, E2, E3 and E4 steels for the nominal diameters of 8 mm, 10 mm and 12 mm.

Table 1: Heights (h), inclination angles (β) and spacings (c) of ribs for 8 mm diameter bars

	HA8		
	Rib height, h (mm)	**Rib spacing, c (mm)**	**Rib inclination, β**
E1	**0.2**	7	44°
E2	**0.15**	6	52°
E3	0.5	6	55°
E4	0.5	6	60
NF EN 10080 [5]	**0.24 à 1.2**	**3.2 à 9.6**	**35° à 75°**

Table 2: Heights (h), inclination angles (β) and spacings (c) of ribs for 10 mm diameter bars

	HA10		
	Rib height, h (mm)	**Rib spacing, c (mm)**	**Rib inclination, β**
E1	**0.25**	9	60°
E2	**0.25**	6	62°
E3	0.5	7	60°
E4	0.75	6	65°
NF EN 10080 [5]	**0.30 à 1.5**	**4 à 12**	**35° à 75°**

Table 3: Heights (h), inclination angles (β) and spacings (c) of ribs for 12 mm diameter bars

	HA12		
	Rib height, h (mm)	**Rib spacing, c (mm)**	**Rib inclination, β**
E1	**0.2**	7	50°
E2	**0.25**	8	54°
E3	0.5	8	60°
E4	1	7	65°
NF EN 10080 [5]	**0.36 à 1.8**	**4.8 à 14.4**	**35° à 75°**

The results obtained in Tables 1, 2 and 3 for the types of steel studied indicate, for locally manufactured steels, that all bars with diameters of 8 mm, 10 mm and 12 mm comply with the requirements with regard to the spacing and angle of inclination of the ribs laid down in the NF EN 10080 standard. However, with regard to the height of the ribs, 66% of the bars studied from local manufacture do not comply with the requirements of the NF EN 10080 standard. This result applies to all steels with diameters of 8 mm, 10 and 12 mm. Only locally manufactured steels, type E3, meet all the requirements with regard to the parameters measured on the geometrical characteristics of the ribs. For steels imported from France, which serves as a control, all the parameters measured (height, spacing and inclination of ribs), for all diameters, comply with the requirements of the standard.

These differences are mainly related to the production of steels and constitute a real risk to the durability of structures and the safety of people. Our results indicate that locally manufactured steels do not always meet the conditions for their use in the realization of projects and show shortcomings in relation to the adhesion properties of reinforcement compatible with the use of Eurocode 2.

Indeed, to calculate the ultimate adhesion stress, the design anchor length and the overlap length, Eurocode 2 proposes equations (1), (2) and (3) respectively.

- ✓ For the calculation value of the ultimate adhesion stress f_{bd} [21]:

$$f_{bd} = 2.25.\eta_1.\eta_2.f_{ctd} \quad (1)$$

With :

η_1 : Coefficient related to adhesion conditions and the position of the member during concreting

η_2 : Coefficient related to the diameter of the bar

f_{ctd} : Tensile Design Strength of Concrete

- ✓ For the Calculation Anchor Length [21]:

$$l_{bd} = \alpha_1.\alpha_2.\alpha_3.\alpha_4.\alpha_5.\frac{\emptyset}{4}.\frac{\sigma_n}{f_{bd}} \geq l_{b.min} \quad (2)$$

With:

α_1 : Depends on the geometry of the bars

α_2 : Coating Function

α_3 : Function of containment by non-welded transverse reinforcement

α_4 : Function of containment by welded transverse reinforcement

α_5 : Depends on transverse compression containment

σ_n : Normal Stress in Steel

$l_{b.min}$: Minimum anchor length

The overlap length, indicated on the drawings, is determined from the calculation anchor length.

- ✓ For the calculation overlay length [21]:

$$l_0 = \alpha_6.l_{bd} \geq l_{0.min} \quad (3)$$

With :

α_6 : depends on the proportion of overlapping bars

$l_{0.min}$: Minimum lap length

However, for the use of relationships (1), (2) and (3), Eurocode 2 indicates that steels must have a high adhesion [21]. Requirements for the adhesion characteristics of bolted reinforced concrete steels shall be based on the geometry of the surface [5], including the spacing, inclination and height of the ribs. Thus, the inadequacies in the height of the ribs observed on locally manufactured steel bars call into question the compatibility of these steels with the use of Eurocodes in Senegal.

4. Conclusion and Perspective

Measurements of the geometrical characteristics of the ribs for locally manufactured steels have shown inadequacies. The results indicate, for the locally manufactured steels studied with diameters of 8 mm, 10 mm and 12 mm, that 66% do not have latch heights that meet the requirements of the standard. The minimum values of 0.24 mm, 0.30 mm and 0.36 mm respectively for steels with nominal diameters of 8 mm, 10 mm and 12 mm are not met. Faced with the resurgence of collapses, these results are of paramount importance in the search for solutions, but also in the application of Eurocode 2 in Senegal. The results obtained show the need to carry out tests before the start of the work to verify the conformity of the characteristics of the materials with the calculation assumptions. A laboratory or certification agency for the quality of construction materials in Senegal can also be set up. In addition, for the safety of structures and occupants, it is essential that the tensile strength of locally manufactured steels conforms to the calculation assumptions. Thus, in perspective, it would be useful to study the behaviour of locally manufactured steels with regard to tension. Indeed, the characteristics of the materials provided for in the design hypotheses must be in line with the quality of the materials used in the constructions for the safety and durability of the structures.

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