BENDING OF REINFORCING BARS
TESTING METHOD AND INFLUENCE ON STRUCTURES

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Abstract

Reinforcing bars in concrete elements functions as the component carrying tensile stresses after concrete cracking. This is due to that fact that concrete exhibit very high compression strength combined with a very low tensile capacity. The tensile stressed are transferred to the bars by the bond between the reinforcement and the concrete.

Bars are generally produced in strands 6 to 12 meter in length so that bending for transportation and handling purposes becomes necessary. At the site bars are straightened, and then sometimes re-bent for assembling purposes. This process will result in a loading and re-loading of steel.

The ASTM E-290 mandated that bars have to pass the bending test, whereas reinforcing steel bars are bend to almost 180^0 to ensure material ductility. In the past five years the Construction and Material Laboratory, Diponegoro University has been questioned with the issue as to how far this bending and straightening influences the quality and what the significance of testing is.This paper will evaluate the influence of bending and straightening and the testing procedure involved.

Key words: bend test, reinforcing bars, tensile strength, ductility, cracks

Introduction

The ASTM E-290 standard covers bend testing of bars primary for evaluation of their ductility. Specifications such as size and type, radius of bending, angle of bend, number and size of visible cracks if any, are reported. The standard demanded that after testing the convex surface of the bend specimen shall be examined with the unaided eye to identify cracks or other open defects.

While a wide variety of test methods are available, the *Construction and Material Laboratory, Diponegoro University* performed the so called *"Guided-Bend Test"*. The bar being tested is supported by two pins with a distance of three times the bar diameter plus the plunger. The force is applied through a plunger placed midway between the supports (fig. 1). The bar is then bended to an angle of 180^o (fig 2).

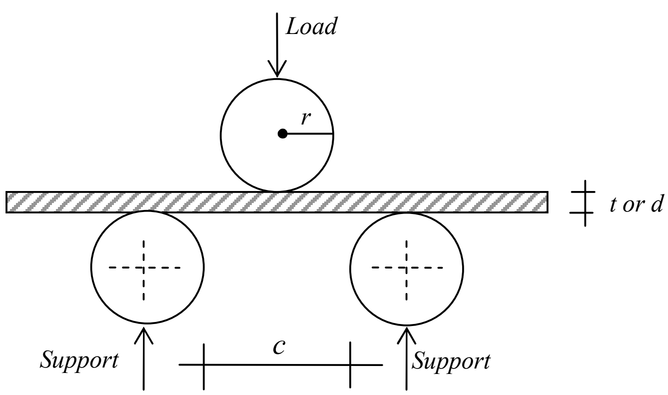

Figure 1. Set Up of Bend Test

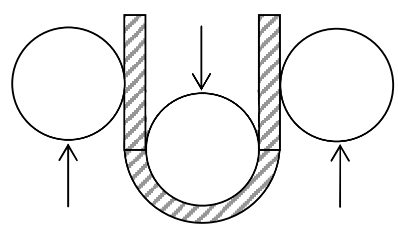

Figure 2. Bar After Testing

In the field bars undergo similar behavior as to the test specimen. Certain structures, especially domes and shells will require bar bending so that the basic form of the structure can be achieved. Thus in practice these bars are straightened and re-bend. While tests result will give a figure of the material's ductility, it does not reflect its influence to material strength.

Another example of typical field bending is the adjustment of column reinforcing steel at the beam joints. To enable assembling, bars are bent in between the beam reinforcement, this also happens for bar connections when no mechanical fasteners or connectors are used.

Laboratory Testing and Evaluation

At the *Construction and Material Laboratory, Diponegoro University*, reinforcing bars are bend-tested using the *Universal Testing Machine* (UTM).

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Bars are placed horizontally on the supports that are positioned in accordance to the code. The plunger *"r"* in diameter is defined by the equation:

$$r = 4\ x\ d_{bar}\ or\ t.$$

Where:

R = diameter of the plunger in mm

d_{bar} = diameter of bar being tested in mm

t = thickness of tested specimen other than bars in mm

The force required to bend the bar 180^o is a function of bar diameter (figure 3). To avoid instability at the supports, the base-blocks are fixed using anchorages.

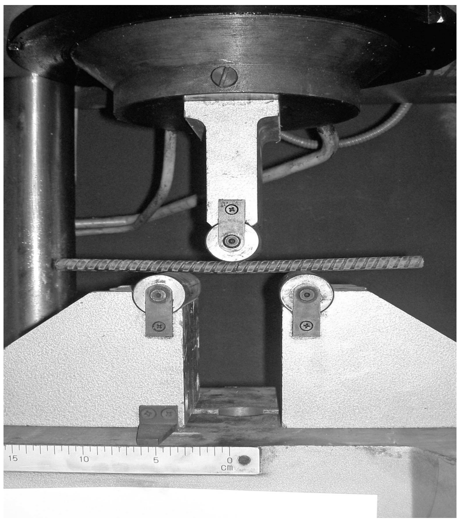

Figure 3. Bars Prior to Testing

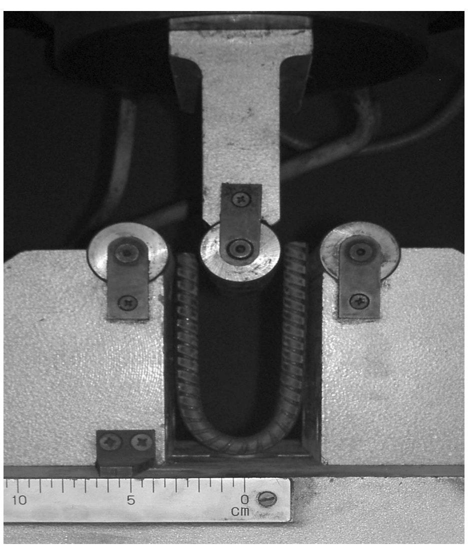

Figure 4. Bars Bent at 180^o

A loading rate is set to be 0.5kN per graduation and the deformation process is observed during testing. When a full bend is achieved, the load is removed and the bar detached from the apparatus (figure 4).

In accordance to the ASTM code the bend is observed without any equipment and inspected for cracks or chipping (figure 5).

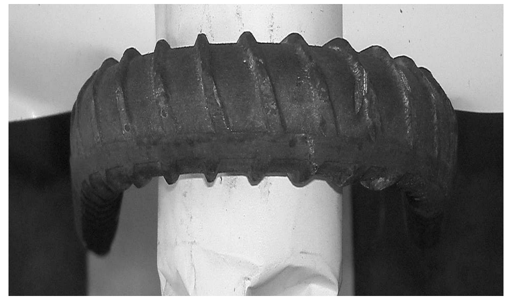

Figure 5. Observation after Testing

The Laboratory has tested reinforcing bars ranging from 16 mm to 32 mm in diameter and so far all specimens have passed the bending test. All reinforcing bars exhibit sufficient ductility to withstand the 180^o bend.

Cold Bending versus Hot Bending

When a bar is bent at room temperature, a mechanical torque is applied directly to the bar resulting in a condition where the outer fibers at the bend are in tension and the inner fibers undergo compression strain and stresses. This type of bending is distinguished as cold bending. The majority of bars in Indonesia are cold bend regardless as for transportation or assembling purposes. These cold bend bars will undergo strain aging and hardening.

For hot bending, the bars at the position of bend are preheated to a temperature of 600^o to 800^o C using an *oxygen- acetylene* torch or other sources that can induce the same heat level. The heated bar is then bent manually in the same manner as for cold bending.

Research work (*Restrepo et al, 1999 and Babaei et al, 1991*) where tensile tests were performed on cold bend specimens concluded that strain aging resulted in a shifting of fracture mode from ductile to brittle as a function of temperature transition.

It is also acknowledged that reinforcing bars that have undergo stresses beyond the strain hardening can yield at stress levels *higher* than their original yield point, ultimate tensile strength will also slightly increase. On the other hand, plastic deformation will result in a decrease of ultimate strain (figure 6).

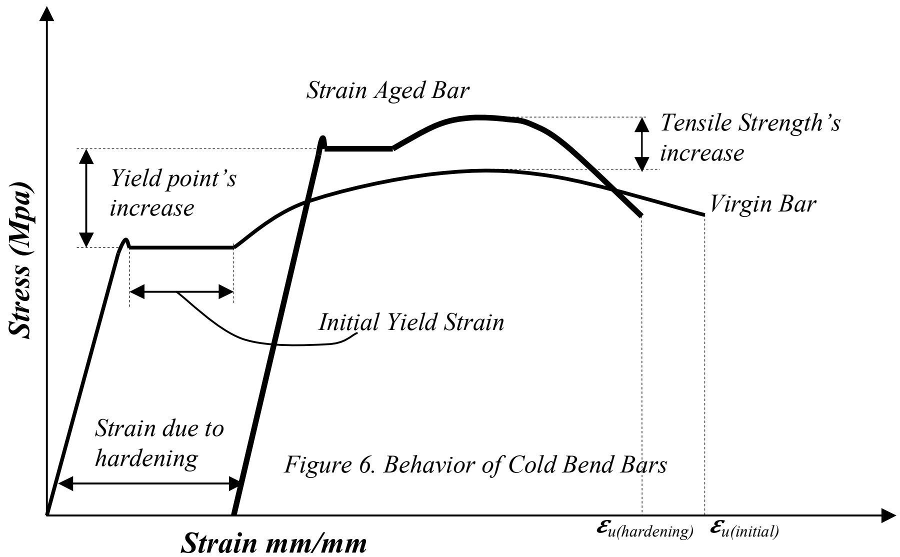

Figure 6. Behavior of Cold Bend Bars

From this behavior it can be predicted that bent bars with initial plastic strains will more likely fail in a brittle mode when re-loaded.

Requirements and Standards

The Indonesia Concrete Code *"Peraturan Beton Bertulang Indonesia 1971"* stated in Chapter 5-3 that:

1. Bars shall not be bent or straightened using any method harmful to the steel.
2. Deformed bars may not be re-bent within a distance of 600 mm from the bent and straightened location.
3. Cold bending is recommended unless stated different by the designer.
4. Only low strength non-deformed bars can be hot bent and the required temperature shall be 850^{o}C. Hot bending of deformed bars is restricted.

The "*Bina Marga Directorate"* mandated in section 5 of its BBPJN IV/SMM/PP/RENEWS/B7.002 that:

1. Reinforcing steel shall be bent cold in accordance to ACI 315 from a bar that is virtually straight and show no chipping or irregularities.
2. If hot bending should be approved caution has to be taken to ensure that physical impact on steel is minimized.
3. Bars with a diameter larger than 20 mm should be mechanically bend.
4. Bars that have underwent bending, straightening and re-bending are rejected.

The "*MPC-ACI 2006"* 318M-05/318RM-05 stated in Chapter 7-3 that:

1. All reinforcement shall be bent cold, unless otherwise permitted by the engineer.
2. Reinforcement partially embedded in concrete shall not be field bent, except as shown on the design drawings or permitted by the engineer.

Further details are:

R7.3.1 — The engineer may be the design engineer or architect or the engineer or architect employed by the owner to perform inspection. For unusual bends with inside diameters less than ASTM bend test requirements, special fabrication may be required.

R7.3.2 — Construction conditions may make it necessary to bend bars that have been embedded in concrete. Such field bending should not be done without authorization of the engineer. The engineer should determine whether the bars should be bent cold or if heating should be used. Bends should be gradual and should be straightened as required. If cracking or breakage is encountered, heating to a maximum temperature of 820°C may avoid this condition for the remainder of the bars. Bars that fracture during bending or straightening can be spliced outside the bend region. Heating should be performed in a manner that will avoid damage to the concrete. If the bend area is within approximately 150 mm of the concrete, some protective insulation may need to be applied. Heating of the bar should be controlled by temperature-indicating crayons or other suitable means. The heated bars should not be artificially cooled (with water or forced air) until after cooling to at least 320°C

The Indonesia code of practice clearly does not recommend bending. Both standards Indonesia and American however, favor cold bending when necessary. While the *PBI'71* permits re-bending within a radius of distance, the *Bina Marga* standard does not allow any re-bending.

The American code is basically more detailed, but generally it underlines the Indonesian code i.e., that cold bending is preferable. For hot bending, the temperature suggested by both codes is similar and range from 820^{o} to 850^{o} C.

Summary of Test Results

Although all standards discourage bending, specimens tested at the *Undip Laboratory* showed no cracks or discontinuities. The bars were deformed beyond their plastic limit, but were able to rebound to an angle of almost 150^o. No permanent fractures occurred while cold bending will enhance the yield and ultimate stress.

Excessive research was done in New Zeeland *(WSDOT Report, 1991 and 1988)* and it was proved that bending and straightening does not weaken the steel bars. A maximum angle of 90^o for re-bending is recommended, based on test results.

Research at The University in Urbana Champaign *(Parker, 2008, Babaei et al, 1991)* showed that for lager rebar diameters micro cracks exhibited in the tension zone of the bend. This strengthens the *Bina Marga* requirement that bars larger than 20 mm should be mechanically bend. However, the 32 mm bars that were tested at *The Undip Laboratory* did not show micro cracks.

The *Concrete Reinforcing Steel Institute* has a more detailed description. In generally smaller (24 mm diameter) bars can be successfully field bent/straigh-tened but larger bars will have a better performance when hot bent. For very large bars (30 mm diameter or higher), bending and straightening becomes risky and should therefore be avoided.

Conclusion and Recommendation

Having the same dimension and grades, comparison of test results showed that Indonesia based steel bars are more ductile than American or New Zeeland bars.

Bending, straightening and re-bending of Indonesia bars therefore become less sensitive to cracking.

Since cold bending will enhance yield and ultimate stresses, a *one-time* re-bending should not be a high risk. For lager bar diameters however, bending and straightening should be avoided

A wide variety of steel mills, large and small have risen in the past decade, their product quality and performance should be mapped in accordance to give the reinforced concrete industry a better insight for selecting the steel bars to use.

Bend testing is not widely adapted in the Indonesian concrete industry, and the *National Building Code SNI 2002* does not cover this important testing item in its requirements. Steps toward socialization of testing methods and its important role should be conducted nationwide.

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