INVESTIGATION INTO THE STRUCTURAL PERFORMANCE OF MMFX REINFORCING

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ABSTRACT

The Department plans to substitute MMFX reinforcing for Grade 60 reinforcing on a project designed for Grade 60 reinforcing. To determine the effects this substitution would have on the structural performance, a series of 4 beam tests comparing the performance of MMFX reinforcing with standard Grade 60 reinforcing were conducted. In addition, tension tests were conducted on the reinforcing bars used in the study to determine the material properties. The MMFX reinforcing performed well but it was determined that due to its higher strength and indeterminate yield stress that additional consideration should be given to detailing when using this material.

Keywords: Concrete, Beam, MMFX

Disclaimer

The opinions, findings and conclusions expressed in this article are those of the author and not necessarily those of the Florida Department of Transportation (FDOT).

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INTRODUCTION

The Florida Department of Transportation plans to utilize MMFX reinforcing as a substitute for Grade 60 reinforcing for the substructure reinforcing on a bridge where the design had been completed assuming the use of Grade 60 reinforcing. The impetus for this substitution was the expected improved corrosion resistance of the MMFX reinforcing. The concern our office investigated was the structural performance of this reinforcing. MMFX reinforcing has a higher strength than Grade 60 and it also lacks a well defined yield point. Its stress strain diagram is similar to that of high strength prestressing steel. To determine the differences in structural performance that could be expected a series of 4 beam tests were conducted to compare the behavior of MMFX reinforcing with that of Grade 60 reinforcing. Each test consisted of two beams exactly alike except in one, the critical reinforcing was MMFX and in the other it was Grade 60. In addition, tension tests were conducted on the reinforcing.

EXPERIMENTAL PROGRAM

The test setup for the first three tests can be seen in Figure 1.

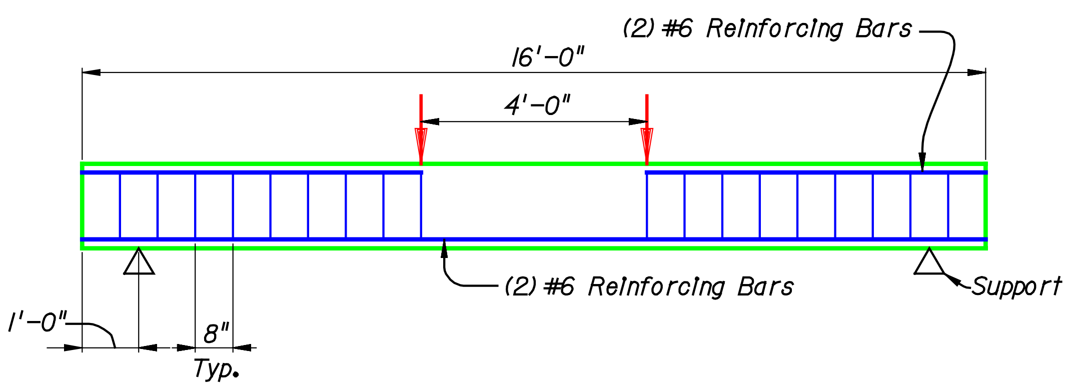

Fig. 1 Typical Beam Test Setup

For the first test the two number 6 bottom-reinforcing bars were the reinforcing of interest and were varied between the two material types. The second and third tests were a variation of this test with a splice provided at midspan to check bar bond and development. Test 2 used a 10-inch lap to force a bond failure and test 3 provided a Class C lap splice for the Grade 60 reinforcing of 30.5 inches. The Test 2 and 3 configurations are depicted in Figure 2. As in Test 1 the flexural steel was varied, MMFX for one beam and Grade 60 for the other

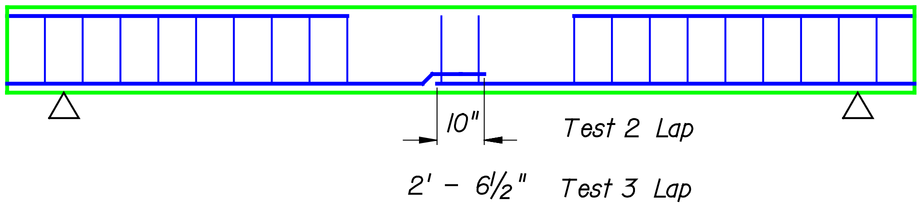

Fig. 2 Test 2 and Test 3 Bar Laps

All beam tests had the same cross section properties. These are provided in Figure 3 along with the stirrup dimensions. A cover of 1 inch on the stirrups was used for all tests.

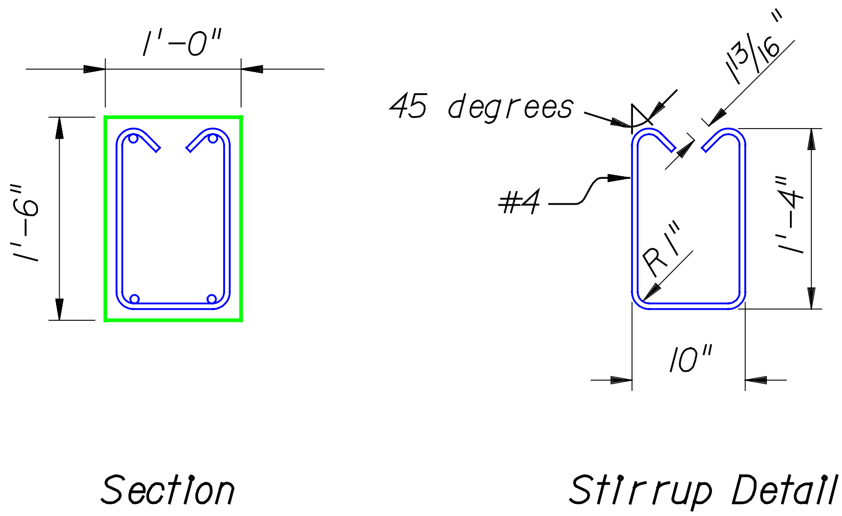

Fig. 3 Test Beam Cross-Section and Stirrup Dimensions

The intent of test 4 was to compare the performance of the reinforcing types when used as shear reinforcing. To insure a shear failure a different span, loading and reinforcing layout was required. The layout used for Test 4 is shown in Figure 4

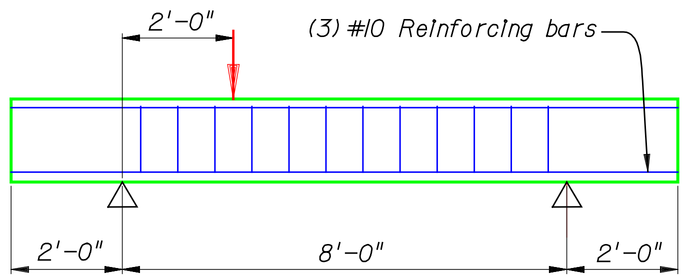

Fig. 4 Test Setup for Test 4

The cross section of the beam and the configuration and spacing of the stirrups remained the same. In this case, the flexural steel (3 #10) was ASTM A615 and only the stirrup steel was varied between the specimens.

Table 1 summarizes the tests information. Each test consisted of two beams poured at the same time one with MMFX reinforcing and the other with Grade 60 reinforcing for the critical bars. Concrete strengths given are the average value of cylinder tests conducted the day of the beam tests.

Table 1

Test Number	Test Type	Concrete Strength at Time of Test	FDOT Concrete Class
1	Flexural Test with continuous reinforcing	6683 psi	IV
2	Flexural Test with reinforcing lapped 10 inches	6034 psi	IV
3	Flexural Test with reinforcing lapped 30.5 inches	5420 psi	IV
4	Shear Test	4943 psi	II

The flexural tests were instrumented with crack gages and LVDTs (displacement gages) as shown in Figure 5. A load cell was provided in line with the single actuator to measure the force being applied to the beam. The crack gages had a gage length of 200mm. As shown in Figure 5, the crack gages wree numbered from 1 to 7. Two LVDTs were used at the actuator location to monitor if any transverse rotation was occurring.

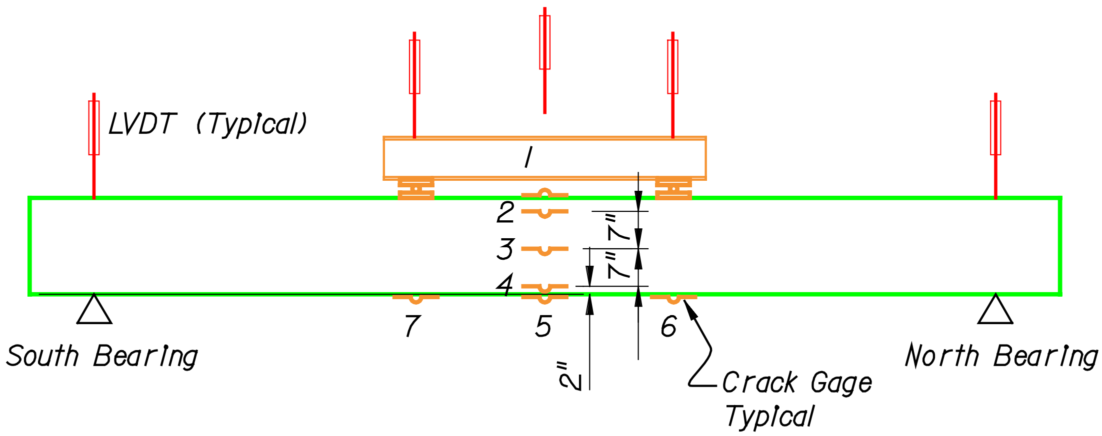

Fig. 5 Location of Instrumentation

A photograph of a beam with the instrumentation undergoing testing is shown in Figure 6. This beam is the first flexural test with Grade 60 reinforcing. Pinned rollers were used for the supports.

Crack gages were not used for the shear test. The instrumentation consisted of 2 LVDTs at the actuator, one at each bearing and one at the centerline of the span and the load cell inline with the jack. In addition, rollers were not used at the bearings but 7 inch wide neoprene pads were used instead. This was done due to safety concerns with rollers caused by the brittle and sudden nature of a shear failure.

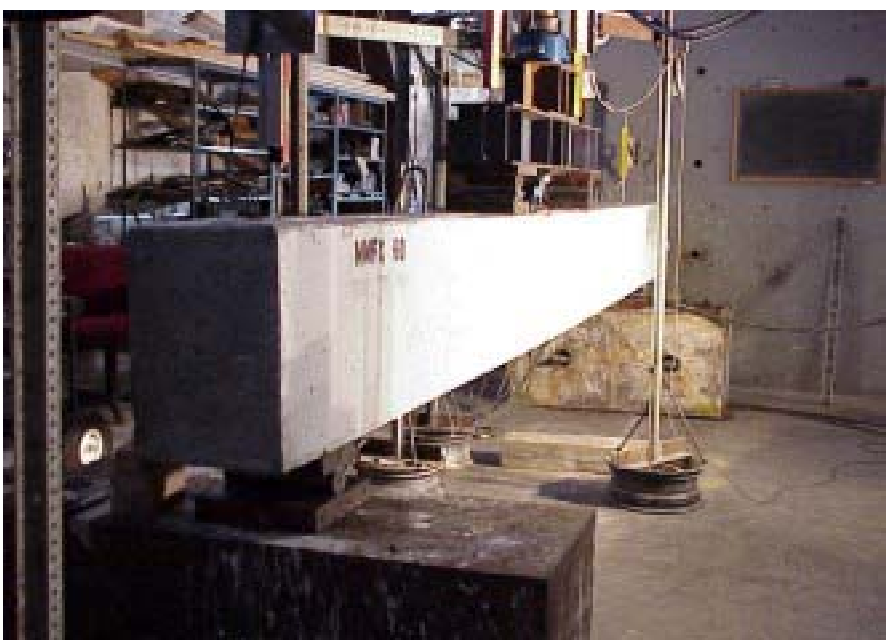

Fig. 6 Beam During Test

In addition to the beam tests, a number of tension tests were performed on both types of reinforcing bars with elongation measured over 8 inches. Also several bars were reduced in section on a lathe to remove the ribs and then tested with elongation measured over a 2 inches.

TEST RESULTS

Test 1 was a comparison of pure flexural behavior between MMFX and Grade 60 reinforcing. The bottom reinforcing for both beams was two #6 bars. Figure 7 plots for both beams, the deflection at the north load location versus the applied load from the actuator. Using the south load location would change the plots very little since the difference in the deflections was on the order of 0.02 inches for most of the loading. The difference in beam behavior is due solely to the difference in the reinforcing material properties.

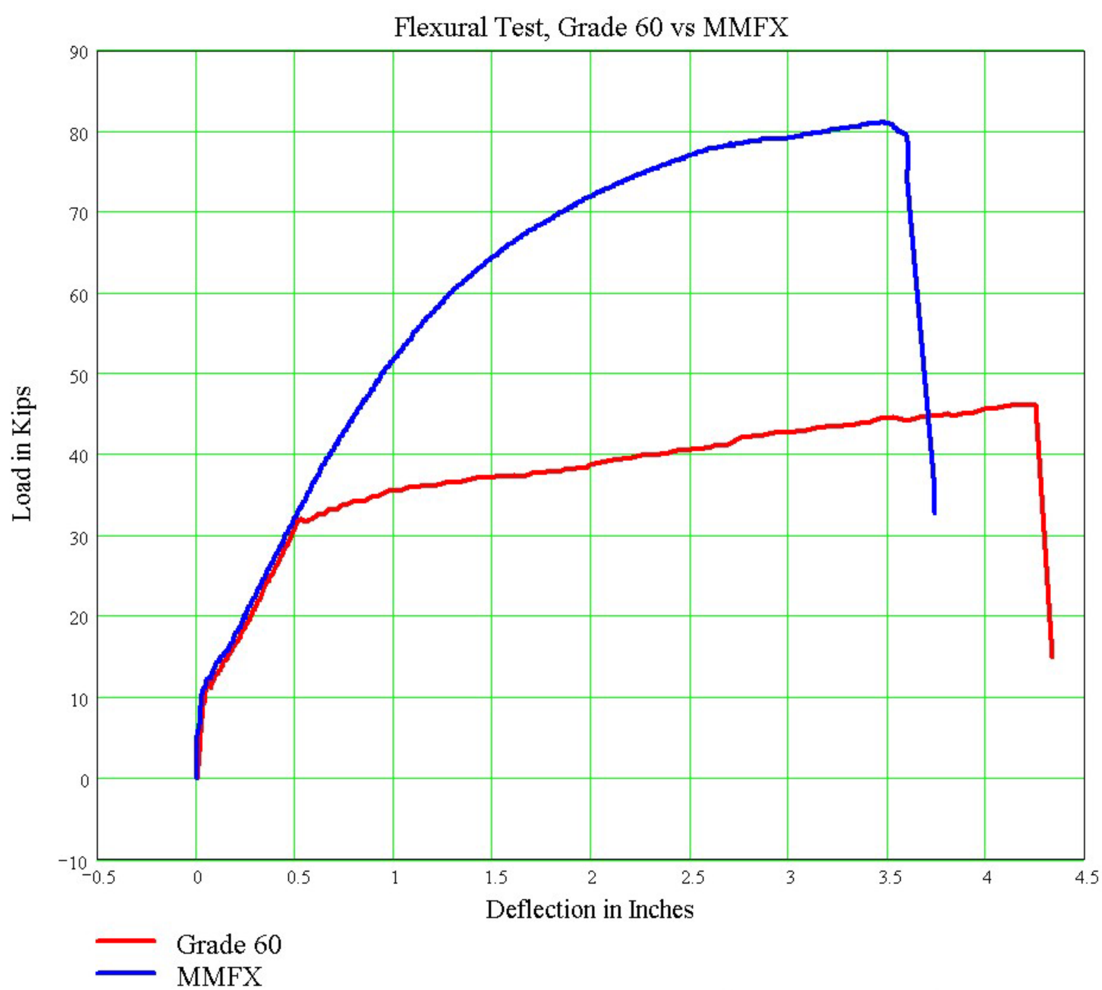

Fig. 7 Test 1 Results

For a general idea of the ductility, the area under the load deflection curve for the MMFX reinforced beam is around 40 percent greater than that of the one for the Grade 60 reinforcing. It can also be observed that the behavior of the two beams is very similar up to the yield loading of the Grade 60 beam at around 32 kips and both exhibit the same cracking load at around 10 kips.

Test 2 was the same as test 1 but the flexural steel was lapped 10 inches at midspan instead of being continuous. Figure 8 provides the load deflection curve.

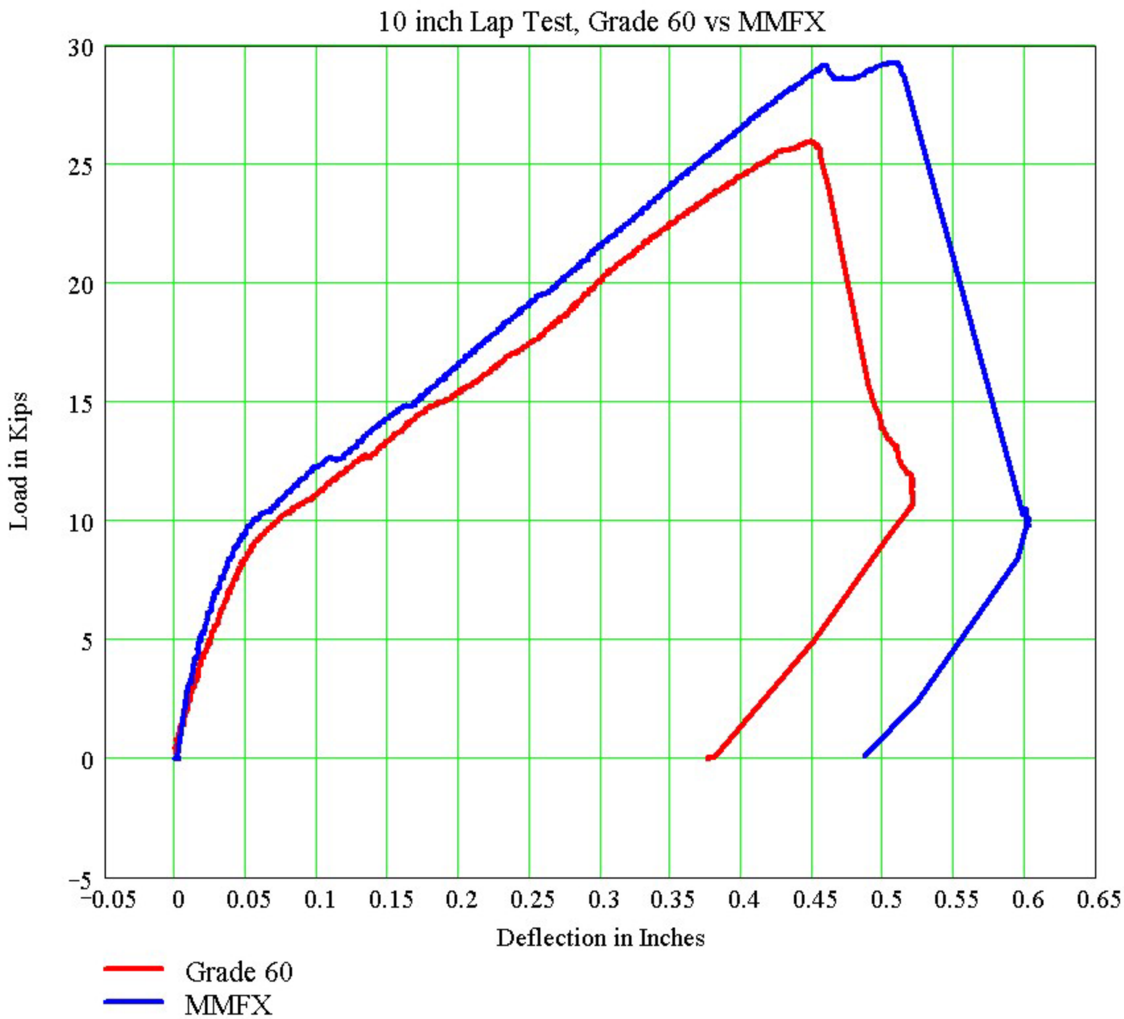

Fig. 8 Test 2 Results

Examining Figure 8 it is apparent that both beams failed before yielding of the reinforcing was reached. In addition, this test indicates that the bond behavior of the MMFX reinforcing is equal to or slightly better than that of the Grade 60 reinforcing.

For Test 3 the lap was increased to 30.5 inches. In Figure 9 the results of Test 1 are included with Test 3 so that the effect of the lap can be easily seen. It is apparent from this Figure that the lap provided was sufficient to provide the Grade 60 beam with ductile behavior, however, this lap length was not sufficient to provide ductile behavior for the MMFX reinforcing. Similar to the results of Test 2, the MMFX reinforcing did demonstrate bond behavior equal to or better than the Grade 60 reinforcing since it failed at a greater load.

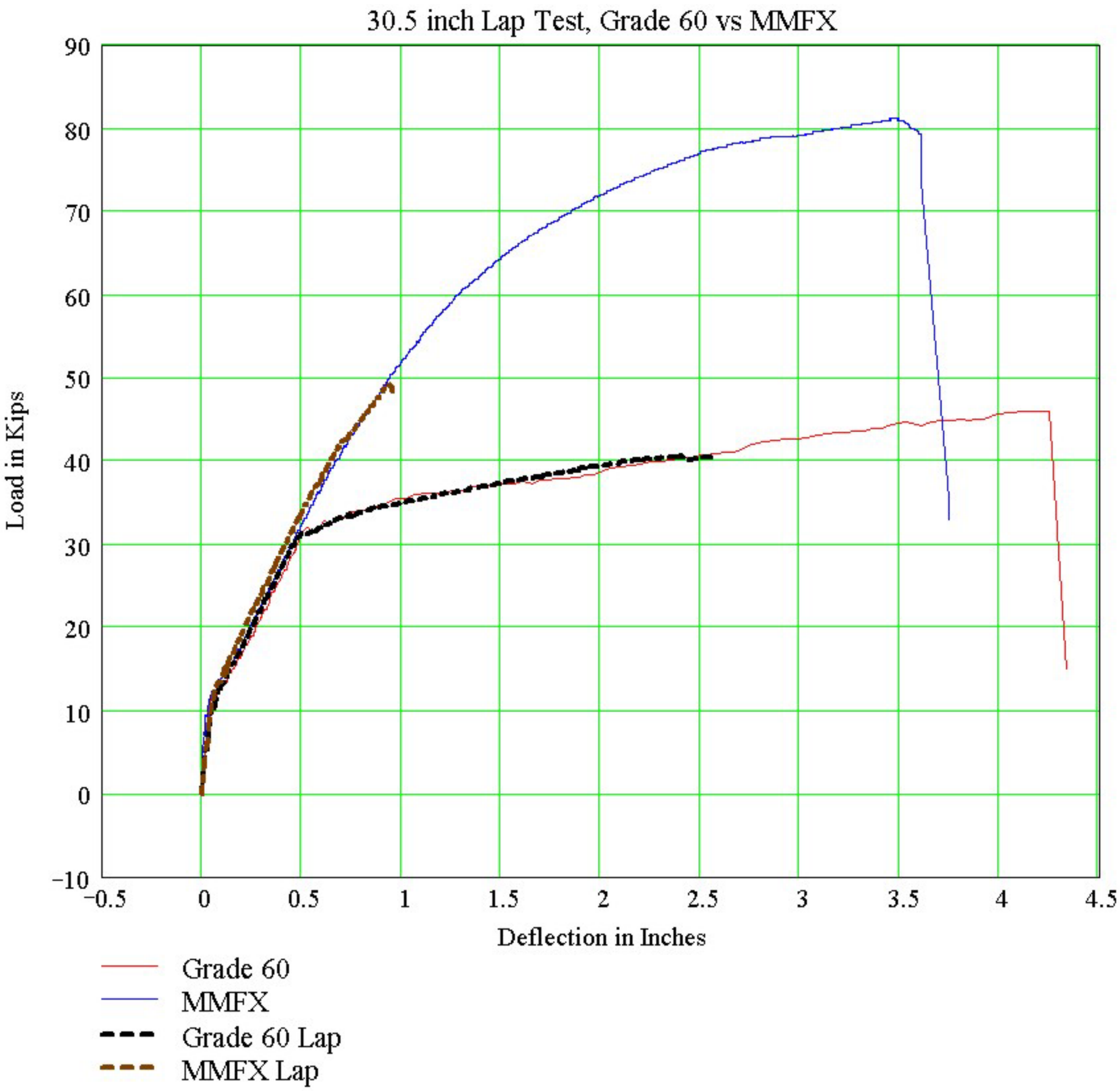

Fig. 9 Test 3 Results

The intent of Test 4 was to compare the performance of Grade 60 and MMFX stirrups in a condition where a shear failure was expected. Figure 10 is a graph of the applied load and the deflection at midspan of the beam.

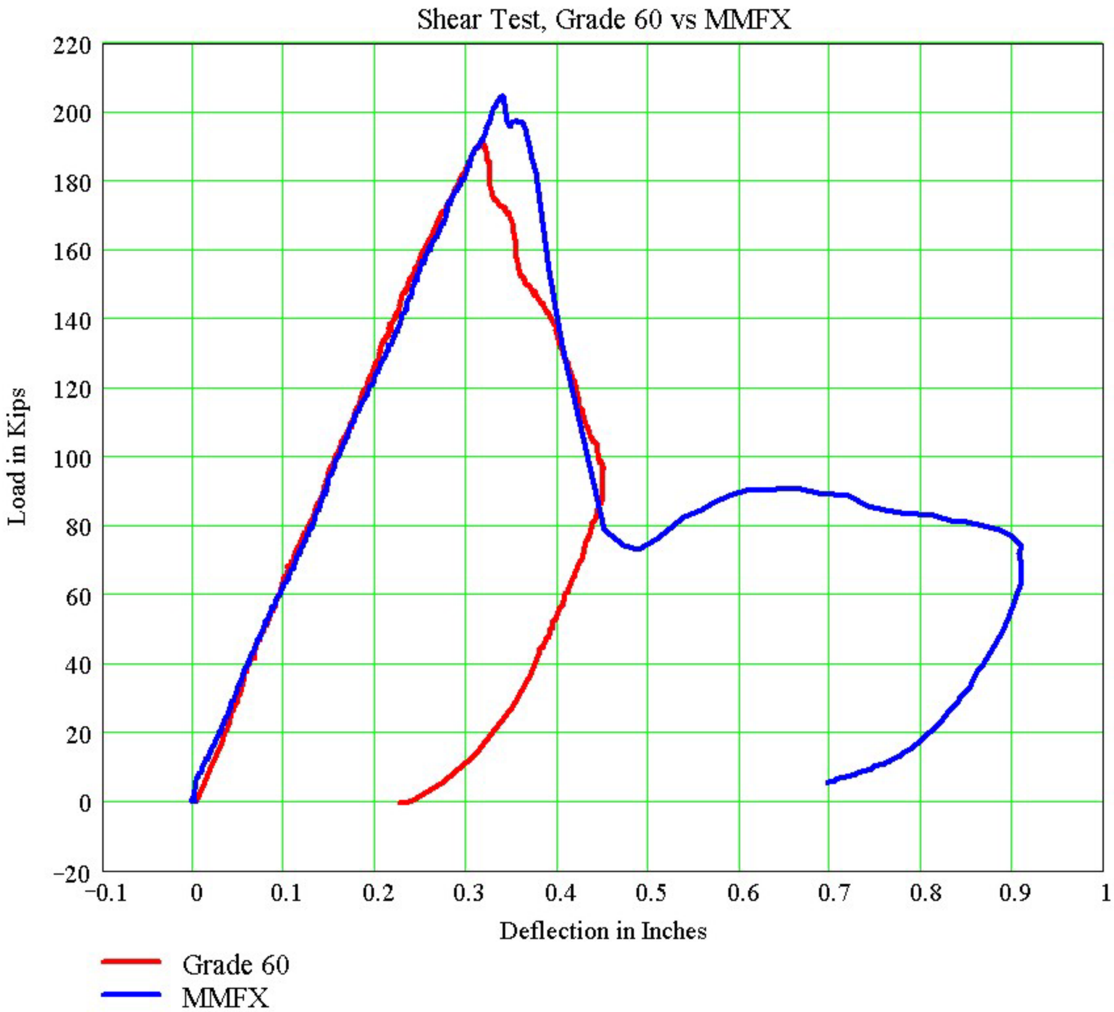

Fig. 10 Test 4 Results

In reviewing the results it is believed that the stirrups played only a minor part in the shear capacity of the section. Looking at the failure location for the MMFX section, Figure 11, and the Grade 60 section, Figure 12, it can be seen that a strut and tie model would be appropriate. The yield stress of the number 10 bars used for longitudinal reinforcing was 69 ksi. A simple truss model indicates that at a load of 231 kips the longitudinal reinforcing would reach yield. This is a little more than the 190 to the 200 plus kips where actual failure occurred for the Grade 60 and MMFX sections respectively. One possibility is that the interior bar of the three longitudinal bars was not as effective as the exterior bars.

Fig. 11 MMFX Test 4 Beam

Fig. 12 Grade 60 Test 4 Beam

A number of tension tests were conducted on samples of the Grade 60 and MMFX reinforcing. Figure 13 contains a stress strain diagrams for several of the tests.

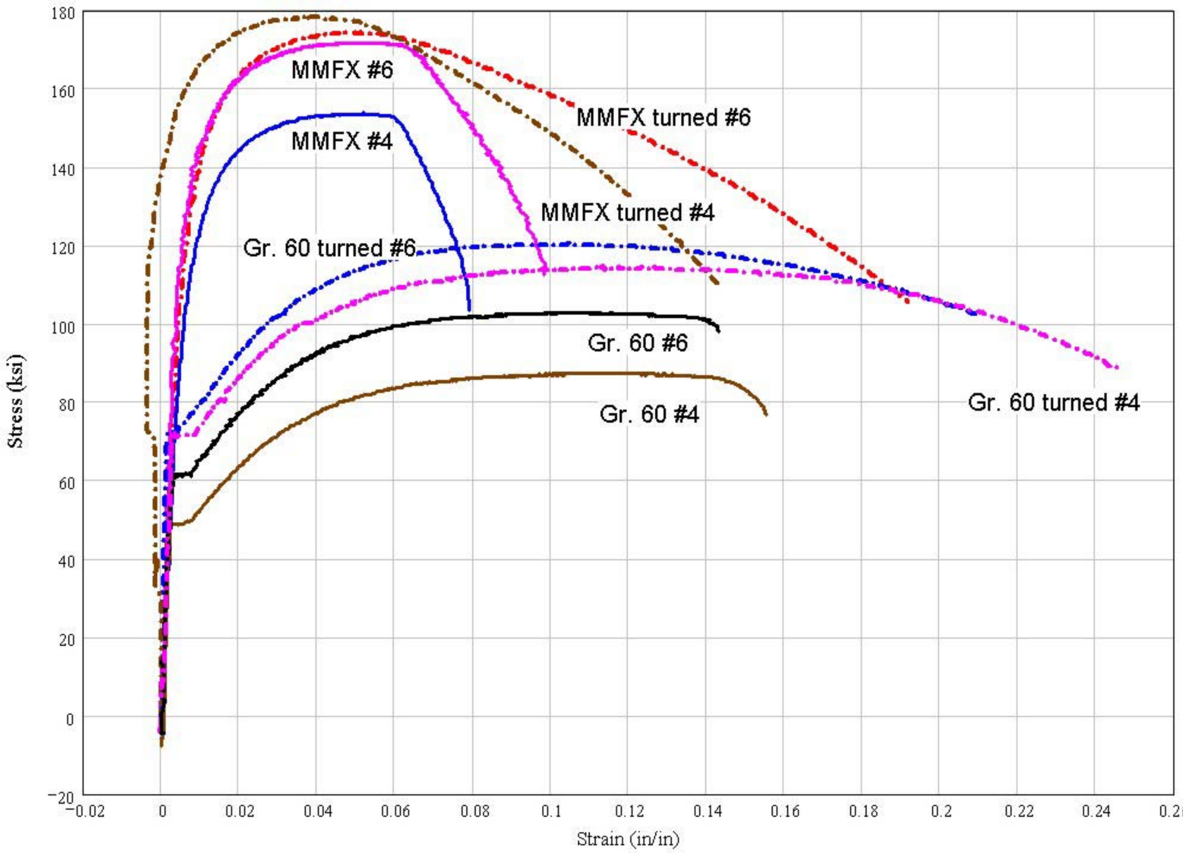

Fig. 13 Stress Strain

The bars labeled as turned were milled down on a lathe to remove enough material so that the bars were smooth and without ribs. These turned bars were tested with elongations measured over 2 inches. The remaining tests were on full size bars with elongations measured over 8 inches. The variation between the response of the number 6 bars and the number 4 bars in terms of strength and yield was consistent for both the MMFX and Grade 60 reinforcing. This disparity became much less when the bars were tested as coupons with the ribs removed. Also it can be seen that the MMFX bars lack a distinct yield point. The odd behavior of the MMFX turned number 4 bar is believed to be due to slippage of the knife-edges of the extensometer.

CONCLUSIONS

The behavior of the MMFX reinforcing compares favorably to the typical Grade 60 reinforcing. However, due to its higher strength and to some extent the lack of a distinct yield point attention must be given to detailing with this reinforcing. Test 3 indicates the potential problems with a blind substitution where although the strength was actually greater with the MMFX reinforcing the ductility was inadequate. Lap splices, hook embedments, etc. that are sufficient for Grade 60 reinforcing will likely be inadequate for MMFX reinforcing. It is not readily apparent what yield stress should be used for detailing with this reinforcing. The whole approach of how to deal with reinforcing that lacks the distinct yield point, around which most codes are written, needs to be addressed.

The disparity between the number 4 bars and number 6 bars when tested as whole bars versus when tested as coupons indicates that the present rib sizes may be detrimental for these smaller bars. We recently tested full size bars conforming to ASTM A955 (stainless) and noticed a similar disparity in behavior between number 5 and number 4 bars.