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THE EFFECT OF CUTTING TECHNIQUES ON MATERIAL PROPERTIES OF PRE-STRESSED BARS

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ABSTRACT

The prestressing and pre-casting of concrete are inter-related features of the modern building industry and it is increasingly popular nowadays. This research investigates the material properties, the development length and ultimate strength of the pre-stressed bar using different cutting methods. The experiment conducted in the Mono-jack Calibration Frame for tensioning of the pre-stressed bar specimens. Three bar diameters have been studied. They include 26 mm, 29 mm and 36 mm. The experiment involved two cutting methods, abrasive blade cut and flame cut. The results analysed the factors such as ultimate load, ductility, ultimate strain and Young's Modulus. The experiment results indicated the Young's Modulus increased according to the bar diameter. However, when compared with two cutting methods, the flame cut illustrated higher loss in ultimate load, ductility, ultimate strain and Young's Modulus when compared to abrasive blade cut. It was also observed that the flame cut is four times faster than abrasive cut. Through this study, a series of design graphs were proposed. These design graphs are useful for the practice design engineers to choose the best and most practical cutting method on site.

KEYWORDS

Prestressing bars, abrasive blade cut, flame cut, material properties.

INTRODUCTION

Prestressing systems are not only world renowned for reliability and performance but also most suitable for all applications in post-tensioned and pre-stressed constructions. They embrace the whole spectrum from bridge construction, buildings, to civil applications, above and underground. Pre-stressed concrete has several advantages over conventionally reinforced concrete. One advantage is that the number and width of cracks can be limited or even eliminated. Another benefit is that camber can be used to offset and reduce deflections from loads. In addition to these serviceability advantages, pre-stressed concrete allows for the effective use of high strength steel reinforcement and high strength concrete. Longer span lengths can be achieved, and precast construction is possible.

Caprani (2007) mentioned transmission length in pre-tensioned or pre-stressed concrete, which is the length from the edge of a concrete beam where the energy is transferred to the concrete is normally 50 times the bar diameter. Kose (2007) determined the transmission lengths within pre-stressed concrete and discussed the relationship between this length and the diameter. The author also mentioned the increase of the transmission length during the flame cutting has been ignored. Therefore, suggested that further research should look at different methods of cutting has on the transmission length.

Okumus et al. (2012) noted that bridge designs recently created efficient pre-stressed concrete girder sections that provided high pre-stressed levels. According to Okumus et al. (2012), pre-stressed concrete design should fundamentally transfer compressive forces from prestressing bars to any surrounding concrete in order to achieve crack free members under a service load. The properties of concrete and bar interface can cause visible cracks at a short distance from a girder end under high stress conditions caused by cutting methods. Therefore the research herein studies the effect of cutting on the pre-stressed bar.

Bhatia (2011) stated that flame cutting is the process of fusing materials by applying heat to create a gas induced flame. The characteristics idealised in a flame cutter must have high temperature of the open flame, high rate of flame propagation from the nozzle and adequate heat content and a chemical reaction of the flame with any fillers such as solder. Bucknam & Young (1937), Furrer & Wehrli (1982) and Moon et al. (2010) studied the methods of de-tensioning strands through flame cutting. The flame cutting method is generally applied to single strands. Bucknam & Young (1937) also mentioned that flame cutting required a big machine on site which sometimes caused congestion issues. This is supported by Moon et al. (2010).

Kasan (2012) described the abrasive implements as composite tools consisting of thousands of cutting edges or grains, positioned and orientated in randomised directions allowing for a serrated cutting surface and edge to be used. Kasan (2012) studied the Lake View Drive Bridge (an adjacent box girder bridge) which related to impact damage. Due to truck-to-concrete overhead damage, this exposed pre-stressed steel bars in the pre-stressed concrete. The section of girder then experienced a loss of strength, with the exposure and gradual weakening of the bars as a result of rust and method of cutting during construction. Kasan (2012) applied strain gauges along pieces of the damaged girder taken from the bridge. An abrasive cut-off wheel at 8000 rpm was used for shortening the bars and testing along the length. A cut-off wheel that is suitable for cutting bars in the pre-stressed concrete. It is mobile and relatively small. The abrasive cut exhibited a lower material property change in the bar. This research herein will study the effect of abrasive and flame cut methods on the material properties of pre-stressed bars. The cutting methods should be easily available and manageable on construction sites.

EXPERIMENTAL STUDIES

The experiment used 1030 MPa stress bars with 3 different diameters. There are 26 mm, 29 mm and 36 mm. The stress bars consist of 3 samples per cutting method and 2 samples as control specimens as in uncut specimens. There will be two series of experiments. Series 1 consists of abrasive cutting on the pre-stressed bars whilst series 2 consists of flame cuts. The samples are 2000 mm in length.

Experimental studies were carried out at University of Western Sydney (UWS) laboratory strong floor. Strain gauges were used to measure the stresses along the bar length. Figure 1 shows the Monojack Calibration Frame used to test the pre-stressed bars. Strain gauges are located 968 mm from the end of the pre-stressed specimens. Four strain gauges were located at 100 mm intervals.

The purpose of these strain gauges is to measure the strain values and to observe the effect of the cutting method on the pre-stressed bars. Two linear potentiometers were placed in the specimens to measure the elongation of the stressed bars.

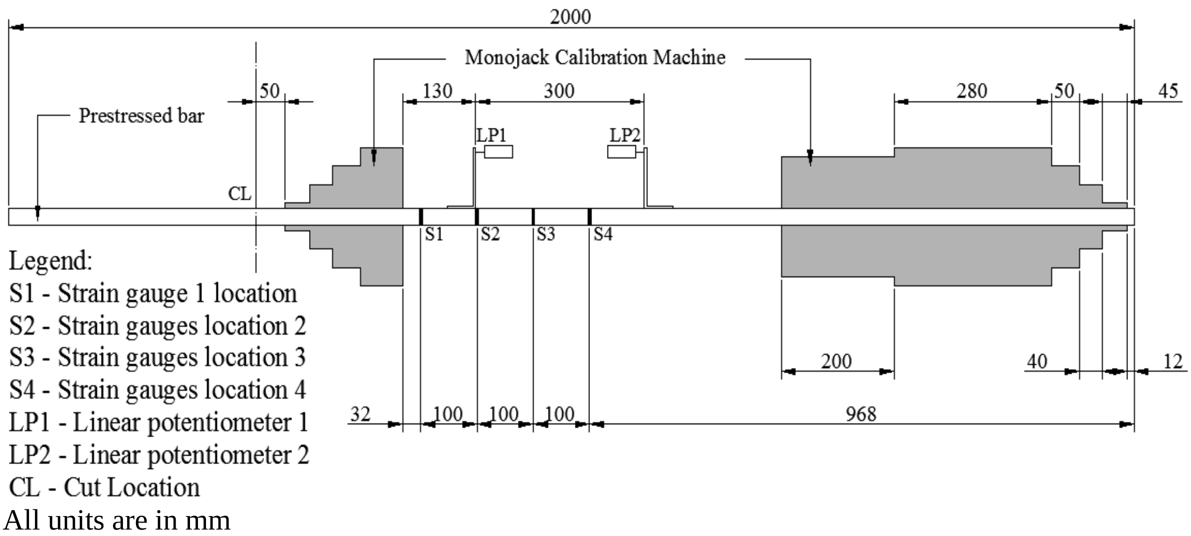

Figure 1. Monojack Calibration Machine and test specimen

Before the stressing begins, the strain value was measured. The pre-stressed bar was stressed to 40% of breaking load to simulate under service condition. The strain gauges were measured 5 minutes after the stressing. The pre-stressed bars are cut 50mm from the Monojack Calibration Machine (CL), as shown in Figure 1. The strain values were measured immediately before and after the cutting procedure then followed by 5 minute interval strain measurements. Finally, the specimens were loaded until failure. The breaking load for each specimen is shown in Table 1.

Table1. Experimental studies loading conditions

Specimen (Bar diameter), mm	Breaking Load, kN	40% of Breaking Load, kN
26	590	236
29	728	291
36	1048	419

RESULTS AND DISCUSSIONS

General Observation

In order to determine the effect of cutting method on the pre-stressed bars, 20 test specimens were carried out to verify the ultimate capacity, ductility, ultimate strain and Young's Modulus. Table 2 shows the ultimate capacity, ductility, ultimate strain and Young's Modulus of the test specimens.

Table 2 illustrates that all bar diameters show similar patterns where after cutting, the ultimate loads reduced its capacities. It was observed that the abrasive cutting had higher ultimate loads when compared to flame cutting. When compared to the control specimen, abrasive cutting and flame cutting shows a reduction in their ultimate capacities, Furthermore, the abrasive cut shows a reduction of 2.4 %, 0.3 % and 0.1 % for diameter of 26 mm, 29 mm and 36 mm, respectively. Compared to the control specimen, the flame cut shows a reduction of 2.8 %, 2.0 % and 0.3 % for diameter of 26 mm, 29 mm and 36 mm, respectively. A similar pattern was also observed for ductility and ultimate strain. From experimental studies, the ductility of the abrasive cut shows a reduction of 10.4 %, 5.2 % and 4.6 % for diameter of 26 mm, 29 mm and 36 mm, respectively when compare to control specimen whilst a reduction of 16.9 %, 8.5 % and 7.4 % for diameter of 26 mm, 29 mm and 36 mm, respectively.

Table 2. Experimental results

Specimen	Ultimate Capacities (kN)	Ductility	Ultimate Strain (ε) (Average)	Young Modulus (MPa)
26 CS_{av}	605	77	0.084	220721
26FC_{av}	588	64	0.073	208968
26AC_{av}	590	69	0.081	198979
29 CS_{av}	745	71	0.075	224719
29FC_{av}	730	65	0.073	213829
29AC_{av}	743	67	0.074	201862
36 CS_{av}	1070	95	0.090	230719
36FC_{av}	1067	88	0.085	220591
36AC_{av}	1069	91	0.087	207033
CS_{av} represents average control specimens FC_{av} represents average flame cut specimens AC_{av} represents average abrasive cut specimens				

As for ultimate strain, the abrasive cut also shows higher ultimate strain when compared to flame cut. This is due to the flame cut transferring heat to the pre-stressed steel material properties. All flame cut specimens had a large heat-affected zone at the torch side of the specimens due to the larger heat input from the cutting nozzle which caused the material to deteriorate. Compared to the control specimen, the abrasive cut shows a reduction of 3.6 %, 1.3 % and 3.3 % for diameter of 26 mm, 29 mm and 36 mm, respectively. Compared to the control specimen, the flame cut shows a reduction of 13.1 %, 2.7 % and 5.6 % for diameter of 26 mm, 29 mm and 36 mm, respectively.

In order to study the effect of cutting method on the stiffness of the pre-stressed bars, Young's Modulus was measured during the test. Stiffness is a structural property influenced by the geometry of the specimens as well as the Young's Modulus. From the experimental study, the abrasive cut shows a reduction of 5.3 %, 6.3 % and 12.5 % for diameter of 26 mm, 29 mm and 36 mm, respectively. Compared to the control specimen, the flame cut shows a reduction of 9.8 %, 10.0 % and 10.3 % for diameter of 26 mm, 29 mm and 36 mm, respectively.

Proposed Design Graph

Figure 2 illustrates the ultimate load versus pre-stressed bar diameter for both the abrasive and flame cut. Figure 2 shows the ultimate load for the three stress bars are in favour of the abrasive cut method. The experimental studies also take into consideration the cutting time between the two methods. The flame cutting was four times less compared to abrasive cutting. It should be noted that cutting time increased proportionally to the increasing diameter size. From the experiments, the authors herein proposed an ultimate capacity as a function of bar diameter as shown in Equations 1 and 2 for abrasive cut and flame cut respectively.

$$F = 0.6d_p^2+10.8d_p-53 \quad \text{for } 26mm<d_p<36mm \quad (1)$$

$$F = 0.4d_p^2+21.7d_p-225 \quad \text{for } 26mm<d_p<36mm \quad (2)$$

Where
F is the ultimate capacity;
d_p is the bar diameter.

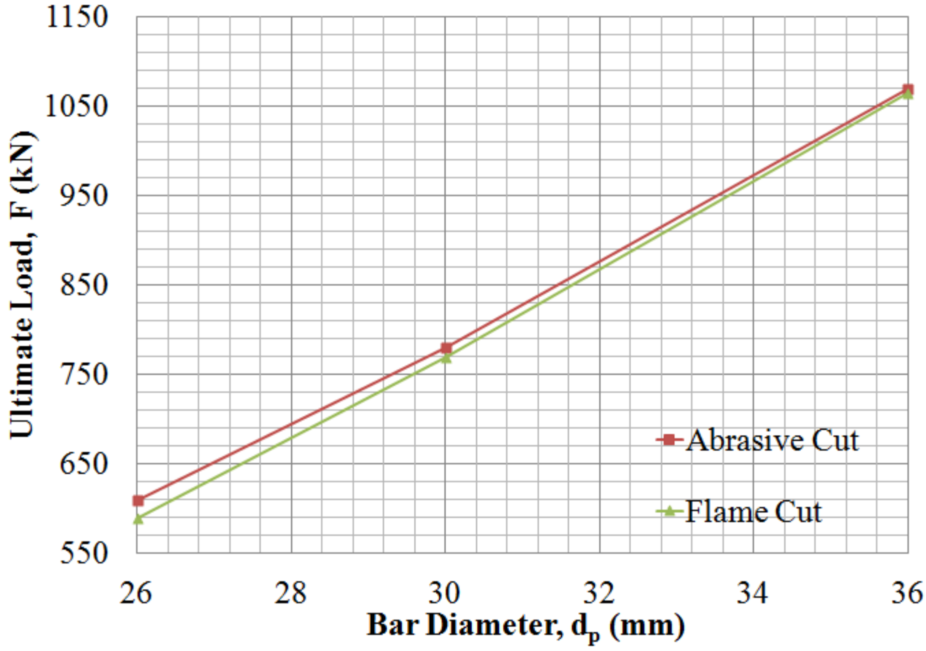

Figure 2. Ultimate capacity according to diameter

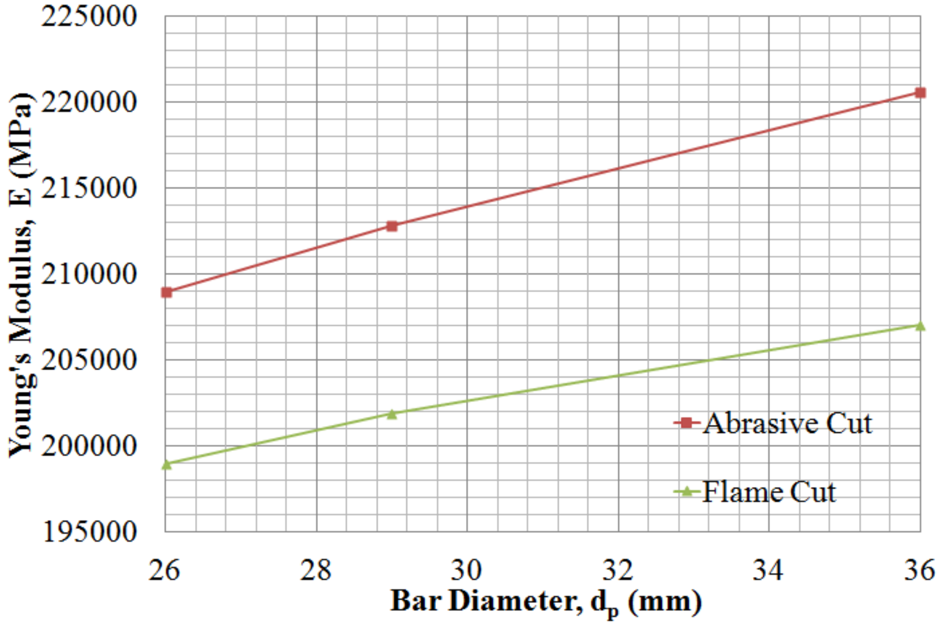

Figure 3. Young's Modulus according to diameter

Figure 3 shows that behaviour of Young’s Modulus according to bar diameter for both abrasive cutting and flame cutting. Figure 3 illustrates that the abrasive cut has a higher Young’s Modulus compared to flame cut. They behave linearly according to the bar diameter. The Young’s Modulus as a function of bar diameter can be determined in Equations 3 and 4 for abrasive cut and flame cut respectively.

$$E = 1127.5d_p - 180261 \quad (3)$$

$$E = 793.6d_p - 178553 \quad (4)$$

Equations 1 to 4 are useful for designers. When choosing method for a required strength and stiffness for the pre-stressed bars, Equations 1 to 4 are very useful to estimate these values. Additionally, the strength in the bar can be determined to confirm structure capacity if an alternative method to that specified in the work method statement or design requirements was used. Further experimental research is considered necessary in order to validate more bar diameters and different pre-stressed bars or strands to enhance the understanding on the effect of cutting method.

CONCLUSIONS

Based on the test results and with respect to the analysis of all the data gathered, the following conclusions can be made:

1. Pre-stressed steel bars lose their strength when subjected to both abrasive cut and flame cut. The size or diameter of the bar has a higher effect on the Young's Modulus.

2. The ultimate load, ultimate strength and ductility for all three bars are in favour of abrasive cut. However the difference between the two cuts is minimal.

3. The availability of the cutter and the ratio of cuts to time should also be considered when choosing the cutting options.

4. Flame cut is proven to be the better solution in terms of cut to time ratio.

5. The two design graphs are useful for design engineers to choose a suitable cutting method according to their design requirement.

This is a preliminary investigation which will be further supported by more testing and analyses in the further research.

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REFERENCES

Bhatia, A. (2011), *Fundamentals of Gas Cutting and Welding*, CED Engineering, Stony Point, NY, <http://www.cedengineering.com/upload/Fundamentals%20of%20Gas%20Welding%20and%20Cutting.pdf>.

Bucknam, J. & Young, L. (1937), "Method and Apparatus for Welding and Cutting", patent, 542963, America.

Caprani, C. (2007), *Prestressed Concrete*, Civil Engineering Design, pp. 1-76

Furrer, A. & Wehrli, H. (1982), "Process and Device for Laser-beam Melting and Flame Cutting", patent, 207926.

Kasan, J. (2012), *On the Repair of Impact-damaged Pre-stressed Concrete Bridge Girders*, University of Pittsburgh.

Kose, M.M. (2007), "Prediction of Transfer Length of Prestressing Strands Using Neural Networks", *ACI Structural Journal*, vol. 104, no. 2, pp. 162-9.

Moon, D., Zi, G., Kim, J., Lee, S. & Kim, G. (2010), "On strain change of prestressing strand during detensioning procedures", *Engineering Structures*, vol. 32, pp. 2570-8.

Okumus, P., Oliva, M.G. & Becker, S. (2012), "Nonlinear finite element modeling of cracking at ends of pretensioned bridge girders", *Engineering Structures*, vol. 40, no. 0, pp. 267-75.