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The Possibility of Using Waste PET Plastic Strip to Enhance the Flexural Capacity of Concrete Beams

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ABSTRACT

The most widely used material after water is the concrete composite. However, it is commonly accepted that concrete is weak in tension compared to its compression, therefore, conventionally, it is usually reinforced with steel rebars. Recently, reusing of waste plastic materials has become a norm among researchers whom used it in different forms in improving some mechanical properties of the concrete such as impact and tensile strength. However, using PET plastic strips as a replacement of main steel rebars is a novel idea. Therefore, in this study the experimental laboratory work is conducted to investigate the possibility of using waste plastic strips as a replacement of the main reinforcement steel bars to promote the flexural capacity of concrete beams at 28 days. For this purpose, a total number of 10 beams were casted with dimensions of (200mm x 200mm x 1200mm) to investigate the effects of using waste plastic strips in enhancing the bending capacity of the beams. The results showed that the incorporation of the plastic strips can improve the load carrying capacity and toughness of the concrete beams compared to unreinforced concrete beams.

Key words: Concrete; recycling plastics; flexural Strength; Deflection.

INTRODUCTION

One of the significant innovations of the twentieth century was plastics and their usage has become prevalent all over the world. Nowadays, the use of plastic has significantly increased, which leads to accumulation of a considerable amount of waste plastics in the environment all over the world (Saikia and De Brito, 2012). Over the last two decades, waste plastics were accounted for causing a big issue to the environment they are measured as one of the extreme risky sources of environmental pollution (Ismail and Al-Hashmi, 2008) (Al-Salem et. al., 2009) (Guerrero et. Al., 2013) (Iucolano et. al., 2013) (Wu et. al., 2013) (Liguori et. al., 2014).

Globally, plastic manufacturing has been skyrocketed. For instance, only in 2018, about 359 million tons of plastics were produced where 51% of these plastics were made in Asia and 17% were made in Europe (Europe, 2019). EU28+NO/CH in 2018, illustrated the remediation of waste plastics which is presented in Figure1. In the same year, around 32.5% of post-consumer plastics was mechanically recycled, 42.6% was recovered for energy, and the rest 24.9% was landfilled among the total plastic wastes (Europe, 2019).

Plastics have a bulky nature and degrade very slowly, so they cause serious challenges when they are land-filled, because they may restrict the underground water movement, and also cause obstacles to tree roots. It should also be known that the lead and cadmium are ingredients of waste plastics which contain a variety of toxic materials that may pollute earth soils and water when they mix with rainwater.

Therefore, to tackle the negative effects of post-consumer plastics on the environment, recycling and reusing them are measured as one of the best solutions. In recent years many studies have been conducted to reuse of waste plastics in a mortar and concretes in different forms such as an alternative to natural sands (Aslani, 2016) (Aslani, et. al., 2018) (Bušić, et. al., 2018) (Faraj, et. al., 2019) (Thorneycroft, et. al., 2018) (Kohistani and Singh, 2018) (Verdolotti et al., 2014), or as fiber to reinforce mortar and concretes (Boiny et. al., 2016) (Alshkane et. al., 2017)

(Mohammed and Rahim, 2020). The researchers have reused different types of post-consumer plastics, for instance, polypropylene(pp) (Yang et. al., 2015), polyvinyl chloride (PVC) pipes (Kou et. al., 2009), expanded polystyrene foam (EPS) (Kan and Demirboğa, 2009), high density polyethylene (HDPE) (Naik et. al., 1996), thermosetting plastics (Panyakapo and Panyakapo, 2008), polycarbonate (Hannawi et. al., 2010), polyurethane foam (Fraj et. al., 2010) (Mounanga et. al., 2008), glass reinforced plastics (GRP) (Asokan et. al., 2010), and polyethylene terephthalate (PET) (Harini and Ramana, 2015), (Boiny et. al., 2016), (Alshkane et. al., 2017) and (Mohammed and Rahim, 2020).

PET is the most used thermoplastic polyester and it has a good mechanical and dimensional stability performance under variable loads. It also has a good chemical and gas barrier properties (Jabarin, 1996).

On the global level, the most frequently used construction material is the concrete, which is made by mixing sand, gravel, cement, water, and sometimes admixtures. This important construction material has a weak point which is a low tensile strength compared to its compressive strength. Therefore, steel reinforcement has been used to improve the tensile behavior of concrete elements (Neville, 1995). In addition, many research studies have been conducted on the structural concrete level to study the structural behavior of concrete which contains a variety form of post-consumer plastics (Dai et. al., 2012), (Mahdi et. al., 2013), (Marthong and Marthong, 2016), (Zhang et. al., 2016), (Mohammed, 2017), and (Kim et. al., 2010). However, using PET strips as replacement of main steel rebar is very rare.

This study is conducted to show the possibility of using waste plastic strips as the main bars to reinforce normal concrete beams compared to plain and steel reinforced concrete beams. The source of waste plastic strips used are the leftovers of packaging industry as they were used in fastening different forms of materials such as brick and blocks. Nine, six and three strips of this waste plastic strips are used as main bars reinforcement in the concrete beams and then tested at 28 days.

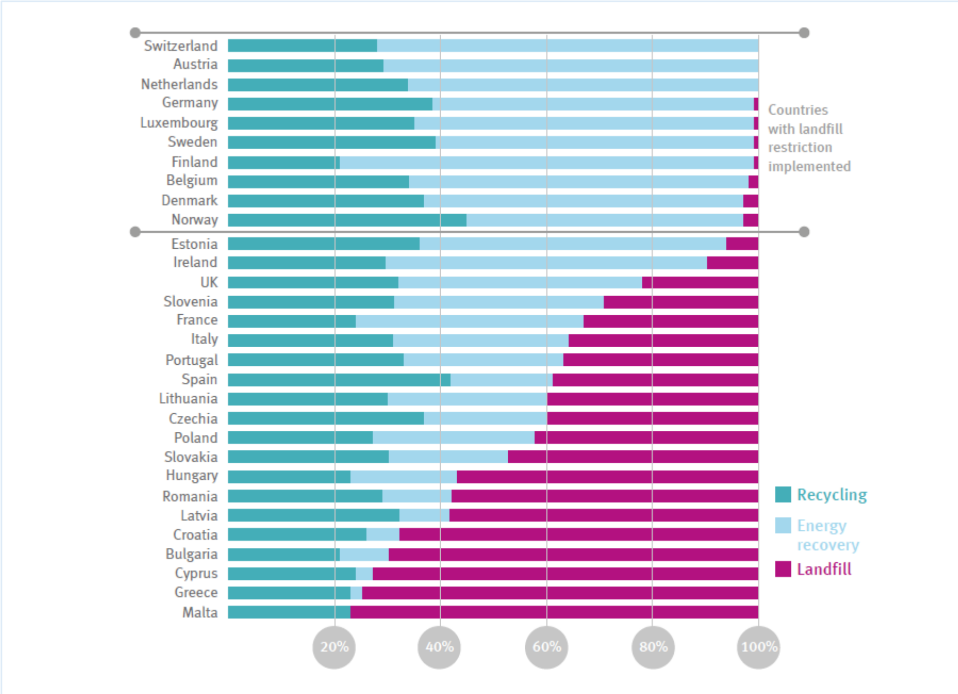


Figure 1 Plastic post-consumer waste rates of recycling, energy recovery and landfill per country in 2018 by EU28+NO/CH (Europe, 2019)

SIGNIFICANCE OF THIS STUDY

Conventionally, steel reinforcement is commonly used to reinforce concrete elements, but one of the challenges of this century is to find out an alternative material to replace steel bars inside the concrete elements. Another issue related to this century is the possibility of reusing of waste materials to protect our environment from pollution. Therefore, this research aims to show the possibility of using waste plastic strips to reinforce normal concrete beams. It can be counted as an attempt to contribute in tackling the above related issues.

MATERIALS AND METHODOLOGY

The materials are available in the local areas of (Sulaimaniyah City, Qalachwalan, and Darbandikhan). All the materials are tested and then mixed to prepare the samples.

MATERIALS

The following materials are used in this study:

CEMENT

Ordinary Portland Cement is used which is commercially available in Tasluja Cement Factory in Sulaimaniyah, Iraq. The compressive strength of the cement was tested based on ASTM C109-16 after 28 days which was 26.8 MPa, and if they compared with ASTM C150- 17 and ASTM C778-17, it can be found that it is more than the minimum value required by the code.

COARSE AGGREGATE

The maximum size of the aggregate is selected to be 25 mm and a crushed stone type is used for the sake of the designing the mixes which is available in Qalachwalan quarry after testing some samples brought in Darbandikhan and Qalachwalan. Figure 2 shows the sieve analysis results of the coarse aggregate based on the procedures describes in ASTM C136-14, and then compared to the ranges set by ASTM C33-16. The specific gravity of the coarse aggregate was 2.69 according to the procedures indicated in ASTM C127-15.

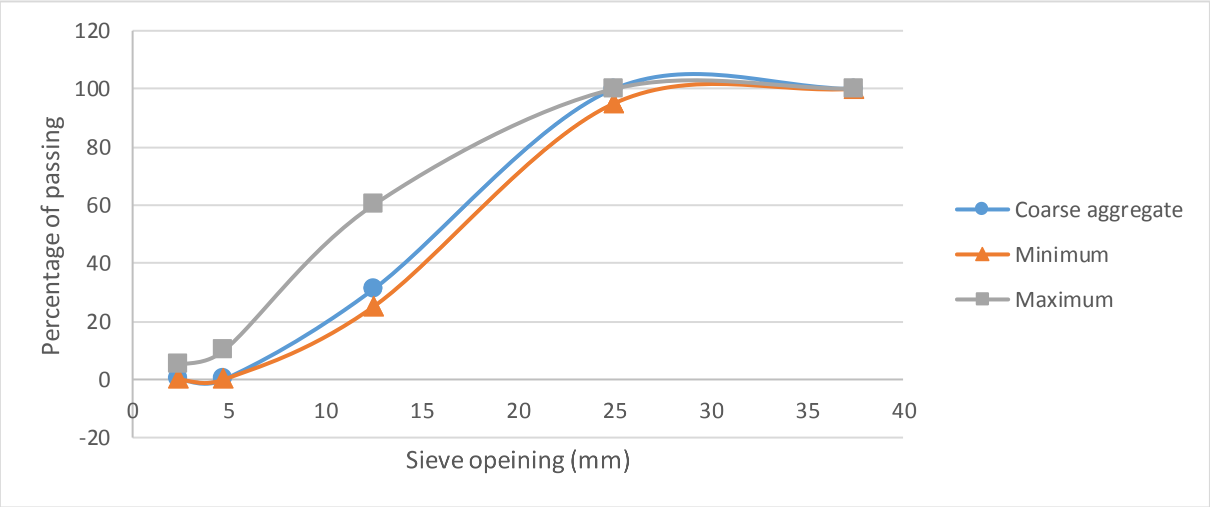


Figure 2 Sieve analysis of the coarse aggregate

FINE AGGREGATE

The fine aggregate had the maximum size of 4.75 mm which its source was Darbandikhan quarry. Figure 3 shows sieve analysis of the sample compared with the ranges provided by ASTM C33-16. The specific gravity of the sand was 2.62 based on the procedures that describes in ASTM C128-15.

PLASTIC STRIPS

Plastic strips were 12 mm wide and 0.8 mm thick and green in color. They were reused from the construction sites where initially used in package industry. The elongation of them varied between 10-15% with the breaking strength variation of 40-50 kg/ mm^2.

SPECIMENS

The total number of 10 beams were cast. Those ten beams are distributed to represent some variables in the number of the plastic strips used in each beam. For each variable two beams were cast. Based on the design of a load of 50kN, the dimensions of the beams are selected to have a cross section of 200 mm x 200 mm and the length of 1200 mm with a clear span of 1000 mm between the supports. Figure 4 shows the beam profile with its designing load. The two control beams had no reinforcement and they are called “plain beams" hereafter. The beams are considered as simply supported beams.

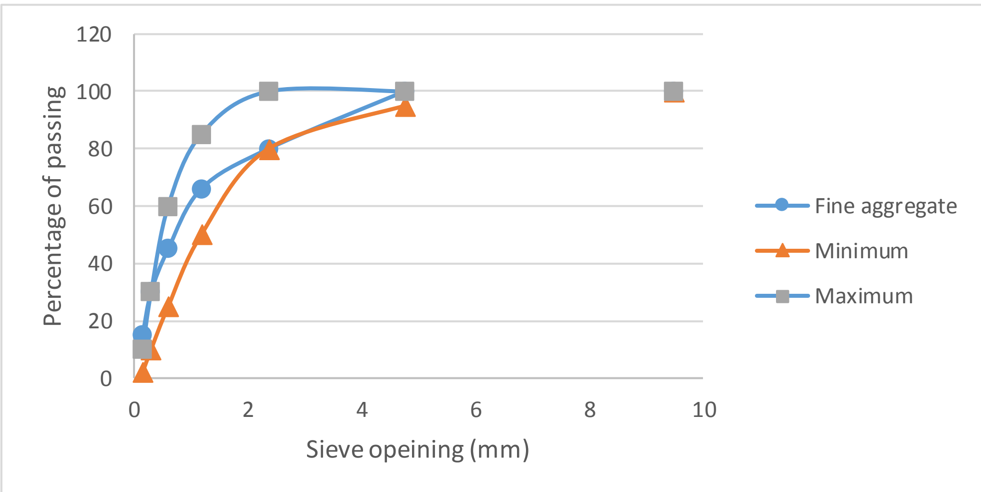


Figure 3 Sieve analysis of the fine aggregate

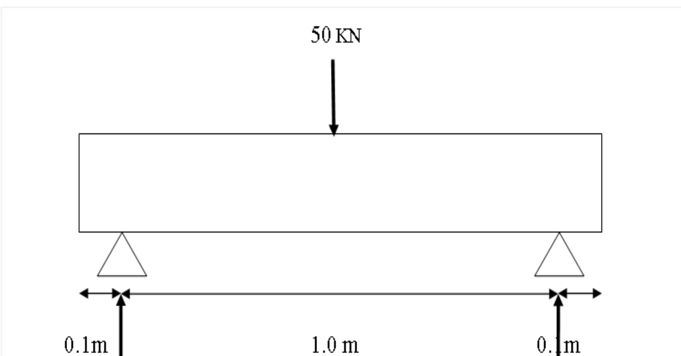


Figure 4. The beam configuration with its design load and reactions including the self-weight of the beam

After the designing process, it was found that 3 reinforce rebars with 10 mm of diameters are required to resist the applied load of 50 kN. However, the target was to use plastic strips instead of reinforce bars. Therefore, three sets of beams were cast each with having a different number of plastic strips as replacements for the number of the steel rebars regardless of the difference in their areas. The number of bars is replaced with multiplying the numbers by two each time. Therefore, two beams were casted to have 3 strips of plastic at the bottom as a replacement for the three reinforcement steel bars. More, two beams were cast to have 6 strips of plastic at the bottom of the beam arranged in three strips with two layers on top of each other. Finally, two beams were cast with 9 strips of plastic at the bottom of the beam arranged in three rows with three layers of plastic strips on top of each other. To compare the effectiveness of the strips with the conventional reinforced steel beams as an additional step, two beams were cast with 3 steel bars in their tension zone.

To ensure the flexural failure of the beams, all the beams, apart from the plain beams, were supplied with traverse reinforcement of 10 mm with a spacing of 200 mm. Also, to hold up the stirrups, except for the plain beams, all the other beams had two 10 mm steel bars on top. The plastic strips were fastened to the stirrups in the same manner as normal reinforce bars. Figure 5 shows an example of the molds with the strips at the bottom of the beams.

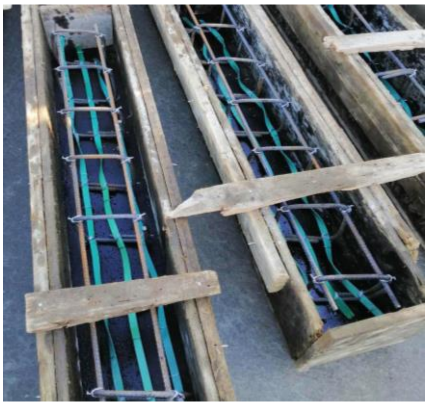


Figure 5 Beam molds with plastic strips.

MIXING

All the beams were cast from the same mix and the same day. The beams were taken out from their molds after two days of their casting and transferred to the "concrete laboratory" in College of Engineering in the Sulaimani University. The average compressive strength of the concrete was 21 MPa after 28 days. Figure 6 shows the labelled samples just after transferring them to the university.

Figure 6 Label of the beams after transferring them to the lab premises.

TESTING THE SPECIMENS

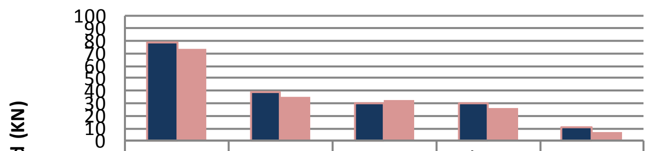
The specimens were tested in accordance to ASTM C293 using flexural testing machine from Control company available in the "concrete laboratory" in College of Engineering of Sulaimani University. The samples were loaded until failure with the rate of 1 N/ mm^2 / minute. Figure 7 shows a specimen under the loading machine. A dial gauge, shown in Figure 8, was used to measure the deflection of the beams. The test is performed using three-point flexural testing. The clear span of the beam was 1000 mm as 100 mm is left for the supports to rest on the supports form both ends of the beam. Also, and the load is applied from the center of the beam, therefore, the distance from the edge of the load to the supports is 500 mm.

Figure 7 Concrete beam under the flexural testing machine

Figure 8 Dial gauge used in measuring the mid span deflection

RESULTS AND DISCUSSION

After testing all the beams for bending, it was found out that the average ultimate load that can be carried by the plain beams was only 8.8 kN with the average deflection of 2 mm, see Figure 9. However, this ultimate load has increased to 28.18 kN when only three plastic strips were used in the tension zone. Additionally, the defection capacity of the beam has increased by 190% to reach approximately 6 mm. These numbers were elevated when 6 strips of plastic were used where the failure load reached 31.1 kN which represents 253% of increase which is due to having a plastic strip which have fairly good tensile strength. Also, the deflection of the beams has increased to 8.62 mm which counts for 330% of increase in the deflection. Finally, the best case of using strips has happened when 9 strips were used in the tension zone where the ultimate load was 36 kN which means 310 % increase compared to the control samples. Additionally, the maximum deflection of the beam was 12.32 mm which is 516%.



	steel reinforced baem	nine plastic strips reinforced beam	six pastic strips reinforced beam	three plastic strips reinforced beam	plain concrete beam
Specimen 1	78.128	38.785	30.164	30.34	10.263
Specimen 2	73.432	34.857	32.089	26.017	7.44

Figure 9 Ultimate load of the sample beams.

To comprehend the effectiveness of using plastic strips as a replacement of steel rebars, the beams with steel rebars showed superiority as their tensile strengths are more than that of the plastic strips. The ultimate load carried by the steel reinforced beams was 75 kN which was nearly twice of the capacity of the beams with 9 strips and it is 752% increase if compared with the control samples without any reinforcement.

The deflection of the steel reinforced beams was less than that of the plastic reinforced beams despite of the difference in their cross-sectional areas. From Figure 10, it can be seen that using plastic strips lead to a ductile failure mode while it is a brittle mode when no reinforcement is provided in the tension zones of the beams. Moreover, it can be noticed that using steel bars in reinforcing beams can enhance the strength of the sections while the ductility can be improved when plastic strips are used. This will be particularly beneficial when a ductile structure is needed or some parts of the buildings need to be ductile as in the case of designing buildings for earthquake loads. Also, it would be a significant replacement for the steel bars where only the minimum reinforcement is required for controlling shrinkage and temperature. Therefore, this type of plastic strip can be used in the zones where secondary or minimum rebars are required. Additionally, using plastic strips for the foundation can improve the tensile strength of it without providing concrete cover which is needed when reinforced bars provided due to fear of corrosion. If only deflection is to be compared, then the beam with 9 strips of PET has deflected 35% more than that of the ultimate deflection of the steel reinforced beam. If their deflection is to be compared for the same load, it can be seen that they have similar deflections until the load application of 30 kN. However, at its ultimate load carrying capacity of 40 kN, the deflection of the beams with 9 strips of plastic was three times of that of the steel reinforced beam.

Furthermore, it can be noticed that the failure mode was brittle when no reinforcement was provided in the beam, however, the mode has changed to be more ductile after providing PET or steel in tensioning zone. Finally, it can be observed that the ductility of the beams increases with increasing the number of plastic strips in the tensioning zone as the beam with 9 strips shows better ductility that the beam with only 3 strips.

It worth mentioning that there is a sudden increase in deflection of the beams reinforced with plastic strips. This can be seen after applying approximately 25 kN on the beams. The reason for that might be debonding between the concrete paste and the plastic strips. For this reason, it is a recommendation for future work to find the bond between the concrete and the plastic strips.

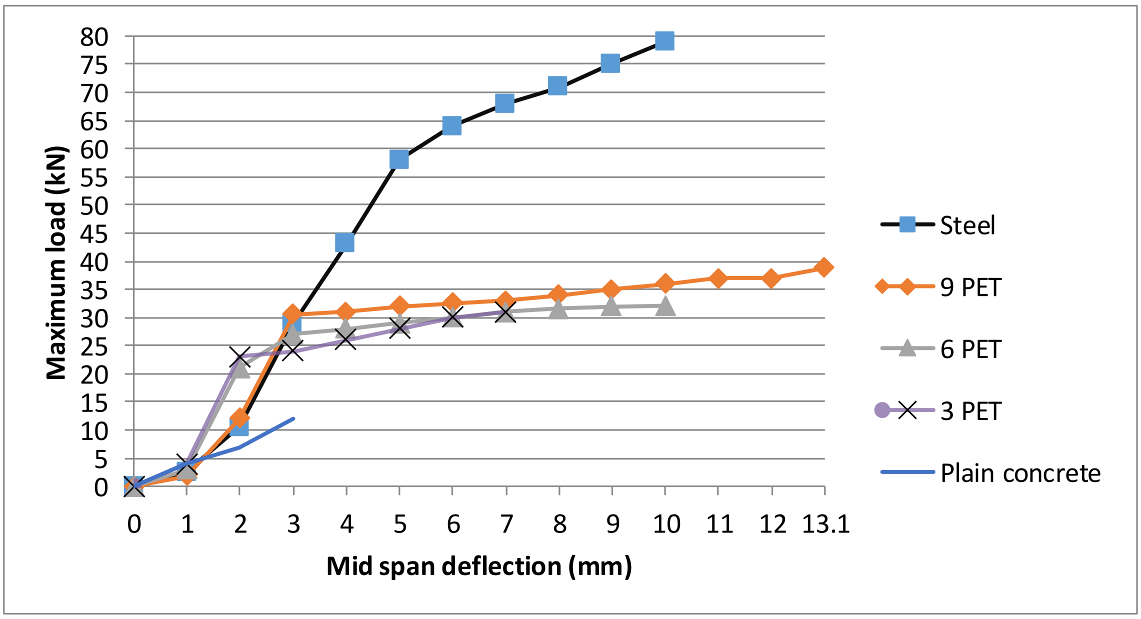


Figure 10 Load- deflection diagram of the beams.

CONCLUTIONS

Based on the results of this study it can be concluded that:

1- Waste plastic strips used in package industry can be used successfully in the tension zones of concrete beams to partially replace the steel bars especially where the tensile strength required is not large enough and only minimum reinforcement should be provided for shrinkage and temperature.

2- The load carrying capacity of the plain concrete beam can be enhanced by 225%, if only 3 plastic strips are provided, and by 280% if 9 strips of PET are provided in the tensile zone of the beams.

3- The ultimate deflection of a plain beam can increase by 190%, if only 3 strips of PET are provided, and by more than 500% if 9 strips of PET are provided in the tensioning zone of the beams.

4- The usage of PET strips can be a suitable way in reusing them inside the concrete. Even though, more research work is needed to verify the other aspects of using plastic strips such as bonding concerns.

5- The ductility of the beams increases with an increase in the number of strips as the beams with 9 PET strips in their tension zones had greater deflection capacity compared to those beams with only 3 plastic strips in their tensioning zone.

6- When compared to the usage of steel, PET may partially replace the steel bars in tensioning zone if replaced with equivalent areas not with equivalent numbers. In this research the comparison is performed to understand the efficiency of the PET with respect to steel reinforcement which is found that the load carrying capacity of the PET reinforced beams with 9 strips of PET can reach nearly half (36.82kN) of that of the beams reinforced with 3 bars of steel (76.78kN).

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