Effects of Waste Plastic PET Fibers on The Fresh and Hardened of Normal Concrete

Ali H. Allawi1, Abdulkader I. AL-Hadithi1, Akram S. Mohmoud1

1Civil Engineering department, College of Engineering, University Of Anbar, Ramadi, Anbar, Iraq.

ARTICLE INFO

Article history:
Received 12/04/2021.
Received in revised form 20/04/2021.
Accepted 21/04/2021
Available online 23/06/2021

Keywords:
waste plastic fibers,
polyethylene
terephthalate PET,
Toughness
Concrete

ABSTRACT

In this paper, the laboratory experiments works were conducted to study the effect of adding recycle waste plastic as polyethylene terephthalate PET fibers on the fresh properties as the slump test and hardened properties as a compressive strength, splitting strength, elastic modulus, ultrasonic pulse velocity (UPV), density, absorption, voids, flexural toughness and flexural rupture for the normal concrete. The parameter of this paper included percentage of fibers content (0%, 0.5%, 1%, and 1.5%). The geometric design of the PET fibers was a strip with dimensions 4mm width, 70mm length, and 0.035mm thickness. The aspect ratio of the PET fibers in this work was about 50. The results showed that the PET fibers improving the most properties of the normal concrete and on the other hand there is negative effect on some properties of concrete. There is a significant increase in flexural toughness, about 21.2%, while the compressive strength and splitting were increased by 5% and 18.8%, respectively. Besides this improving, using PET fibers conform to the principle of sustainability, which is reducing the pollution and the cost of waste plastic disposal. It’s observed that properties of concrete as a static modulus of Elasticity and density were decreased with the fiber percentage increased.

1. Introduction

In this world, the polyethylene terephthalate PET most extensively plastic used to produce the containers and other items. According to the worldwide production, the PET production in the Asian market increase by more than 6.7 million tons per (Kim et al., 2010). However, if PET is not properly disposed of, it may trigger environmental and economic problems. Since the cost of solid waste disposal is that while landfill space is shrinking, recycling is the best option for converting waste into usable items. The efficiency of concrete reinforced with short plastic fibers is significantly improved, including its tensile strength and ductility, according to the findings. Short plastic fibers act as a bridging force around the crack, preventing it from spreading further (Alhozaimy & Shannag, 2009; Auchey, 1998; de Oliveira, Castro-Gomes, & Materials, 2011; Naaman, Garcia, Korkmaz, & Li, 1996; Wang, Wu, & Li, 2000) . (Kim et al., 2010) studied the effect of the PET on the mechanical properties of concrete. The results showed that the compressive strength and elastic modulus decrease with the fiber content increase; furthermore, the cracks due to drying shrinkage were delayed in the presence of PET fibers in concrete. (Choi, Moon, Kim, Lachemi, & Materials, 2009) reported that the use of recycled PET fibers industrial gives the environmental, economic and technical advantage to the construction industry sector. (Najm & Balaguru, 2002) evaluated the effect of the PET fibers with different aspect ratio on the controlling cracking. The results showed that the higher aspect ratio more effective in controlling cracking.
(Li, 2005) investigated the effect of PET fibers shape on the plastic shrinkage cracking. The results showed that the fibers with polygonal shapes have more effective than the circular shapes

1.1. Aim of the Study

The aim of this study includes improving the mechanical properties of the concrete.

2. Experimental Work

2.1. Material Properties

2.1.1. Cement

The locally available materials were used in this paper, the ordinary Portland cement conformable with the (Standardization & Control, 1984) such as shown in table 1.

Table 1 – Chemical and physical properties of Ordinary Portland cement

| compositions | Result | The limitations of specification according (I.Q.S.) No.5/1984 |
|--------------|--------|-------------------------------------------------------------|
| Chemical properties | | |
| CaO | 66.26 | --- |
| Fe2O3 | 3.73 | --- |
| SiO2 | 19.11 | --- |
| Al2O3 | 6.42 | --- |
| MgO | 1.45 | Not more than 5 % |
| SO3 | 2.31 | Not more than 2.5 % |
| Insoluble residue | 0.96 | Not more than 1.5 % |
| Lime saturation factor | 0.91 | 0.66 — 1.02 |
| Loss on ignition | 2.2 | Not more than 4 % |
| Major compounds of cement | | |
| C3A | 2.9 | Less or equal 3.5 % |
| C2S | 8.52 | --- |
| C3S | 61.8 | --- |
| C4AF | 7.07 | --- |
| physical properties | | |
| Initial settling time | 194 min. | Not less than 45 min. |
| Final settling time | 245 min. | Not more than 10 h. (600 min.) |
| Fineness (cm²/gm.) by Blaine method | 2600 | Not less than 2300 |
| Compressive Strength at 3 days (MPa) | 16 | Not less than 15 (MPa) |
| Compressive Strength at 7 days (MPa) | 28 | Not less than 23 (MPa) |

2.1.2. Fine Aggregate (Sand)

As a fine aggregate, red sand was used in this paper. Fine aggregate was tested according to the (Specification, 1984) such as shown in table 2.

Table 2 – Grading Test and properties of fine aggregate.

| Test Type | Result | The limitations of specification according (I.Q.S.) No.45/1984 |
|-----------|--------|-------------------------------------------------------------|
| Sieve size (mm) | Passing % | Zone1 | Zone2 | Zone3 | Zone4 |
| 10 | 100 | 100 | 100 | 100 | 100 |
| 4.75 | 98.2 | 100 - 90 | 100 - 90 | 100 - 85 | 100 - 95 |
| 2.36 | 84.8 | 95 - 60 | 100 - 75 | 100 - 85 | 100 - 95 |
2.1.3. Coarse Aggregate Gravel

Coarse aggregate was used with max size 10mm, specific gravity 2.65% and absorption 0.68%. Coarse aggregate was tested according to the (Specification, 1984), the grading and physical properties of the coarse aggregate are shown in table 3.

| compositions                  | Result          | The limitations of specification according (I.Q.S.) No.5/1984 |
|------------------------------|----------------|------------------------------------------------------------|
| **Grading Test**             |                |                                                            |
| Sieve size mm                | Passing %      | The limits of cumulative passing (%)                       |
| 20                           | 100            | 100                                                        |
| 14                           | 100            | 90-100                                                     |
| 10                           | 80.7           | 50-85                                                      |
| 5                            | 9              | 0-10                                                       |
| **Chemical and Physical properties** |                |                                                            |
| % of SO3                     | 0.03%          | Not more than 0.1%                                         |
| Clay                         | 1%             | Not more than 2%                                           |
| Specific gravity             | 2.65           | ---                                                        |
| Absorption                   | 0.68%          | ---                                                        |

2.2. Mix Design

The perfect mixture with a good workability and compressive strength was designed according to the (Committee, 2005) Figure 1 shows the effect of the PET fibers on the workability of concrete. Table 4 shows the details of the mix design as a mix proportion and compressive strength at 7-day and 28-day. The high performance Superplasticizer concrete mixture.

**Fig. 1 Slump test.**
Table 4 – Proportions and weights of mixture contents.

| Mix | Components kg/m³ | W/C | Super % of Cement | Slump (mm) | Comp. strength MPa at 7 day | Comp. strength MPa at 28 day |
|-----|-------------------|-----|-------------------|-----------|--------------------------|---------------------------|
| A   | 430 900 1020 184  | 0.42| 0.5%              | 110       | 31                       | 37.5                      |

2.3. Waste Plastic Polyethene Terephthalate (PET)

In this paper, the waste plastic PET were obtained by cutting the soft drink bottles to strips with the specified dimensions (70*4) mm as shown in figure 2. The waste plastic (PET) properties were illustrated in table 5.

![Figure 2Procedure of cutting the soft drink bottles.](image)

Table 5 – Properties of waste plastic fiber (PET).

| Dimensions (mm) | Aspect Ratio | Density (kg/m³) | Water Absorption | Color                      |
|-----------------|--------------|-----------------|------------------|----------------------------|
| 70 * 4 * 0.35   | 50           | 1.38            | 0                | Crystalline Colourless transparent |

2.3.1. Tensile Strength of PET Fiber

According to the (standards, 1993), the test of PET fibers was carried out at the laboratory of the University of Technology as shown in figure 3. Table 6 was illustrated the results of the PET fiber test.

Table 6 – Results of the tensile strength of the (PET) fiber.

| Type of plastic        | Max Tensile stress MPa | Total percent elongation % | Elastic modulus (GPa) |
|------------------------|------------------------|----------------------------|-----------------------|
| polyethene terephthalate| 110                    | 28.57                      | 0.59                  |
3. RESULTS AND DISCUSSION

3.1. Workability

According to the specification (C. J. A. I. ASTM, 2003), the workability for fresh concrete was decreased with the fiber percentage increased and the maximum decreased was (75%) at the fiber percentage 1.5%. Figure 4 illustrated the effect of PET fibers on the workability. The decrease that happen in concrete workability when added the fiber attributed to the geometric design of the fiber (ribbon with sharp edges) and its role in mixture concrete, which is restrained the movement of the components of the mixture. (Bhogayata, Shah, Vyas, Arora, & technology, 2012) showed that the workability of normal concrete decreases as the addition of waste plastics fibers in concrete increases by up to 25%.

![Figure 4: Effect of PET fibers on the workability](image)

3.2. Compressive Strength ($f_c$)

In this research, the compressive strength has been calculated according to the (Standard, 2010). Three cylinder were tested for each fiber percentage and take the average. The compressive strength of normal concrete increased by 5% at the fiber percentage 0.5%, while decreased by 15.9% and 32.7% at the fiber percentages 1% and 1.5%, respectively as shown in figure 5 due to the role of fibers in connected the two opposite side of cracks (Al-Hadithi & Abbas, 2018a). Exegesis the increasing of the compressive strength is that the fiber work as a ribbon inside the mixture of concrete, which connected the composites of the concrete.
This lead to delay appearance the crack and increased the amount of the absorbed energy after the crack has happened because the fiber work as a bridge in this case between the two opposite sides of the crack, thus increasing the load capacity. But the decrease in the compressive strength at the fiber percentage 1% and 1.5% was due to increase of forming the gaps under the fibers inside the concrete as a result to increase the amount of fiber in concrete. Figure (4-3) illustrated the failure of the cylinders under the load that has been applied by the instrument and the cracks forms affected by the fiber percentage. (Malagavelli, Patra, & Engineering, 2011); (Pelisser, Montedo, Gleize, & Roman, 2012); (Ramadevi, Manju, & engineering, 2012); (Rahmani et al., 2013); (Prahallada, Parkash, & Technology, 2013) observed that the addition of PET and HDPE fibers in small amount results in an increase in compressive strength fc but the addition of large amount of PET particles reduce the strength.

Fig. 5 Effect of PET fibers on the compressive strength.

3.3. Splitting Strength ($f_t$)

The splitting tensile strength has been tested according to the (C. J. U. S. A. I. ASTM, 2004) specification. The splitting strength of the normal concrete increased by 11% and 18.8% at the fiber percentages 0.5% and 1%, respectively, while decreased after these percentages by 13.5% as shown in figure 6. As a previous explanation in compressive strength (Al-Hadithi & Abbas, 2018b).

Fig. 6 Effect of PET fibers on the splitting strength.

3.4. Static Modulus of Elasticity ($E_c$)

Elastic modulus has been tested according to the (C. J. A. B. o. A. S. ASTM, 2002) specification which is defined the elastic modulus as being the slope of the stress-strain curve from the point strain 50 micro strains to
the point 40% of the stress. The Elastic modulus of the normal concrete decreased with the fiber percentage increase and the maximum decreased value was by 17% at the fiber percentage 1.5% as shown in figure 7. The results above can be clarified based on the relationship between strain stress curve, which that there is a difference in the amount of increasing in the value of the strain when the concrete is contented the fiber. Existence the fiber was made the increasing value of the strain more than the increasing value of stress.

![Fig. 7 Effect of PET fibers on the Static Modulus of Elasticity.](image)

### 3.5. Ultrasonic Pulse Velocity (UPV)

According to the (C. J. A. I. Astm, West Conshohocken, PA, 2009), the Ultrasonic Pulse Velocity (UPV) of the normal concrete decreased with the fibers percentage increase and the maximum decreased value was by 9.1% at the fiber percentage 1.5%. Figure 8 was illustrated the effect of PET fiber.

![Fig. 8 Effect of PET fibers on the Ultrasonic Pulse Velocity.](image)

The explanation of this decrease in the pulse velocity is the presence the porosity in concrete. The pulse is scattered as it travels through the porous concrete. As a result, the actual travel path of waves is longer than the distance between the transducers and the time pulse travel is longer because the pulse cannot travel through the porosity (Al-Hadithi & Abbas, 2018b).
3.6. Density, Absorption and voids in Hardened Concrete.

According to the ASTM C 642; Standard Test Method for absorption, density, and voids in hardened concrete (C. J. A. b. o. A. s. Astm, 2006), the Bulk density dry and after immersion in hardened concrete decreased by 2.5% at the fiber percentage 1.5% while the Volume of permeable pore space voids and absorption in hardened Concrete increased by 15% and 16.8% respectively, at the fiber percentage 1.5%. Table 7 showed the effect of the PET fiber on the absorption, density, and voids in hardened concrete. Increasing the PET fiber in concrete increases the porosity, thus lead to decrease the mass of specimen and increase the absorption during fill these porosities with water. The density equal mass/volume, therefore the density decreased with the mass decreased (Al-Hadithi & Abbas, 2018b; Albano, Camacho, Hernandez, Matheus, & Gutierrez, 2009; Araghi et al., 2015).

Table 7 – The results of density, absorption, and voids in hardened concrete.

| Dimensions (mm)                                | 0%         | 0.5%        | 1%          | 1.5%        |
|------------------------------------------------|------------|-------------|-------------|-------------|
| Absorption of sample after inundation (%)      | 1.5615     | 1.8582      | 1.8608      | 1.8775      |
| Difference %                                   | ----       | + 15.9      | +16.08      | +16.8       |
| Absorption after immersion and boiling, (%)    | 1.5234     | 1.8198      | 1.8219      | 1.8386      |
| Difference %                                   | ----       | +16.2       | +16.4       | +17.1       |
| Bulk density, dry (g1) (kN/m3)                 | 23.47      | 23.01       | 22.99       | 22.88       |
| Difference %                                   | ----       | - 1.9       | - 2         | - 2.5       |
| Bulk density after immersion (kN/m3)           | 23.84      | 23.43       | 23.42       | 23.31       |
| Difference %                                   | ----       | - 1.7       | - 1.76      | - 2.2       |
| Bulk density after immersion and boiling (kN/m3)| 23.83     | 23.42       | 23.41       | 23.30       |
| Difference %                                   | ----       | - 1.7       | - 1.76      | - 2.2       |
| Apparent density (g2) (kN/m3)                  | 24.34      | 24.02       | 24          | 23.88       |
| Difference %                                   | ----       | + 1.3       | + 1.39      | + 1.88      |
| Volume of permeable pore space (voids) (%)     | 3.5743     | 4.2048      | 4.2083      | 4.1876      |
| Difference %                                   | ----       | - 1.49      | - 1.51      | - 1.46      |

3.7. Flexural Toughness

Flexural toughness is an important characteristic to evaluate the effect of fiber on the post-peak behavior. This test was carried out to obtain the load-displacement curve, which is the area under this curve represented the energy absorption. All specimens were tested such as shown in figure 9 and the ASTM C 1018 (C. J. A. S. o. T. M. ASTM, USA, 1997) and JSCE Standard SF-4 (1995) (JSCE, 1984) methods are used to calculate the flexural toughness.

Fig. 9 Failure of specimen under flexural loads (toughness).
The toughness index I5, I10, I20, and I30 are calculated according to the (C. J. A. S. o. T. M. ASTM, USA, 1997), which is represented the toughness at the deflection 3 δ, 5.5 δ, 10.5 δ, and 15.5 δ respectively, such as shown in figure 10. Table 8 explained the value of the toughness index for all fiber percentage.

![Fig. 10 Toughness indices according to (C. J. A. S. o. T. M. ASTM, USA, 1997).](image)

### Table 8 – Toughness results according to the (C. J. A. S. o. T. M. ASTM, USA, 1997).

| Fiber percentages | 0%  | 0.5% | 1%  | 1.5% |
|-------------------|-----|------|-----|------|
| δ                 | 14.9| 19.683| 20.443| 16.94 |
| 3δ                | 27.786| 40.483| 53.066| 40.083 |
| 5.5δ              | -- | 66.856| 74.083| 62.466 |
| 10.5δ             | -- | 86.566| 86.47| 78.723 |
| 15.5δ             | -- | 105.243| 103.866| 95.86 |
| δ                 | 14.9| 19.683| 20.443| 16.94 |
| **Toughness index** | | | | |
| I5                | 1.863| 2.054| 2.594| 2.365 |
| I10               | 0   | 3.398| 3.627| 3.687 |
| I20               | 0   | 4.402| 4.231| 4.648 |
| I30               | 0   | 5.350| 5.084| 5.659 |
| **Residual strength factor** | | | | |
| R5,10             | -- | 26.885| 20.656| 26.445 |
| R10,20            | -- | 10.036| 6.044| 9.606 |
| R20,30            | -- | 9.480| 8.525| 10.110 |

According to (JSCE, 1984) method, the area ($D_f$) under the load-displacement curve up to the deflection (L/150) obtained, as figure 11. From this area, the flexural toughness factor (FT) is calculated, which its value indicates to the post-crack residual strength of the material when loaded to the deflection span/150. Table 9 explained the value of the (FT) for all fiber percentage.

### Table 9 – Toughness results according to the (JSCE, 1984)

| Fiber percentages | 0%  | 0.5% | 1%  | 1.5% |
|-------------------|-----|------|-----|------|
| δ150              | 14.9| 19.683| 20.443| 16.94 |
| D_f               | 27.786| 40.483| 53.066| 40.083 |
| FT                | -- | 66.856| 74.083| 62.466 |
The maximum value of the modulus of rupture \( f_r \) was at the fiber percentage 0.5% compared with the control specimen without fiber, which is increased about 3.99%. While the failure mode of the specimen changes from the collapse to the failure with appeared the crack and the width of this crack decreased with the fiber percentage increased, such as shown in figure 12. The plastic in concrete works like a crack arrester during the propagation of the crack and bridging the concrete. All results of the modulus of rupture \( f_r \), cracks width, and ultimate load were shown in the table 10.

As a result, the effect of the waste plastic on the toughness index and flexural toughness factor was very clear for the all specimens with the fiber content. The toughness index for the I5 was increased about the 28.18%, while the Flexural toughness index was increased about 59.57%. The explanation of the behavior is that the fiber carried the portion of the stress due to the distribution of stress after the cracks are happening.
4. Conclusions

1. The workability decreased by 75% at the fiber percentage of 1.5% due to the role of fibers in restrict and bridging the concrete.
2. The compressive strength and splitting strength were increased by 5% and 18.8% at the fiber percentage 0.5% and 1%, respectively. As the previous explanation in workability.
3. The Elastic modulus was decreased by 17% at the fiber percentage of 1.5% due to an increase in the strain of the concrete with the presence of PET fibers.
4. The Ultrasonic Pulse Velocity and the bulk density were decreased by 9.1% and 2.5% respectively due to the increase porous and this makes the path of wave longer than the path of the wave in concrete without fibers.
5. The flexural toughness and modulus of rupture of the normal concrete increased with the fiber percentage increase until to the 1% and then decreased with the fiber increased after this percentage, where the I5 increased by 21.2% for the flexural toughness and by 4% for the flexural rupture at the fiber percentage1%, compared with the reference specimen.

5. Reference

Al-Hadithi, A. I., & Abbas, M. A. J. I. J. o. C. E. (2018a). The Effects of adding Waste Plastic Fibers on the Mechanical Properties and Shear Strength of Reinforced Concrete Beams. 12(1), 110-124.
Albano, C., Camacho, N., Hernandez, M., Matheus, A., & Gutierrez, A. J. W. M. (2009). Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios. 29(10), 2707-2716.
Alhozaimy, A., & Shannag, M. J. M. o. C. R. (2009). Performance of concretes reinforced with recycled plastic fibres. 6,(4), 293-298.
Araghi, H. J., Nikbin, I., Reskati, S. R., Rahmani, E., Allahyari, H. J. C., & Materials, B. (2015). An experimental investigation on the erosion resistance of concrete containing various PET particles percentages against sulfuric acid attack. 77, 461-471.
ASTM, C. J. A. B. o. A. S. (2002). 469-02. Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression. 4.
Astm, C. J. A. b. o. A. s. (2006). 642. Standard test method for density, absorption, and voids in hardened concrete. 4, 02.
ASTM, C. J. A. I. (2003). 143: Standard test method for slump of hydraulic cement concrete.
Astm, C. J. A. L, West Conshohocken, PA. (2009). 597, Standard test method for pulse velocity through concrete.
ASTM, C. J. A. S. o. T. M., USA. (1997). 1018:‘Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading).
ASTM, C. J. U. S. A. I. (2004). 496-04. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.
Auchey, F. L. J. J. o. C. E. (1998). The use of recycled polymer fibers as secondary reinforcement in concrete structures. 3(2), 131-140.
Bhogayata, A., Shah, K., Vyas, B., Arora, N. J. I. j. o. e. r., & technology. (2012). Performance of concrete by using non-recyclable plastic wastes as concrete constituent. I(4), 1-3.
Choi, Y. W., Moon, D. J., Kim, Y. J., Lachemi, M. J. C., & Materials, B. (2009). Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles. 23(8), 2829-2835.
Committee, A. (2005). Building code requirements for structural concrete (ACI 318-05) and commentary (ACI 318R-05).
de Oliveira, L. A. P., Castro-Gomes, J. P. J. C., & Materials, B. (2011). Physical and mechanical behaviour of recycled PET fibre reinforced mortar. 25(4), 1712-1717.
JSCE. (1984). SF-4, Method of Test for Flexural Strength and flexural Toughness of Fiber Reinforced concet, JCI Standard SF-4.
Kim, S. B., Yi, N. H., Kim, H. Y., Kim, J.-H. J., Song, Y.-C. J. C., & composites, c. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. 32(3), 232-240.
Li, Q. C. G. F. L. J. J. o. S. U. (2005). Mechanism research on improvement of resistance to plastic shrinkage and cracking of cement mortar by polypropylene fibers [J]. 5.
Malagavelli, V., Patura, N. R. J. I. J. o. E. S., & Engineering. (2011). Strength characteristics of concrete using solid waste an experimental investigation. 4(6).

Naaman, A. E., Garcia, S., Korkmaz, M., & Li, V. C. (1996). *Investigation of the use of carpet waste PP fibers in concrete*. Paper presented at the Materials for the New Millennium.

Najm, H., & Balaguru, P. J. M. J. (2002). Effect of large-diameter polymeric fibers on shrinkage cracking of cement composites. 99(4), 345-351.

Pelisser, F., Montedo, O. R. K., Gleize, P. J. P., & Roman, H. R. J. M. r. (2012). Mechanical properties of recycled PET fibers in concrete. 15(4), 679-686.

Prahallada, M., Parkash, K. J. I. J. o. A. E. R., & Technology. (2013). Effect of different aspect ratio of waste plastic fibers on the properties of fiber reinforced concrete e an experimental investigation. 2, 1-13.

Rahmani, E., Dehestani, M., Beygi, M., Allahyari, H., Nikhin, I. J. C., & Materials, B. (2013). On the mechanical properties of concrete containing waste PET particles. 47, 1302-1308.

Ramadevi, K., Manju, R. J. I. j. o. e. t., & engineering, a. (2012). Experimental investigation on the properties of concrete with plastic PET (bottle) fibres as fine aggregates. 2(6), 42-46.

Specification, I. (1984). No. 45” Aggregates from Natural Sources for Concrete and Building Construction”, the Iraqi Central Organization for Standardization and Quality Control. In: Baghdad-Iraq.

Standard, A. J. A. C. (2010). Standard test method for compressive strength of cylindrical concrete specimens. Standardization, I. S. I. N. J. C. A. f., & Control, Q. (1984). Portland Cement. In: Planning Council, Baghdad, IRAQ.

standards, A. J. A. B. o. A. (1993). Standard test method for tensile properties of plastics by use of microtensile specimens.

Wang, Y., Wu, H., & Li, V. C. J. J. o. m. i. c. e. (2000). Concrete reinforcement with recycled fibers. 12(4), 314-319.