Performance of Shred Tires Mixed with Railway Subgrade in Reduction of Train Induced Vibrations

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Abstract:

In this study, the performance of shred tire mixed with railway subgrade was evaluated for reducing the environmental vibrations caused by trains' passage. Since incorporating the shred tire seeds in soil affected on its shear strength and deformability parameters, so the first stage of the study was allocated to conducting a series of laboratory tests such as the unconfined compression, CBR and cyclic plate loading tests on the base material of GW-GC in combination of tire derived aggregates with particle size ranged from 0.475 to aggregation 2.5 cm in four various percentages of 0, 5, 10 and 15. Moreover, the cyclic plate loading tests were accomplished to determine the mixture elasticity modulus in the second loading cycle as Ev_2. By using the obtained values of shear strength as well as deformability parameters in the lab, a 2D numerical model of ballasted track was established under step train loads corresponding to a passenger bogie. The numerical results showed that the vertical vibration velocity at the ballast shoulder decreased up to 44.56 percent while this value reached to 44 percent for a point with 5 m distance from track shoulder with increasing in the shred tire percentages from 5 to 15 percent. As a practical result, an equation was proposed to show the relation between shred tire percentages and values of environmental vibrations.

Keywords: *Shred tire mixed with railway subgrade, Plate loading test, Train Induced vibrations*

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1. Introduction

In the recent years, considerable progresses have been made in the field of rail transportation similar to other industries. Because of suitable services, high safety, speed, comfort and other services, this system can be competed with other transportation systems. One of the major components in the railway tracks is bed and subgrade that should provide stable and reliable support for passing trains. For this purpose, bed and subgrade of railway tracks should supply the required bearing capacity until settlement value is less. Usually, both bearing capacity and settlement are hidden in bed stiffness, therefore in-situ tests such as the density, bearing ratio of California (CBR), and the plate loading test (PLT) are considerable in development of railway tracks and these tests are used for controlling the bed and subgrade. Allowed values of the density, CBR and elasticity modulus in the second cycle of plate loading test for bed and embankment materials have been presented in the regulations related to railway earthworks like European regulations, UIC 719R (1996), American regulations, AREMA (2006), Indian railways regulations (2003), Indian heavy railways regulations (2009) and 394 magazine of Iran transport (2007). For example, minimum density, CBR and elasticity modulus are 90 percent, 3 MPa and 45 MPa for bed materials respectively and they are 90 percent, 7 MPa and 45-60 Mpa (45 Mpa for cohesive material and 60 Mpa for granular material) for embankment materials respectively in UIC 719R regulation. Therefore, every soil materials used in the bed and embankment should supply the requirements of regulations. On the other hand, utilization of shred tires is one of the environmental problems in the most industrialized countries. Use of these materials as mixed with soil materials in the road and bridge embankment was considered by researchers in the 80's. Humphrey et al. (1986) studied conditions of 37 embankments mixed with shred tires during 1986 to 2004 and they confirmed their positive performance (Wolf and Humphrey, 2000; Humphrey and Holtz, 1986; Humphrey, 1999) but the specific studies have not been reported in the field of shred tires mixed with bed and embankment of railway tracks. Also, several studies such as work of Nakhaei et al. (2011), Edil and Bosscher (1994), Ghazavi et al. (2000) and Sivakumar Babu et al. (2011) have been made in the field of shred tires effects on shear resistance and plasticity parameters for soils. Most big cities are faced with nearness of railroads to vibration-sensitive areas such as research centers, laboratories, hospitals and communication structures because of development of railway tracks. Today, most researchers consider train induced vibrations and their effects on human comfort. There are several methods for reduction of ground borne vibrations caused by moving trains such as reduction of train induced vibrations in the source, path of wave propagation and receiver. One of the approaches for vibration reduction in the path of wave propagation is use of shred tires as sub ballast in railway tracks that their successful applications have been confirmed in Korea and U.S.A for field tests (Cho et al., 2007; Towers, 2010). In this paper, the objective is investigation of shred tires effects mixed with railway subgrade in reduction of train induced vibrations. Since shred tires mixed with railway subgrade can affect on shear strength and flexibility of soil, so in the first step of study the shear strength parameters, compressibility and elastic modulus in the second cycle of loading (Ev_2) were determined by using compression, CBR, straight shear tests and loading chamber on the subgrade mixed with different percentages of shred tires in school of railway engineering in Iran university of science and technology. Then in the second step of study with using the developed 2D plane strain finite/infinite element model, the problem of environmental wave's propagation with and without existence of shred tires in railway subgrade has been studied with considering step load caused by Iran MD36 train with amplitude of 93 KN and time interval of 0.02 seconds.

2. Laboratory experiments on mixture of soil and shred tire

In order to determining an optimal percent for soil mixed with shred tires, laboratory tests were carried out on mixture of soil with different percentages of shred tire (0, 5, 10 and 15 percent) with certain gradation. So in this regard, the experiments such as gradation, determination of the maximum dry density, determination of the optimum water content percentage, CBR, direct shear, and plate loading tests were performed.

3. Characteristics of used materials

Soil materials used in this study were provided from river materials as broken stones. Also, shred tires that were used in this study consisted of old vehicles tires that were shredded mechanically in several steps and they have a uniform particle size. The characteristics of these materials would be discussed in continue.

3.1. Soil materials

Soil materials used in this study consist of coarse particles with a small amount of clay according to river materials that are called GW-GC based on Unified Soil Classification (Figure 1). Table 1 shows technical specifications of coarse particles that are calculated from laboratory tests.

3.2. Soil and shred tire specifications

Tire seeds used in this study are old shredded and grinded vehicle tires that are provided by Ghadir rubber Company. Size distribution curve of shred tire is presented in Figure 2. Tables 2 and 3 show technical and mechanical specifications of shred tire and its mixture with base soil respectively.

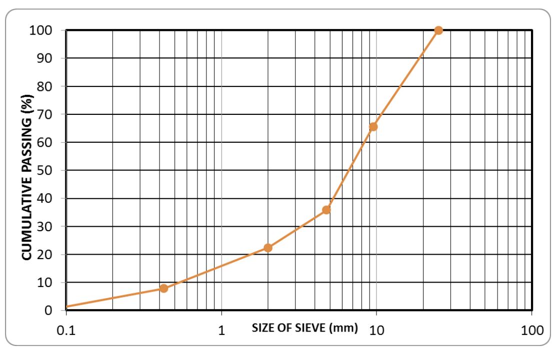

Figure 1. Size distribution curve of Soil

Table 1- Technical properties of coarse soil

parameters	sign	unit	value	Test standard
Specific gravity	γ	KN/m³	22.51	ASTM D698 (ASTM, 2000)
water content	ω	%	6.82	ASTM D2216 (ASTM, 2000)
density	G_S	-	2.546	ASTM D854 (ASTM, 2000)
California bearing ratio	CBR	%	33.21	ASTM D1883 (ASTM, 2000)
cohesion	C	KN/m²	12.66	ASTM D3080 (ASTM, 2000)
Angle of internal friction	F	Degree	36.88	ASTM D3080

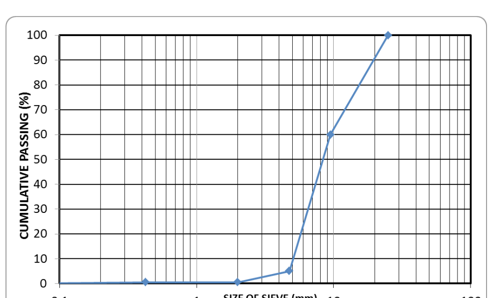

Figure 2. Size distribution curve of shred tire

Table 2. Technical properties of shred tire

Parameters	Sign	Unit	Values	Test standard
Specific gravity	γ	KN/m^3	6	ASTM D698
Water content	ω	%	-	ASTM D2216
Density	G_S	-	1.1	ASTM C 127 (ASTM, 2000)
California bearing ratio	CBR	%	17.07	ASTM D1883
Cohesion	C	KN/m^2	-	ASTM D3080
Angle of internal friction	F	Degree	37	ASTM D3080
Elasticity modulus	E	MPA	10.02	ASTM D6270 (ASTM, 2000)

Table 3. Technical properties of soil and shred tire

Parameters	Sign	Unit	Soil With 5% Shred Tire	Soil With 10% Shred Tire	Soil With 15% Shred Tire	Test standard
Specific gravity	γ	KN/m^3	19.84	19.22	18.15	ASTM D698
Water content	ω	%	8.1	8.59	9.82	ASTM D2216
Density	G_S	-	-	-	-	ASTM D854
California bearing ratio	CBR	%	21.8	21.33	10.8	ASTM D1883
Cohesion	C	KN/m^2	12.94	11.28	9.23	ASTM D3080
Angle of internal friction	F	Degree	33.04	29.95	28.6	ASTM D3080

4. Effect of shred tire content on compression tests

In this part, the result of compaction tests which have been performed in accordance to ASTM D - 698 (Hammer weigh is 10 pounds, number of layers is 5, Number of applied impacts to each layer is 56, and diameter of density framework is 6 inch) including optimum water content, ω_{opt}, and maximum dry density, γ_d, are presented in Table 4.

The tests for soil mixed with shred tires with different percentages, 5, 10 and 15 percent indicated that the optimum water content increased about 18.76 to 43.98 percent and maximum dry density decreased about 11.86 to 19.36 with increasing shred tire percentages. These results are justifiable because of low water absorption of shred tire as well as low specific gravity of this material.

5. Influence of shred tire on the CBR test

The CBR tests were carried out on four samples with different weight ratios of shred tire. Table 5 shows the results.

The results are presented in Table 5. As observed, the value of CBR reduced about 67.47 to 34.35 percent

Table 4. Optimum water content and maximum dry density based on compression tests

Shred Tire (%)	Maximum dry density (kN/m^3)	Optimum water content (%)
0	22.51	6.82
5	19.84	8.1
10	19.22	8.59
15	18.52	9.82

Table 5. Results of CBR test

Final CBR	CBR 0.2” (%)	CBR 0.1” (%)	Shred Tire (%)
33.21	33.21	29.56	0
21.80	21.80	16.70	5
21.33	21.33	14.17	10
10.80	10.80	9.31	15

with increasing shred tire. The number of CBR did not significantly reduce with increasing shred tire from 5 to 10 percent.

6. Influence of shred tire on plate loading test

In this section, effect of shred tire was investigated by using the plate loading test. This section included preparation of sample, test procedure and test equipment used in the experiment.

6.1. Sample preparation and test procedure

This test is accomplished according to ASTM D1194 (ASTM, 2003). Firstly, soil is compacted by using a laboratory scale roller in the loading chamber in both cases of soil with and without shred tires. After preparation of soil samples in loading chamber, a loading jack with 30 tones capacity is used and the load is applied in 0.5 tone stages till reach to the maximum tolerable load and then unloading is performed in two steps in the first loading cycle. In continue and in second cycle, 0.5 ton loads are applied till achieving 3 tons load and again the unloading is carried out in four steps. In third cycle, the loading is continued to soil failure. Figures 3 and 4 indicate the plate loading tests on soil without shred tires and soil mixed with 10 percent of shred tires respectively.

6.2. Characteristics of loading box and used equipments

In this study, a loading chamber with dimensions of 1.2 × 1.2 ×1 m (Figure 5) was used for plate loading test (PLT). Plate loading tests were performed on a square plate with width and thickness of 30 and 2.5 cm respectively. Also for testing, other equipments such as hydraulic jack with axle load of 30 tons and a displacement gauge with precision of 0.01 mm were used (Figure 6). This test was carried out with different weight percentages of soil and shred tires (0, 5, 10 and 15 percent).

Figure 3. Plate loading test on soil without shred tire

Figure 4. Plate loading test on soil mixed with 10% shred tire

Figure 5. Loading box for plate loading test

Figure 6. Other equipments for plate loading test

According to the presented descriptions in the previous section and the obtained diagrams, the elasticity modulus was presented in Table 6 in the second cycle of loading for four different samples. As observed, the elasticity modulus decreased about 27.54 to 54.29 percent in the first and second cyclic of loading with increasing the shred tires in soil. This modulus could be properly expressed by the following equations. In these equations, Ev_1 is curve slope in the first cycle and Ev_2 is curve slope in reloading.

$$E_{v1} = -0.382x + 27.46 \quad R = 0.957 \qquad (1)$$

$$E_{v_2} = -0.360x + 27.24 \quad R = 0.958 \qquad (2)$$

Table 6. Elasticity modulus for mixture of soil and shred tires

Mixture of soil-Shred tire (%)	EV_1 (Mpa)	EV_2 (Mpa)
0	73.66	77.54
5	53.58	56.18
10	47.94	49.72
15	33.79	35.44

Cyclic diagrams for soil samples mixed with different percentages of shred tires (0, 5, 10 and 15 percent) are as follows:

If these values are compared with the allowed values of UIC R719 regulations, it could be understood that the Ev_2 values are below 45 MPa for shred tires values above 10 percent then their application is not allowed on the railway bed and subgrade.

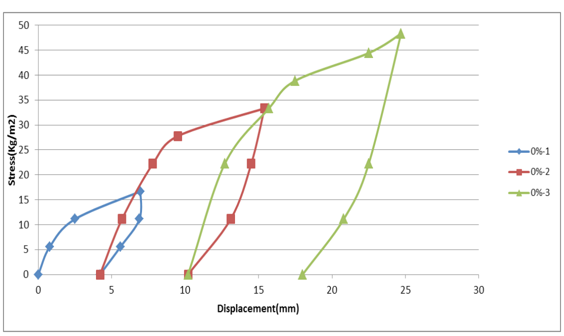

Figure 7. Cyclic diagram for 0% mixture of Soil-Shred Tire

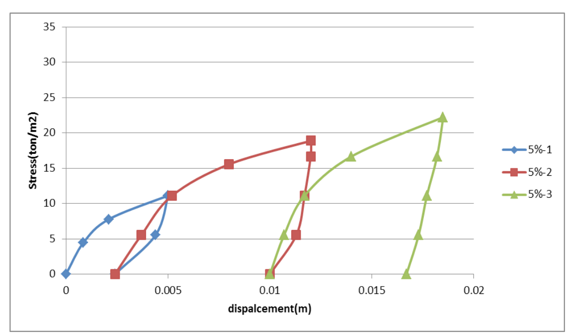

Figure 8. Cyclic diagram for 5% mixture of Soil-Shred Tire

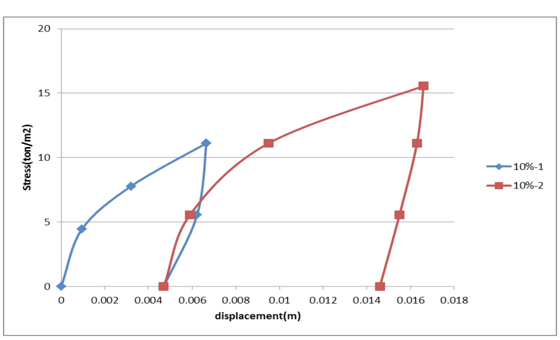

Figure 9. Cyclic diagram for 10% mixture of Soil-Shred Tire

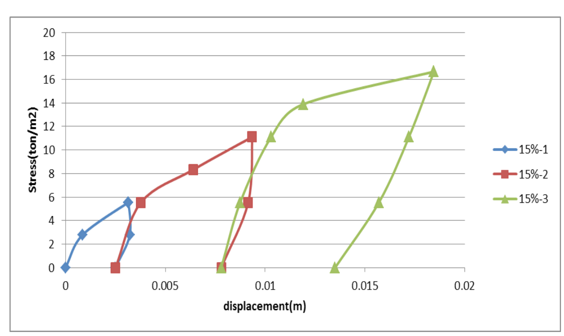

Figure 10. Cyclic diagram for 15% mixture of Soil-Shred Tire

7. Numerical Simulations

According to the obtained laboratory specifications for shred tires mixed with subgrade in this section, a series of numerical investigations using ABAQUS software is implemented to evaluate train induced environmental vibrations reduction in the case of using shred tire mixed with subgrade. The modeling process is presented in continue.

7.1. Model geometry

The model geometry considered was selected based on the finite/infinite element model developed by Zakeri et al. (2012) in this paper. It included both near and far field (Figure 11). As observed in this figure, the near field included sleeper, ballast, shred tires mixed with subgrade with various percentages and natural soil while the far field included infinite areas. Because of one of dimensions of railway structure was larger than two other dimensions, plane strain conditions and 2D dimensional section was considered for solving this problem.

7.2. Properties of material

Material properties were considered based on the experimental tests in the previous section. Upper and lower soil layers were shred tires mixed with subgrade and natural soil respectively. Properties of shred tires mixed with subgrade were considered based on the laboratory tests in the previous sections and according to Tables 3 to 6.

7.3. Boundary conditions

As mentioned, the model geometry included both the near and far field which finite and infinite elements were used for the near and far field respectively. Infinite element was four nodes plane strain element (CINPE4) that caused to damp energy and waves generated by a train in the distance (Zakeri et al., 2012).

7.4. Specifications of train loading

Wheel load for Iranian passenger train (MD36) was 93 KN and it was considered as a step load with time intervals of 0.02 seconds. Figure 11 shows pattern of train loading (Zakeri et al., 2012).

8. Numerical results and discussion

The obtained results from numerical analyses can be interpreted in several cases. First, results are presented as environmental vibrations based on the shred tires percentages and distance from ballast shoulder. Then, a series of mathematical relationship is presented between the percentages of shred tires and maximum environmental vibrations due to passing trains. Finally, the results are interpreted based on the vibration parameters of root mean square (RMS), vibration acceleration level (L_{va}) and peak particle acceleration (PPA).

8.1. Environmental vibrations based on the shred tire percentages

After modeling the finite/infinite element and applying

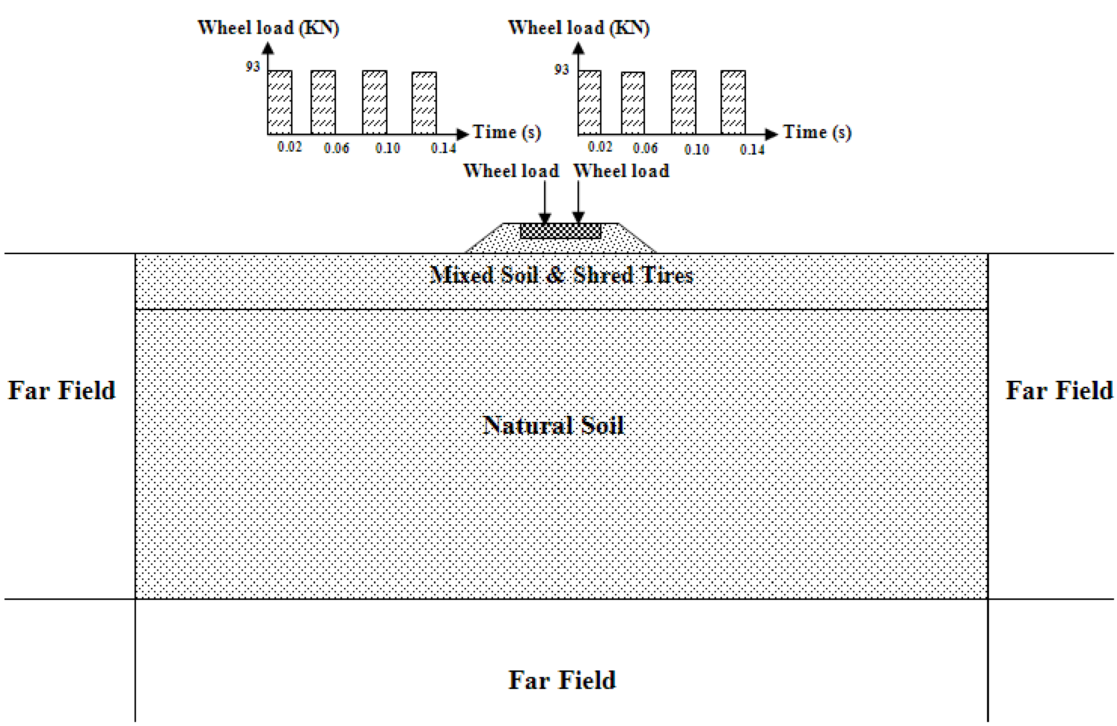

Figure 11. Geometry of model

train load, environmental vibrations caused by train are evaluated with different percentages of shred tire mixed with subgrade. Considering that effects of vibration acceleration are more significant and tangible than vibration velocity, therefore effects of vibration acceleration are presented in this section. Figures 12, 13, 14 and 15 show the environmental vibrations induced by train with different shred tires percentages of 0, 5, 10 and 15 percent respectively. In each figure, effect of distance from ballast shoulders was considered.

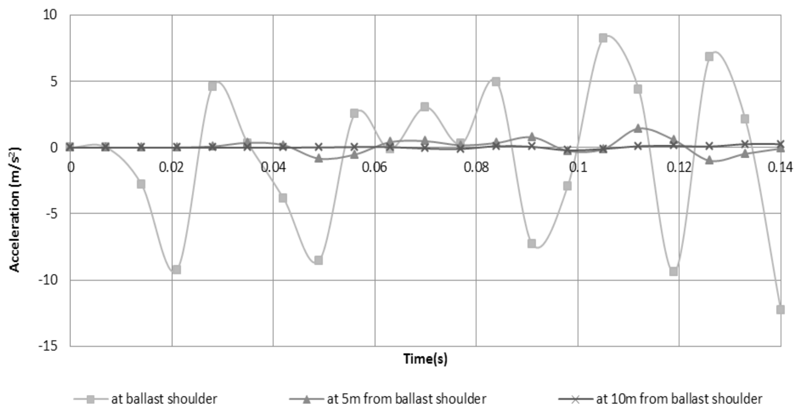

Figure 12. Vibration accelerations for various points with 0 percent mixed subgrade and shred tires

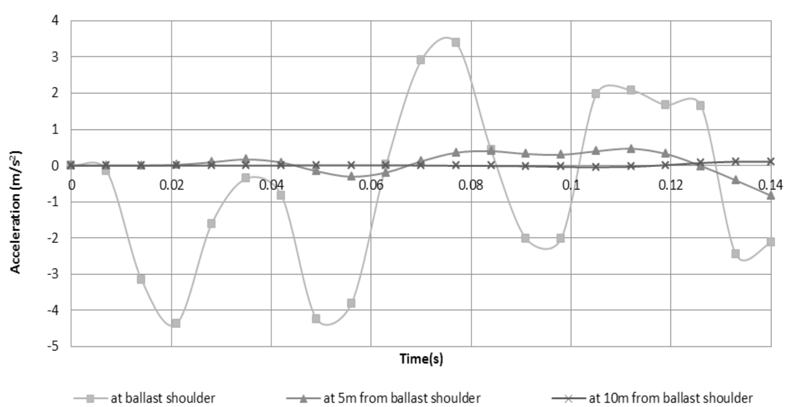

Figure 13. Vibration accelerations for various points with 5 percent mixed subgrade and shred tires

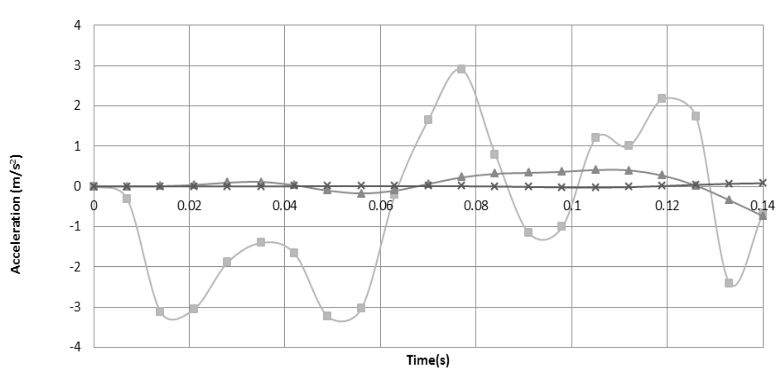

Figure 14. Vibration accelerations for various points with 10 percent mixed subgrade and shred tires

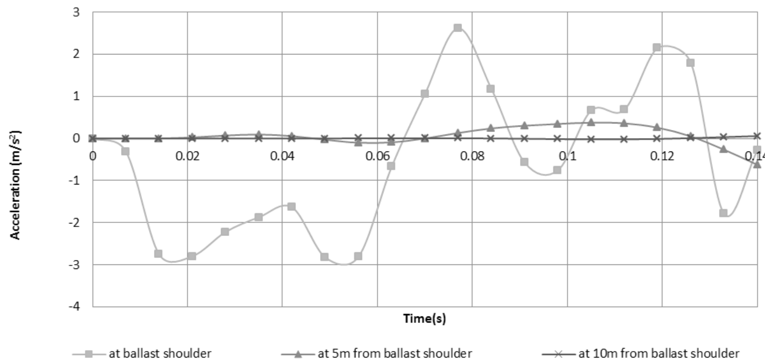

Figure 15. Vibration accelerations for various points with 15 percent mixed subgrade and shred tires

According to the above figures, environmental vibration induced by train is lower with increasing the shred tires values in subgrade. In continue, the mathematical relationship is presented between the percentage of shred tires and the maximum environmental vibrations.

8.2. Mathematical relationship between the percentages of shred tires and maximum environmental vibrations

According to the obtained results from the previous section, the mathematical relationship can be presented between the maximum environmental vibrations and percentage of shred tires. Figures 16, 17 and 18 show the mathematical relationship between the maximum environmental vibrations and percentage of shred tires at the ballast shoulders, 5 meters of ballast shoulder, and 10 meters of the ballast shoulder respectively.

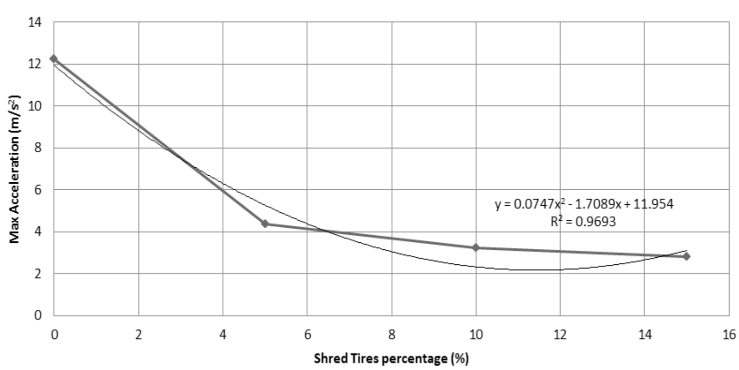

Figure 16. The mathematical relationship at ballast shoulder

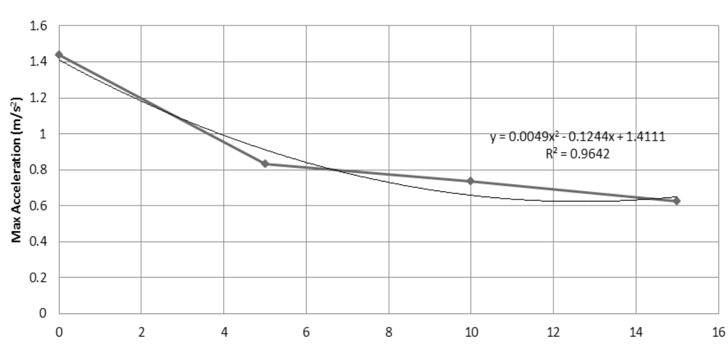

Figure17. The mathematical relationship at distance of 5m from ballast shoulder

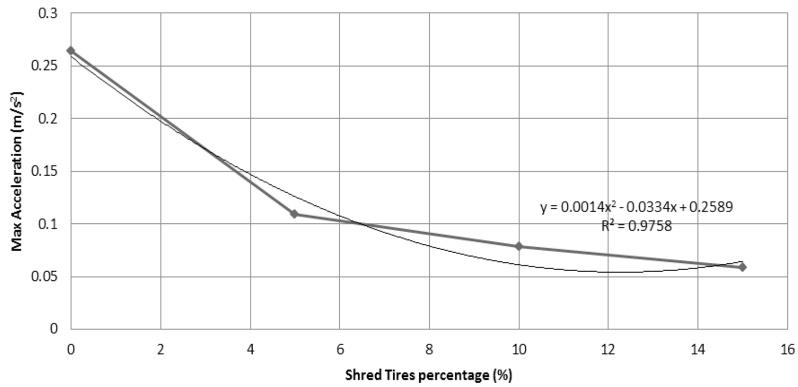

Figure 18. The mathematical relationship at distance of 10m from ballast shoulder

As observed, the maximum environmental vibrations are reduced with increasing shred tires values. Reduction values of train induced vibrations have a smooth slope and trend with increasing distance from the source of vibration. After presenting diagrams respect to the maximum environmental vibrations versus to percentage of shred tires, the mathematical relationships between the environmental vibrations and shred tires is presented in Table 7.

In the above Table, MVA and PST are maximum vibration acceleration and percentage of shred tires respectively.

8.3. The relationship between shred tires and vibration parameters

In this section, parameters of RMS, L_{va} and PPA (Yang and Hung, 2008) can be evaluated according to values of environmental vibrations caused by passing trains. In continue, each parameter is defined and calculated for percentages of shred tires and different distances from ballast shoulder.

8.3.1. Parameter of root mean square (RMS)

The root mean square (RMS) is calculated as the following equation:

Root mean square :

$$rms = \left(\frac{1}{T_2 - T_1} \int_0^T A^2(t)dt \right)^{0.5} \quad (3)$$

The following Table shows the RMS for percentage of shred tires mixed with subgrade for different points.

Table 7. Relation between Percent of shred tires with maximum vibration

Distance from ballast shoulder	Equation	Error
At ballast shoulder	$MVA = 0.074PST^2 - 1.708\ PST + 11.95$	$R^2 = 0.969$
At distance of 5m from ballast shoulder	$MVA = 0.004\ PST^2 - 0.124\ PST + 1.411$	$R^2 = 0.964$
At distance of 10m from ballast shoulder	$MVA = 0.001\ PST^2 - 0.033\ PST + 0.258$	$R^2 = 0.975$

Table 8. Root mean square (RMS)

Mixed shred Tires% / Points	0	5	10	15
At ballast shoulder	34	5.88	3.88	3.26
At distance of 5m from ballast shoulder	0.3	0.1	0.076	0.056
At distance of 10m from ballast shoulder	0.013	0.0017	0.0007	0.0003

According to the above Table, the RMS decreased 44. 56 and 44 percent at ballast shoulder and 5 meters of ballast shoulder respectively with increasing the shred tires values mixed subgrade from 5 to 15 percent. Also for 5 percent of shred tires mixed with subgrade, the RMS reduced 82, 67 and 87 percent in ballast shoulder, 5 meters of ballast shoulder and 10 meters of ballast shoulder respectively than subgrade without shred tires.

8.3.2. Parameter of vibration acceleration level (L_{va})

The vibration acceleration level (L_{va}) is calculated as the following equation:

Vibration acceleration level (L_{va}):

$$L_{va} = 20 \times Log \frac{A}{A_0} \qquad A_0 = 1 \times 10^{-5} \frac{m}{s^2} \qquad (4)$$

The following Table shows the L_{va} for percentage of shred tires mixed with subgrade for different points.

As observed, the L_{va} decreased 2،7 and 3,33 percent at ballast shoulder and 5 meters of ballast shoulder respectively with increasing shred tires values mixed with subgrade from 5 to 15 percent. Also for 5 percent of shred tires, the L_{va} reduced 17،55 percent at ballast shoulder than subgrade without shred tires.

8.3.3. Parameter of peak particle acceleration (PPA)

The peak particle acceleration (PPA) or maximum environmental vibration acceleration is evaluated and presented as the following table for various percentages of shred tires and different points:

Based on the Table, the PPA decreased with increasing shred tires values. This parameter reduced 35،46 and 25،30 percent at ballast shoulder and 5 meters of ballast shoulder respectively with increasing shred tires values mixed with subgrade from 5 to 15 percent. Also for 5 percent of shred tires, the PPA reduced 65, 42 and 65 percent at ballast shoulder, 5 meters of ballast shoulder and 10 meters of ballast shoulder respectively than subgrade without shred tires.

9. Conclusions

Shred tires mixed with subgrade can improve the elasticity and strength parameters of railway subgrade and they cause to decrease environmental train induced vibrations in the railway tracks. In this paper, effects of shred tires mixed with subgrade in railway tracks were investigated for reduction of vibrations induced by moving trains. Since existence of shred tires in railway subgrade can affect on its shear strength and flexibility, so in the first step of study the shear strength parameters, compressibility and elastic modulus in the second cycle of loading (Ev_2) were determined with using compression, CBR, straight shear tests and loading chamber on the shred tires mixed with subgrade with different percentages in school of railway engineering in Iran university of science and technology. Then in the second step of study with using the developed 2D plane strain finite/infinite element model, problem of environmental wave’s propagation with and without

Table 9. Vibration acceleration level (L_{va})

Mixed shred Tires% / Points	0	5	10	15
At ballast shoulder	131	108	106	105
At distance of 5m from ballast shoulder	90	90	88	87
At distance of 10m from ballast shoulder	63	72	68	64

Table 10. Peak particle acceleration (PPA)

Mixed shred Tires% / Points	0	5	10	15
At ballast shoulder	12.3	4.37	3.24	2.82
At distance of 5m from ballast shoulder	1.43	0.83	0.73	0.62
At distance of 10m from ballast shoulder	0.26	0.10	0.078	0.058

the shred tires in railway subgrade has been studied with considering step load due to Iran MD36 train with amplitude of 93 KN and time intervals of 0.02 seconds. The important findings of this study are summarized as follows:

- The obtained results from CBR tests indicated that the CBR value reduced with increasing shred tires percentages. Also, the CBR value didn't significantly reduce with increasing the shred tires from 5 to 10 percent.
- According to the values obtained from the plate loading tests for the ela s ticity modulus in the second cycle of loading, the amount of shred tires for using in the railway bed must be limited to 10 percent.
- Elasticity modulus in the first and second cycle of loading is linearly related to the percentage of shred tires with good accuracy.
- 5 percent of shred tires reduced the bearing capacity more than 50 percent but settlement value for failure case has been reduced approximately 25 percent.
- Increase of shred tires from 5 to 15 percent hasn't a significant effect on reduction of failure load or its settlement.
- The root mean square (RMS) decreased 44.56 and 44 percent at ballast shoulder and 5 meters of ballast shoulder respectively with increasing shred tires values mixed with subgrade from 5 to 15 percent. Also for 5 percent of shred tires, the RMS reduced 82, 67 and 87 percent at ballast shoulder, 5 meters of ballast shoulder and 10 meters of ballast shoulder respectively than subgrade without shred tires.
- The vibration acceleration level (L_{va}) decreased ٢،٧ and ٣،٣٣ percent at ballast shoulder and ٥ meters of ballast shoulder respectively with increasing shred tires values mixed with subgrade from ٥ to ١٥ percent. Also for ٥ percent of shred tires, the L_{va} reduced ١٧،٥٥ percent at ballast shoulder than subgrade without shred tires.
- The peak particle acceleration (PPA) decreased with increasing shred tires values. This parameter reduced ٣٥،٤٦ and ٢٥،٣٠ percent at ballast shoulder and ٥ meters of ballast shoulder respectively with increasing shred tires values mixed with subgrade from ٥ to ١٥ percent. Also for ٥ percent of shred tires, the PPA reduced ٦٥, ٤٢ and ٦٥ percent at ballast shoulder, ٥ meters of ballast shoulder and ١٠ meters of ballast shoulder respectively than subgrade without shred tires.

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