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Investigation of Using Waste Welded Tuff Material as Mineral Filler in Asphalt Concrete

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Welded tuff,
Koyke,
Tensile strength ratio

Abstract: In this paper, the welded tuff waste- known as koyke in Isparta region - was used in the hot mix asphalt (HMA) as mineral filler for reduction of the moisture susceptibility of HMA. Optimum binder content was assessed with Marshall Design Method. First of all, welded tuff was substituted as filler with limestone filler in proportion of 50% and 100%. After that Marshall Stability test was performed on specimens. The results showed that the 50% substitution was more effective than the 100% substitution. Therefore, welded tuff was substituted with limestone filler in proportion of 25%, 50%, 65% and 75%. Next, Indirect Tensile Strength test was practiced on the fabricated specimens and the results were assessed. According to the Indirect Tensile Strength results, welded tuff with 65% was given higher strength than the limestone filler. As a result, it has come up that welded tuff can be used as mineral filler in the hot mix asphalt.

Kaynaklanmış Tüf (Köyke) Atık Malzemesinin Mineral Filler Olarak Asfalt Betonunda Kullanımının Araştırılması

Anahtar Kelimeler
Nem hassasiyeti,
Kaynaklanmış tüf,
Köyke,
İndirekt çekme oranı

Özet: Bu çalışmada, Isparta bölgesinde KÖYKE olarak bilinen atık kaynaklanmış tüf malzemesi nem hassasiyetini düşürmek amacıyla bitümlü sıcak karışımda (BSK) mineral filler olarak kullanılmıştır. Optimum bitüm miktarı Marshall Tasarım Yöntemi ile belirlenmiştir. Öncelikle kaynaklanmış tüf filler olarak, kireçtaşı filler malzemesi ile %50 ve %100 oranlarda değiştirilmiştir. Sonuçta, %50 filler oranıyla hazırlanan numuneler %100 filler oranında hazırlanan numunelerden daha yüksek dayanım göstermiştir. Bu nedenle, kaynaklanmış tüf kireçtaşı filler ile birlikte %25, %50 %65 ve %75 oranlarında değiştirilerek numuneler hazırlanmıştır. Daha sonra numuneler üzerinde İndirekt Çekme Testi uygulanmış ve sonuçlar değerlendirilmiştir. İndirekt çekme test sonuçlarına göre %65 oranında kaynaklanmış tüf filler kullanılarak hazırlanan numuneler, kireçtaşı filler kullanılarak hazırlanan numunelerden daha yüksek dayanım göstermiştir. Sonuç olarak kaynaklanmış tüf malzemesinin, dayanım açısından sıcak asfalt karışımlarda mineral filler olarak kullanılabilirliği gösterilmiştir.

1. Introduction

Water existence causes moisture damage by decreasing stability in asphalt mixtures. Presence of water weakens the strength of the pavement. Moreover, moisture damage increases the probability of raveling which decreases the skid resistance on the surface of the road [1]. The Modified Lottman Test [2] was used to specify the moisture damage. And the specification criterion required for the Tensile Strength Ratio (TSR) of a mixture at optimum binder content (OBC) is minimum 80%.

Because of the high costs, the requirement to use waste materials are increasing. Also new pavement constructions need more and more virgin aggregates. Because of the depletion of natural resources and increased demand, waste materials become more popular on pavement design.

At the same time by modifying the bitumen, pavement performance can be improved [3-7]. To improve the performance virgin materials can be used. Using of the virgin materials are damaging environment and very expensive. To improve the pavement performance more sustainable, use of waste materials on pavement become more popular

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in the last decades. There are many waste material types tried to improve the pavement performance such as; plastic bottle [8-10], crumb rubber [11-12], glass [13-14].

The use of waste materials provides sustainable, eco-friendly and economical highways. It is important to obtain the waste materials where the highway will be constructed because of the transportation costs. To reduce the transportation costs for a possible highway construction, a waste material called welded tuff in Isparta region is used in this paper.

Decreases in eruption activity or overloading by continued eruption can cause the eruptive column to collapse either continuously or sporadically. The hot pyroclastic material falls from the column and flows outward from the vent following topography, and may flow more than tens or hundreds of square kilometers. Such pyroclastic flows can retain enough heat to fuse or weld the particles together after movement stops. The names applied to these rocks historically have included tuffs, welded tuffs, ash flows, and ignimbrites [15].

Welded tuff has a porous structure and used for industrial purpose. The porous structure of the welded tuff lowers the freezing point temperature [16]. Welded tuff is used as an insulation material for buildings. And, by forging the welded tuff, a large amount of waste material occurs. Occurred waste material is very convenient to replace virgin aggregates. By using this waste material, given damage to the environment is minimized.

Tuff is of interest for use as an isolation material for high heat producing wastes because it provides highly sorptive minerals and suitable thermo-mechanical properties. Also, tuff is widespread in areas that offer long and deep groundwater flow paths [17].

This paper focused on the usability of welded tuff as waste material in Hot Mix Asphalt (HMA). Usability evaluation is performed by Modified Lottman Test. Moisture susceptibility of welded tuff mixed specimens were obtained via Tensile Strength Ratio (TSR).

2. Material and Method

2.1. Materials

In this section, materials (aggregate, binder and welded tuff) which were used in this paper were described in detail.

2.1.1. Aggregate

Limestone aggregates (LS) used in the study were obtained from Isparta region. The nominal aggregate size for wearing course was selected as 12.5 mm. The properties of mineral aggregate properties were shown in Table 1. Grading curve of HMA was selected in accordance with General Directorate of Turkish Highways [18] (Figure 1).

Table 1. Aggregate Properties

Sieve diameters	Properties	Standard	Value
25–4.75 mm	Specific gravity (g/cm3)	ASTM C 128-88	2.700
	Saturated specific gravity		2.660
	Water absorption (%)		0.602
	Abrasion loss (%) (Los Angeles)	ASTM C 131	20.38
4.75–0.075 mm	Specific gravity (g/cm3)	ASTM C 127-88	2.670
	Saturated specific gravity		2.490
	Water absorption (%)		4.400
<0.075 mm	Specific gravity (g/cm3)		2.725

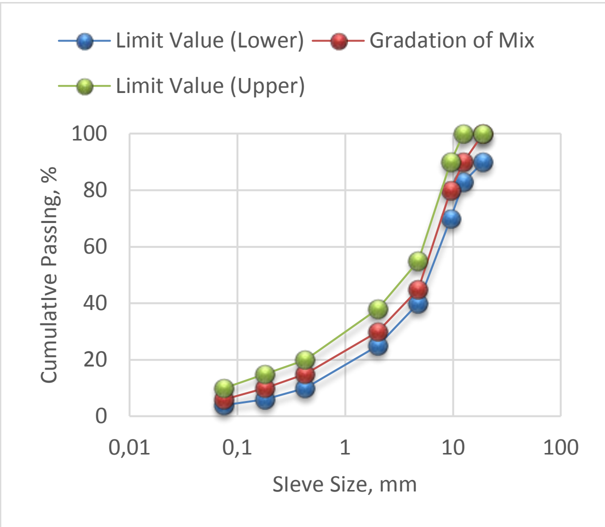

Figure 1. Selected aggregate grading curve

2.1.2. Binder

Standard tests were applied for the purpose of identifying physical characteristics of binder. Test results were given in Table 2.

Table 2. Basic physical characteristics of the binder

Test name	Average values	Standard
Penetration (25 °C)	65	ASTM D5
Flash point	180 °C	ASTM D92
Fire point	230 °C	ASTM D92
Softening point	50.8 °C	ASTM D36
Ductility (5 cm/min)	>100 cm	ASTM D113
Specific gravity	0.979	ASTM D70

The pre-optimum binder content for the mix design was calculated as 4.7%. The optimum binder content (OBC) was obtained from test results with specimens prepared with ±0.5% and ±1.0% to pre-optimum binder content. According to test results optimum binder content was obtained 5%. All specimens were produced according to this optimum binder content.

2.1.3. Welded tuff

The used welded tuff was obtained from Isparta region. The properties of the welded tuff were given in Table 3.

Table 3. Welded tuff properties

Specific Gravity (g/cm^3)	2.395
Water Absorption (%)	2.399

Determining welded tuff elemental properties, Energy-dispersive X-ray spectroscopy (EDS) was carried on welded tuff. Energy dispersive-ray spectra have been taken in a scanning electron microscope (SEM) Cambridge S 200 equipped with a Si (Li) detector. SEM/EDX detects the characteristic X-rays that are emitted from the first few micrometers beneath the specimen's surface after inner shell ionization by the primary electrons. Welded tuff properties obtained by EDS analyses were shown in Table 4.

Table 4. EDS analyses of welded tuff

Element	Wt%	Error%
B K	23,26	14,25
O K	44,52	8,69
Na K	1,03	12,06
Al K	6,03	4,84
Si K	17,49	3,8
K K	3,85	3,4
Ca K	2,09	5,94
Fe K	1,71	11,77

2.2. Method

The strengths of the specimens were obtained by Marshall Stability and Modified Lottman [2] test procedure. The results of the Modified Lottman test were used to obtain the moisture susceptibility of the specimens.

2.2.1. Marshall stability test

Marshall Design procedure was handled to design asphalt concrete mixtures using regional materials [19]. In this paper, HMA mixtures have been produced with Marshall Test Procedure via enforcing 75 blows of compaction on either side of all specimens.

Marshall Stability test has been utilized via scientists to examine bituminous mixtures.

Marshall Stability test is far-going admitted because it is simple and low cost. Taking into account diverse benefits of the Marshall Test, it was concluded to utilize Marshall Stability test to define the Optimum Binder Content (OBC) and examine diverse Marshall Characteristics like Marshall Stability, flow value, specific gravity, air voids etc. [20].

2.2.2. Modified Lottman test

AASHTO T283 [2] test procedure is handled to obtain the Indirect Tensile (IDT) strengths. Firstly, three mixtures for each welded tuff addition rate are prepared as 101,6 mm diameter. The mixtures are compacted with 75 blows for each side. Compacted specimens are left to cool down for 24 hours. Then the specimens are pulled out from the mold and placed in an oven at 40^{0}C. Specimens are cured in that oven for 72 hours. Then the specimens are taken out from the oven and waited till they cool down to 25^{0}C. After the specimens are cooled down, half of the specimens are loaded with 50,8mm/min rate till failure. The max load values are recorded as IDTdry (unconditioned) strengths. The remaining specimens are placed in a water bath at 25^{0}C for 24 hours. After 24 hours, the specimens are get out from water bath and vacuum saturated till the specimens' saturation level is between 55 – 80%. The saturation level is calculated by Equation 1.

$$SL = \frac{(m_{Surf.Dry} - m_a)}{(V_a * V_s)} * 10000 \quad (1)$$

$$V_a = \frac{(G_{max} - G_{bulk})}{G_{max}} \quad (2)$$

$$V_s = m_{Surf.Dry} - m_w \quad (3)$$

$$G_{bulk} = \frac{m_a}{V_s} \quad (4)$$

Where; SL is saturation level (%),$m_{Surf.Dry}$ is saturated surface dry weight (g), m_a is weight in air (g), V_a is air voids (%),V_s is volume of the specimen, G_{max} is theoretical gravity, G_{bulk} is bulk specific gravity and m_w is the weight of the specimen in water.

When the specimens reached the saturation level, they are put into freeze cabin at -18^{0}C for 16 hours. After 16 hours they are put into water bath at 60^{0}C for 24 hours. Finally, they are put into 25^{0}C water bath for 2 hours. After 2 hours they are loaded at a load speed as 50,8mm/min. The failure load values are recorded as IDT_{wet} (conditioned) strengths. The IDT strength is calculated by Equation 5. The ratio of the wet specimen strength to dry specimen strength is Tensile Strength Ratio (TSR) (Equation 6). TSR is used to determine the moisture susceptibility. A minimum TSR value of 80% is recommended by Turkey General Directorate of Highways [18].

$$IDT = 2P/\pi dh \quad (5)$$

$$TSR = \frac{IDT_{wet}}{IDT_{dry}} * 100 \quad (6)$$

Where; IDT_{wet} is the average strength value of the conditioned specimens and IDT_{dry} is the average strength value of the unconditioned specimens.

3. Results

First of all, welded tuff (WT) was substituted as filler with limestone (LS) mineral filler in proportions of 50% and 100% by weight. Following, Marshall Stability test was performed on specimens. It was observed that stability value increases with 50% substitution of welded tuff. Diversion of dissimilar Marshall Stability value versus filler proportion was given Figure 2.

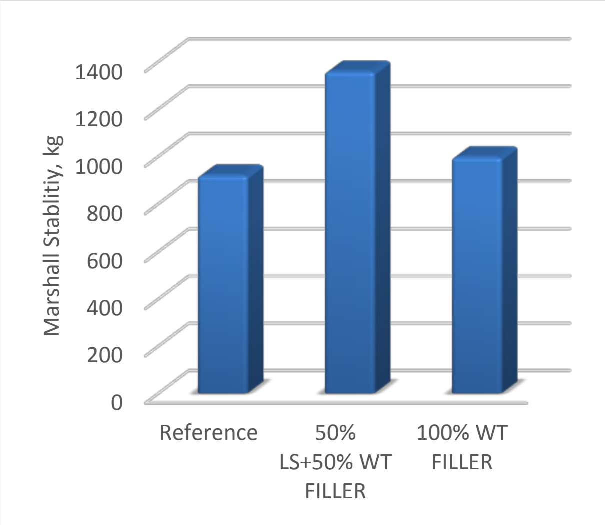

Figure 2. Marshall stability values of mixtures

It was observed that for 50% welded tuff substitution flow data rises. For OBC flow value should be within 2 to 4 mm. Variation of flow value with different welded tuff proportion of OBC with different filler was shown in Figure 3.

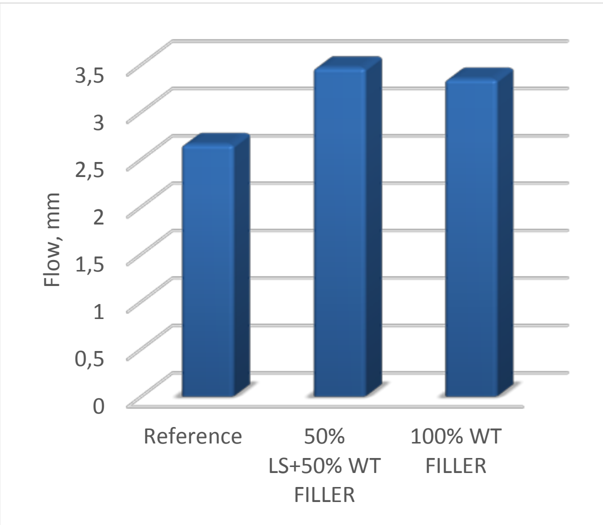

Figure 3. Flow values of mixtures

It was observed that practical specific gravity increases for 50% WT+50% LS substitution up to 100% welded tuff; then decreases. Change of unit weight with dissimilar welded tuff proportion versus different filler was given in Figure 4.

It was observed that for 50% welded tuff substitution air void decreases. Variation of air void with different welded tuff proportion was given in Figure 5.

It was observed that for 50% welded tuff substitution voids in mineral aggregate decrease. Variation of VMA with different binder content was shown in Figure 6.

It was observed that for 50% welded tuff substitution voids filled with bitumen increase. Variation of VFB with different welded tuff proportion was shown in Figure 7.

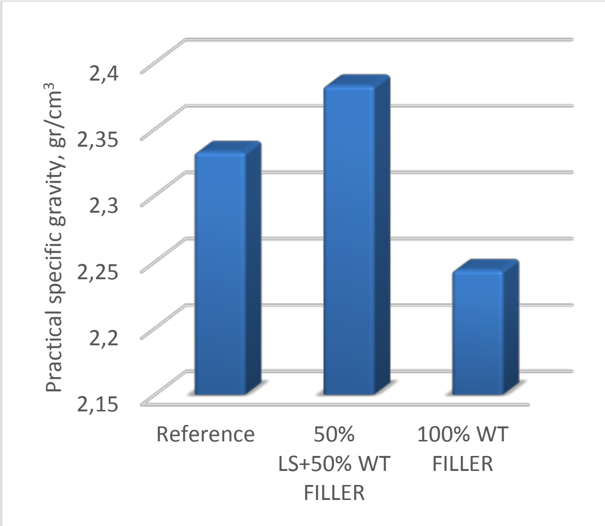

Figure 4. Practical Specific Gravity values of mixtures

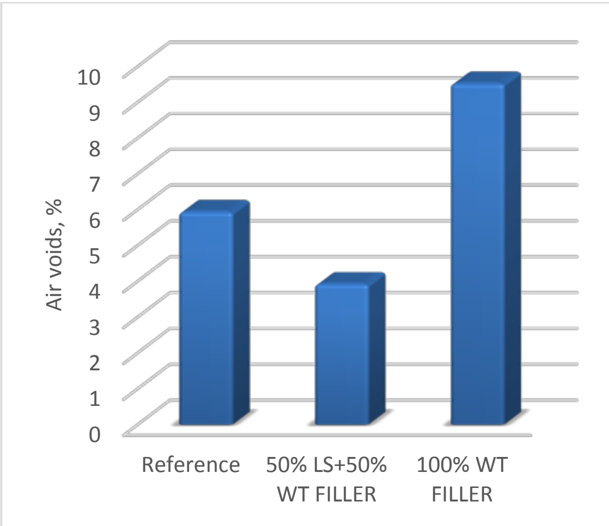

Figure 5. Air voids values of mixtures

The results showed that the 50% substitution was more effective than the 100% substitution. Therefore, in this paper welded tuff was substituted with limestone filler in proportion of 25%, 50%, 65% and 75% by weight. Next, Indirect Tensile Strength test was performed on the fabricated specimens and the results were assessed.

In Figure 8, the conditioned and unconditioned strength values were shown. According to the Figure 8, max IDT_{dry} and IDT_{wet} values were obtained with 65% welded tuff added specimens. The values increase till 65% welded tuff added specimens and then they were tended to decrease.

Figure 9 shows the TSR values of the specimens. As seen in the Figure 9, all specimens were provided the specification limit value and max TSR value was obtained at 65% welded tuff added specimens.

In Figure 10, the comparison between conditioned and unconditioned samples IDT strengths were shown. As seen in the Figure 10, the 65% and 75% welded tuff added specimens were close to the 45^0~line of equality. The meaning of being close to the line is that the conditioned and unconditioned IDT strength values were close to each other. So 65% and 75% of welded tuff added specimens have less moisture susceptibility.

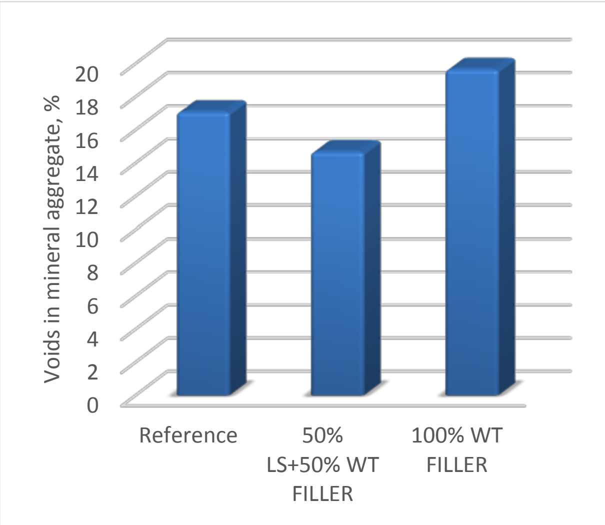

Figure 6. Voids in mineral aggregate values of mixtures

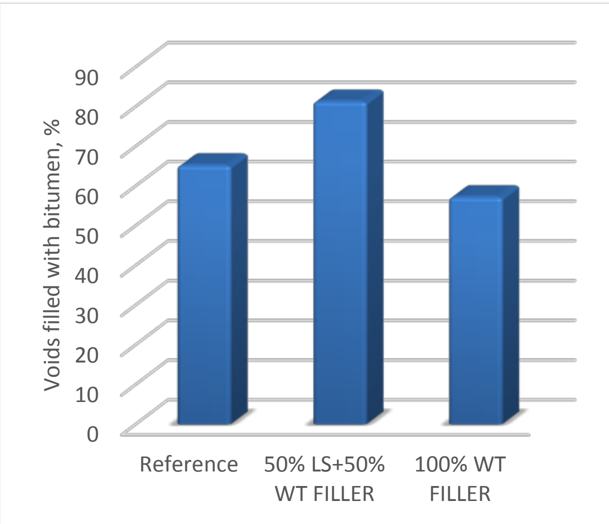

Figure 7. Voids filled with bitumen values of mixtures

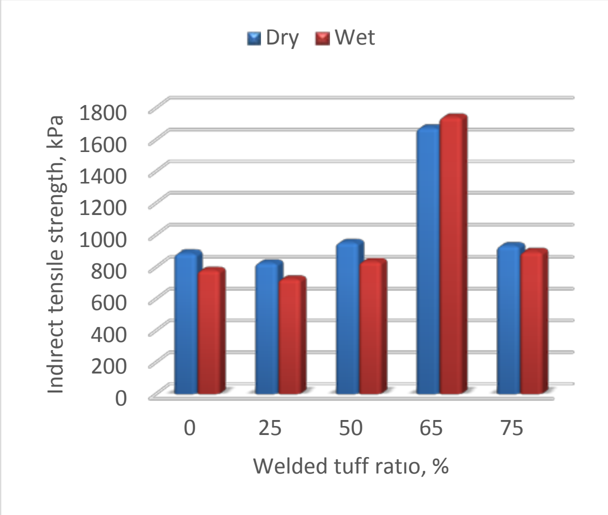

Figure 8. Wet and dry IDT strength values for each welded tuff adding rate

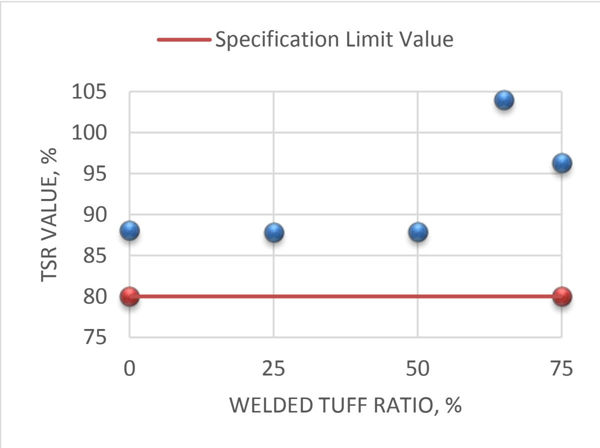

Figure 9. TSR Values

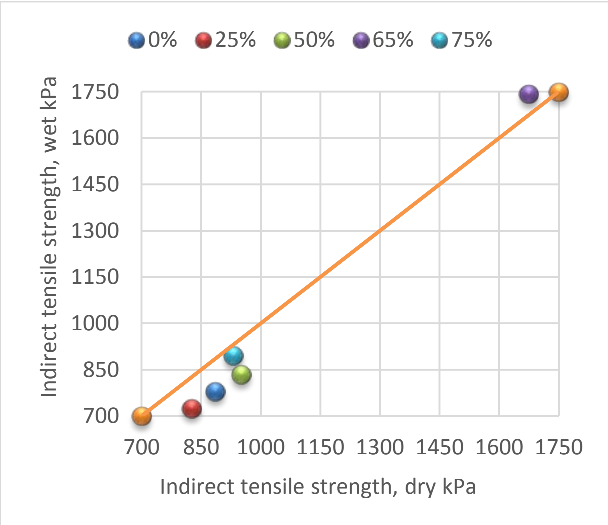

Figure 10. Comparison of IDT_{wet} and IDT_{dry} values

4. Discussion and Conclusion

First of all, welded tuff was substituted as filler with limestone filler in proportion of 50% and 100% by weight. After that Marshall Stability test was performed on specimens. The results showed that the 50% substitution was more effective than the 100%

substitution. Therefore, in this study welded tuff was substituted with limestone filler in proportion of 25%, 50%, 65% and 75%.

According to the results, max IDT_{dry} and IDT_{wet} values were obtained with 65% welded tuff added specimens. Moisture susceptibility of welded tuff mixed specimens were obtained by Tensile Strength Ratio (TSR). As a result, 65% and 75% of welded tuff added specimens have less moisture susceptibility. TSR results ensure the IDT Strength test results.

So that, welded tuff can be used in HMA as waste material in appropriate proportions. Because of these properties, welded tuff provides sustainability to the pavement material industry.

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