Journal of Mechanical Engineering *Vol SI 4 (1), 129-142, 2017*

Influence of Iron Oxide Powders on Braking Performance of Brake Friction Materials

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ABSTRACT

Friction material is used to slow down the moving vehicle and finally stopped at the required position by the pressing it against the rotating brake disc. Four friction material formulations marked as T, T1, T2 and T3 have been prepared through powder metallurgy process. The effect of different volume percentage (vol. %) iron oxide on the braking performance will be the main focus of this study. Each sample was subjected to porosity, hardness, friction and wear in accordance with international standard test procedures. The three samples T1, T2 and T3 which were utilising of activated carbon from kernel shell (PKS carbon) as their carbon content had higher coefficient of friction (COF) than sample which was using commercial carbon, sample T. Thus, PKS carbon produced locally could be used to replace the imported commercial carbon. Sample T2 which was composed of 15% voulme percentage of iron oxide powder produced the highest COF and having slightly higher thickness loss as compared with sample utilising commercial carbon. Thus, the base formulation sample T2 is the best formulation which produce the optimum triblogical and mechanical result. The transisition of wear mechanism from abrasion to severe adhesion under high surface temperature may cause increase in wear rate of the friction material.

Keywords: *Friction Materials, Iron Oxide Powder, Friction, Wear*

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-04-14
Accepted for publication: 2017-06-05
Published: 2017-08-15

Introduction

The braking system is used for slowing the moving vehicle and finally stops by means of friction generated between the brake friction material and the rotating brake disc or drum. The ingredients in the friction material formulation play the crucial factor in determining the coefficient of friction (COF) in the newly developed barke friction materials. The friction material should has a stable COF level over a wide range of operating parameters such as speeds, applied pressure, temperatures, dry and wet conditions. The COF shall be able to return to the pre-fade COF level on cooling (recovery). It shall also have a lower wear rate for long life and not produce noise and vibration during braking.

The resistance against the motion resulted in increased in temperature of friction materials and the brake disc or drum. The COF of the friction materials will fall dramatically at threshold temperature due to the decomposition of polymeric materials in the brake material formulation. The decomposition of organic material starts at 230 OC and the organic contents further decreased with increasing surface temperature [1]. The formation of carbonaceous residues is observed under high surface temperature which subsequently increased friction material exponentially [2]. High surface temperature will decrease yield strength and lead to change real contact configuration [3], subsequently increased the wear rate of the friction material during braking process.

Friction materials are multi-component composites and the ingredints in the formulation become increasingly complex in order to cover the properties of asbestos which have been banned by most advanced countries. Thus, their physical, mechanical and tribological behaviors cannot be predicted based on type of ingredients and volume percentage used in the formulation . Each newly developed friction material needs to be tested and evaluated in the laboratory as well as on-road braking performances before the developed product can be used on the road [4].

Brake friction ingredients are categories into four types; (i) reinforcing fibre, (ii) binder, (iii) friction modifier and (iv) filler [5]. The friction modifier materials such metal powders, carbon, kenaf are introduced into the formulation to improve COF and wear resistance. Iron oxide powder is used as a friction modifier which will improve the coefficient of friction as well as cleaning the brake disc. On the other hand, graphite provides friction stability at high surface temperature and prevent friction material from micro-stick to rotor. Palm kernel shell are consist of elements that can be used in fabrication of brake friction as a replacement for asbestos [6,7].

In this work, the study was focused on the effect of different vol. % of iron oxide powder on the mechanical properties and friction behavior in the composition of brake friction materilas. The adaptability of PKS carbon in the brake friction material will be also explore in this work.

Methodology

In this study, four brake friction materials were prepared by powder metallurgy process; (i) selection of raw materials,(ii) mixing, (iii) pre-form compacting, (iv) warm compacting, and (v) post-baking. Selecting sample T2 as based formulation, vol. % of iron oxide powder was increased by 50 % in sample T3 and decreased by 50 %, in sample T1 while the compositions of the other ingredients are proportionally decreased and incresed, respectively. Sample T was utilising commercial carbon while sample T1, T2, and T3 were using activated carbon from kernel shell (PKS carbon) as their carbon ingredient as shown in Table 1. The ingredients were mixed for 10 minutes and then warm compacted under a pressure of 150 kg/cm2 at a temperature of 190oC. Then, compacted samples were post-baked in an oven for 4 hours at a temperature of 180°C.

Table 1: Composition of Brake Friction Materials

INGREDIENT	**T**	**T1**	**T2**	**T3**
Phenolic resin	10	10.9	10	9.2
Steel fiber	20	21.8	20	18.2
Iron oxide	15	7.5	15	22.5
Friction modifier (carbon and kenaf powder)	30	32.6	30	27.3
Filler (friction dust and Barium)	25	27.2	25	22.8
Total (%)	100	100	100	100

Each sample was subjected to specific gravity, porosity and Rockwell hardness tests in accordance with Malaysia Standard MS 474: Part 6 [8], Japanese Industrial Standard JIS D 4418 [9] and Malaysia Standard MS 474: Part 2 [10], respectively. Rockwell hardness tester in scale R was used in determining the hardness values. The sample was subjected to applied load of 60 kgf using a ball diameter of 12.7 mm. The hardness of the sample was the arithmetic mean of ten indentations.

CHASE dynamometer was used in determining COF and wear behaviors of the samples developed. The friction and wear test procedures were in compliance with Society of Automotive Engineer SAE J616 brake lining test procedures [11]. Samples with a dimension of 25 mm x 25 mm x 6 mm were glued to the backing plate and then attached to brake calipers on the brake drum. The sample was pressed against a rotating brake drum with a constant rotating speed of 417 rpm under a constant normal load of 647 N and subjected to test program as shown in Table 2. The brake friction materials are classified as normal and hot COF. Two-letter friction codes were used, where the first letter represents normal COF and the second letter represents hot COF values, as prescribed by Society of Automotive Engineer SAE J886 [12]. The normal COF is the average of the four readings taken at 200, 250, 300 and 400ºF on the second fade curve. Whereas, the hot COF is the average of the ten readings taken at 400 and 300ºF on the first recovery; 450, 500, 550, 600 and 650ºF of the second fade; and 500, 400 and 300ºF of the second recovery run.

Table 2: Friction and Wear Test Program

Test sequence	Temperature (^{O}C)	Remarks
Conditioning	Less than 95	Continuous braking, 20 minutes
Initial measurement	88 - 99	Take indicator reading at 667 N load
Baseline run	82 – 104	Intermittent braking; 10 s ON, 20 s OFF, 20 applications
First fade run	82 - 288	Continuous and heater ON
First recovery run	288 - 82	Continuous and cooling ON
2nd measurement		Repeat initial measurement
Wear run	193-204	Intermittent braking; 10 s ON, 20 s OFF, 100 applications
Second fade run	82 - 343	Continuous and heater ON
Second recovery run	343 - 82	Continuous and cooling ON
Baseline rerun		Intermittent braking; 10 s ON, 20 s OFF, 20 applications
Final measurement		Repeat initial measurement

Results and Discussion

Physical and Mechanical Properties

The iron oxide powder filled-up the pore in the sample as the vol. % of iron oxide was increased in the formulation, thus increased the density of the sample as shown in Table 3 and Figure 1. This phenomena also reduced the porosity of the sample (Figure 2). It can be seen in Figure 3 that sample T2 had the highest hardness and second lowest porosity, which indicate this sample is the best formulation in producing the the best mechancial properites. As the vol.% of iron oxide powder further increased in sample T3, the hardness of the sample decreased. This could be due to a lesser steel fibres in the formulation as well as due to the non-homegenoues characteristics of the friction material as shown in Figure 3. Figure 3(a) and Figure 3(b) were the SEM images taken on the same sample at two different locations which clearly shows that the ingredients are not evenly distributed. Rockwell Hardness was measured using ½" ball , when the ball hit the area which composed high percentage of metallic material, the hardness will be higher [13]. Test results show that the porosity increases with increase in vol% of iron oxide. However, the hardness increases as the vol% of iron oxide increases up to 15% volume percentage of iron oxide powder and then decreases when further increase of vol% of iron oxide. Thus, it could be concluded that the hardness of the brake friction material was not simply correlated with vol. % of the ingredients in the formulation.

Table 3: Mechanical test results

Sample	**Density (gm/cm^3)**	**Porosity (%)**	**Hardness (HR_R)**
T	2.39	16.8	87.6
T1	2.01	25.9	94.7
T2	2.09	20.2	103.8
T3	2.14	17.4	99.6

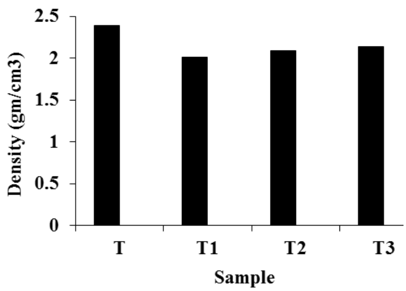

Figure 1: The relationship between density with vol.% of iron oxide powder

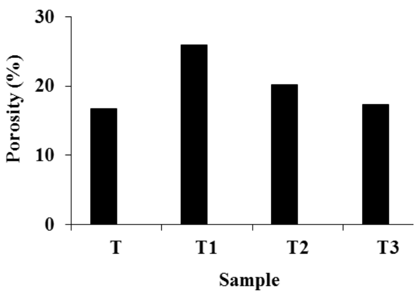

Figure 2: The relationship between porosity with vol.% of iron oxide powder

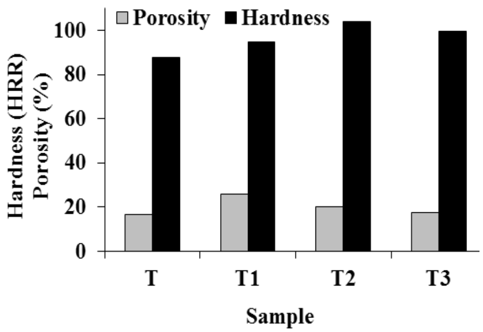

Figure 3: The relationship between hardness with iron oxide vol.%

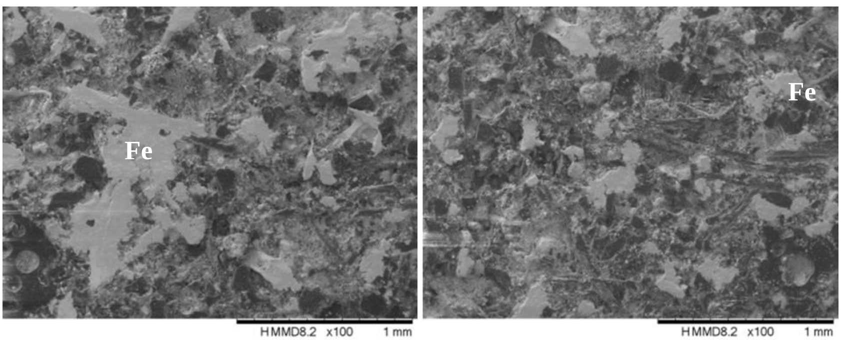

Figure 4. SEM images showing non-homogeneous structure of sample T3 at; (a) location 1, (b) location 2

Coefficient of Friction

Table 4 shows that all the four developed samples complied with the requirements of Automotive Manufacturer Equipment Companies Agency (AMECA), USA [14] which specified that the COF; (a) shall have normal friction coefficient of 0.25 and higher or a hot of 0.15 and above, (b) shall have friction coefficient above 0.15 between 200 and 550 ^{O}F inclusive in second fade, or between 300 and 200 ^{O}F during the secondary fade.

It can be seen in Figure 5 that sample T2 which was composed of 15 % volume percentage of iron oxide powder in the formulation produced the highest COF. Iron oxide powder is used as a modifier to improve COF and cleaning of brake disc. Too much oxide powder in the formulation will result in less binding of ingredients in the formulation, thus reduced COF. Reduction of 50 % volume percentage of iron oxide from based formulation result in slightly lower COF as compared to the base formulation which could due to less resistant to sliding during braking process. All the three samples (T1, T2, T3) utilizing PKS carbon as carbon content had higher COF as compared with sample T using commercial carbon even though compose of different vol. % of iron oxide powder. Thus, it could be concluded that PKS can be used to replace commercial carbon in the formulation of brake friction materials.

Sample T and sample T2 were composed of the same vol. % of ingredients except that sample T was a commercial carbon while sample T2 utilising PKS carbon. Sample T2 has much higher COF than sample T which could be due better properties of PKS carbon as compared with commercial carbon. PKS carbon composed of Alminium oxide and Silica oxide, potassium and phosphorus [15]. Alminium oxide and silica oxide improve the COF and clean the counter friction materials by removing iron oxides the from counter surface material during braking process. This could be the reason why sample using PKS carbon has higher COF than sample using commercial carbon.

Table 4: Friction and wear test results

Sample	**Coefficient of Friction (μ)**				**Fade %**	**Thickness loss (mm)**
	Normal	**Hot**	**Highest**	**Lowest**		
T	0.284	0.270	0.294	0.241	18.0	0.15
T1	0.411	0.322	0.425	0.261	38.6	0.24
T2	0.431	0.364	0.439	0.333	24.1	0.21
T3	0.353	0.303	0.367	0.245	33.2	0.41

Figure 5 shows that COF of all samples slightly increased with increasing brake drum temperature and then decreased when the surface temperature has reached the temperature of 150˚C. This paper discuss only the second fade and recovery characteristics because the temperature generated during this braking operation can go as high as 300°C (572 °F), which is well above the decomposition temperatures of phenolic resin. The COF increased at the beginning of braking due to the abrasion mechanism and enlargement of the contact area during sliding process [16]. Subsequently, COF decreased with increasing surface temperature due to the degradation of the phenolic resin which starts to melt at the temperature of 150˚C. Above the degradation temperature, the bond between metal fiber and resin is weakened by thermal metal grains [1], thus reducing the COF.

Fade percentage of base formulation sample T2 recorded the lowest value as compared to the two sample utilising PKS carbon (Table 4). Higher fade percentage requires higher pedal force to stop the moving vehicles. Thus, it could be postulated that the optimum vol % of iron oxide powder in the formulation was 15 % which produced the highest COF and the lowest fade percentage among the three samples utilising PKS carbon. It can be seen in Figure 6 that all the sample almost recover to to their respective base line COF values when the brake are cooled to 93.3°C (200 °F),

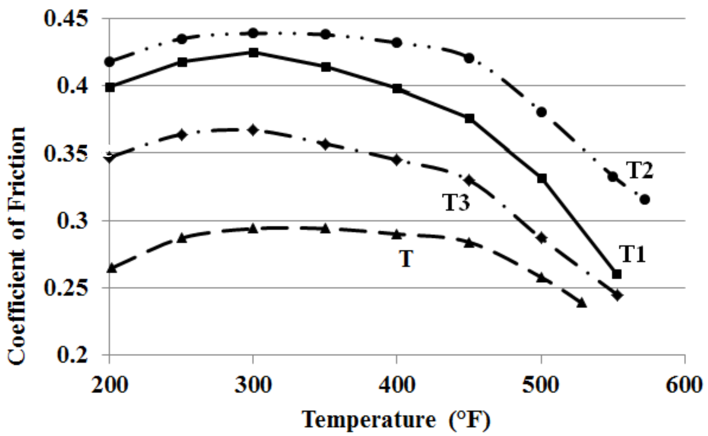

Figure 5: COF on second fade

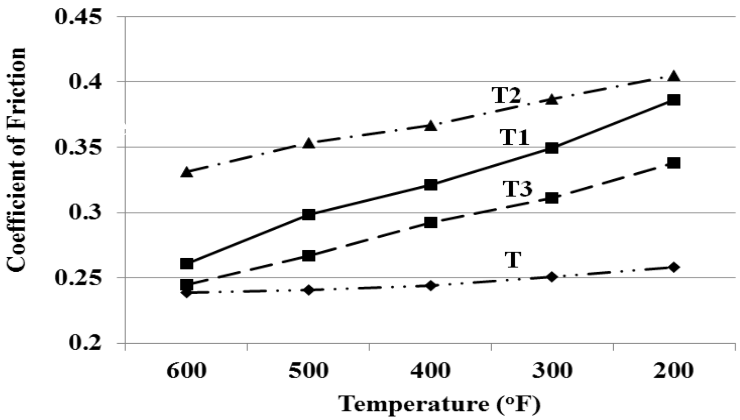

Figure 6: COF on second fade recovery

Thickness Loss

The thickness loss of the friction material increased with increasing vol. % iron powder oxide in the formulation as shown in Fig. 7. The thickness loss of sample T3 which was composed the highest vol. % iron oxide powder recorded the highest thickness loss. This could be due to binding propeties of ingredient become weaker with increased of vol. % iron oxide powder in the formulation. The surface temperature of friction material and brake increased with increasing braking time due the heat generated between the two counterparts. High temperature results decrease in yield strength of the sample and lead to change in the wear mechanism [3]. This phenomenon can be seen in Figure 8 and Figure 9. In early stage of braking, abrasion mechanism was observed due to ploughing of harder asperities on the friction surface materials as shown in Figure 8. Subsequently, the peak asperities were sheared and became blunt. The two-way transfer during braking caused the formation of transfer layers on the sliding surfaces as observed in Figure 9 which is the symptom of adhesive wear mechanism. The adhesion of the transfer layer becomes weak under high temperature resulting in flaking of the transfer layers and thus increase wear rate of the friction material (Figure 10).

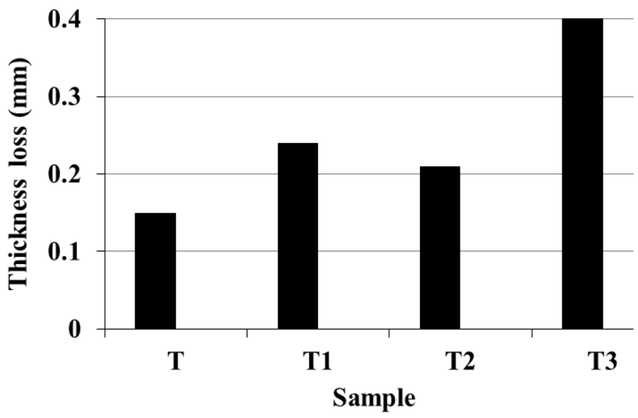

Figure 7: The relationship thickness loss with vol. % iron oxide powder

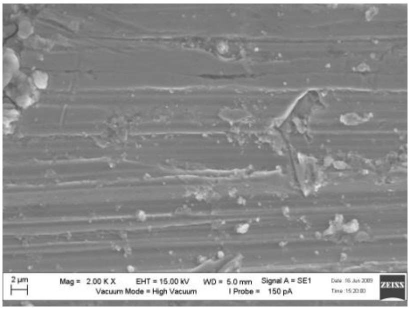

Figure 8: Abrasion mechanism, Sample T2

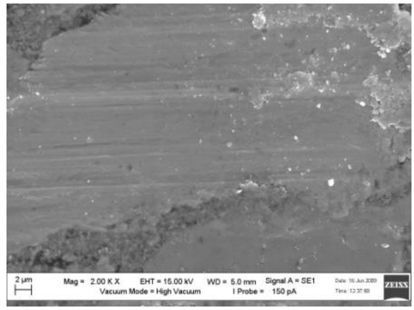

Figure 9: Adhesion mechanism, Sample T2

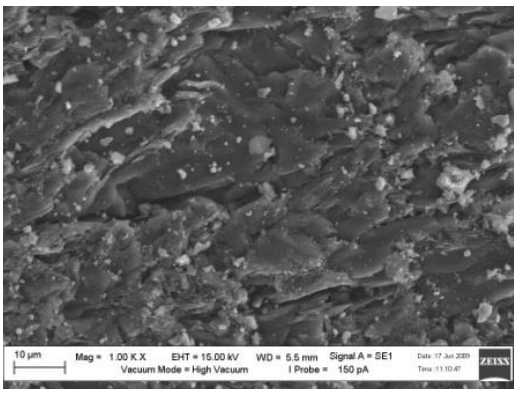

Figure 10: Flaking of transfer layer

Sample T1

Figure 11 represents the relationship between the mechanical with thickness loss. From this figure it could be concluded that there is no simple correlation between the porosity with the thickness loss. Thickness loss of 0.15 mm is a sample T using commercial carbon with 15 % volume percentage of iron oxide powder. When comparing with sample T2 using PKS carbon with the same vol. % of iron oxide powder, sample T has less thickness loss. Thus, the thickness loss of friction materials will depend on what of type of carbon used in the formulation. In case of hardness, it was observed that the thickness loss increased with increasing sample hardness. This phenomenon could be due to less binding between metallic ingredients with increasing vol. % of iron oxide powder in formulation and the non-homogeneous microstructure.

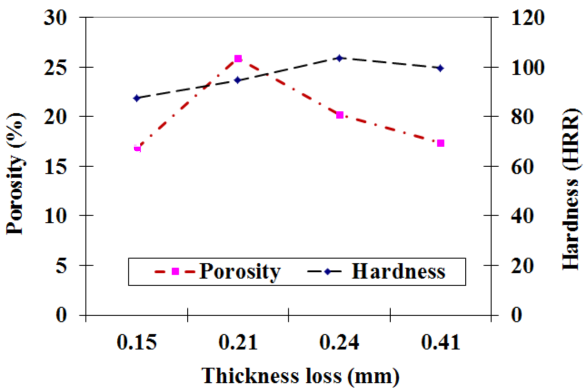

Figure 11: The relationship mechanical properties with thickness loss

Table 5 shows the effect of type of carbon and vol. % of iron oxide powder used in the formulation. Sample using commercial has the lowest mechanical and tribological properties as compared to other three samples using PKS carbon. This shows that type of carbon used in the formulation has significant effect on the mechanical and tribological properties. The highest hardness and hot COF are obtained when the sample was composed of 15 % volume percentage of iron oxide and then decreases as vol. % of iron oxide powder increases. Thus, it could be postulated that there are no simple correlations between vol. % of iron oxide powder with mechanical properties and tribological properties.

It was observed in Table 5 that sample T3 has higher hardness than sample T1 but has higher thickness loss. Sample T1 has higher porosity than sample T3 but has lower thickness loss. Generally, higher hardness shall have less thickness loss and higher porosity shall have higher thickness loss, but not in the case of brake friction materials. These phenomena could due to non-homogeneous characteristics of the friction material as shown in Figure 3. Thus, it could be concluded that there are also no simple correlations between the mechanical properties with tribological properties.

A new formulation needs to be characterised on its mechanical and tribological properties before can be decided which formulation is the best formulation. The decision will be based on the tribological properties rather than the mechanical properties. The best formulation supposed to have the highest hot COF with less percentage of fade and lowest wear rate. On the other hand, the mechanical properties are used for quality control purpose to ensure the manufacturing processes are following the material formulation and the process parameters.

Table 5: Summary of mechanical and tribological test results

Sample	Carbon type	Iron oxide (vol. %)	Porosity (%)	Hardness (HRR)	Hot COF	Thickness loss (mm)
T	Com	15.0	16.8	87.6	0.270	0.15
T1	PKS	7.5	25.9	94.7	0.322	0.24
T2	PKS	15.0	20.2	103.8	0.364	0.21
T3	PKS	22.5	17.4	99.6	0.303	0.41

Conclusions

Four newly developed friction materials samples with varying the vol.% of iron oxide had been subjected to mechanical and CHASE dynamometer friction tests. The following phenomena could be postulated as follows;

(i) The braking performance of brake friction depends on vol. % of iron oxide powder in the formulation. Too much vol. % of iron oxide powder in the composition will result decrease in COF due to less binding of the composition. If less than the optimum vol. % will also result decrease in COF due less resistant to sliding during braking.

(ii) Sample T2 which was composed of 15 % volume percentage of iron oxide powder is the best formulation based on the mechanical and tribological properties test results,

(iii) PKS carbon could be used to replace the commercial in the brake friction material formulation,

(iv) There are no simple correlations between the vol. % of iron oxide with mechanical properties and tribological properties,

(v) There are also no simple correlations between the mechanical properties with tribological properties,

(vi) On set of second fade braking, the COF increased with increasing temperature to abrasion wear mechanism and enlargement of the contact area. Thereafter, COF decreased when the surface temperature has reached the temperature of 150˚C due to the decomposition of the phenolic resin in the formulation. It could be also due to the shearing of the peak asperities and formation of friction film,

(vii) Transition of wear mechanism from abrasion to severe adhesion under high surface temperature could be the reason increase in thickness loss.

Acknowledgement

This research was supported by Ministry of Science, Technology and Innovation, Malaysia with Sciencefund grant No. 06-01-01-SF0809. The author would like to thank Universiti Teknologi MARA and SIRIM Berhad for providing research facilities.

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