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MECHANICAL AND PHYSICAL PROPERTIES OF FLAME RETARDANT MEDIUM DENSITY FIBERBOARD

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Abstract

The mechanical and physical properties of the flame retardancy medium density fiberboard (MDF) from rubberwood fibers were studied. Flame retardant chemicals include sodium aluminate, zinc borate and aluminum trihydrate were used to manufacture experimental MDF panles using dry process. Four concentrations of flame retardant were used ; 10%,15%,20% and 30% based on oven dry weight of fibers along with control. The adhesives use were phenol formaldehyde and urea formaldehyde at 15% resin level based on the oven dry weight of the fibers. The mechanical properties investigated include bending strength, internal bond strength, thickness swelling and water absorption. Compatability of the adhesive with the flame retardant was also studied. Presence of flame retardant chemicals were evaluated using SEM.

Keywords: Dry process MDF, Flame retardant, Zinc borate, Sodium aluminate, Aluminum trihydrate, Mechanical properties, Internal bond, physical properties

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1. Introduction

Medium density fiberboard (MDF) is one of the most widely used wood composites in the building industry as a substitute to manufacture housing furniture. To outcome one of its limitation, an enhanced resistance to fire is desired. The need for fire protection treatment of MDF has been identified (Hashim et al 2005; Chih and Szu, 2003: Rusch, et al. 2003.)

Like other wood composites, a major consideration in the manufacture of flame retardant MDF is maintaining the necessary mechanical and physical properties of these boards. Factors such as wood species, moisture content, pressing conditions, and preservative or fire retardant treatment critically affect these properties (Gillespie, 1980). Previous studies showed that the influence of chemical treatment on strength properties highly dependent on the thermal stability of the fire retardant formulation (LeVan et al, 1996).

Flame retardancy MDF can be manufactured either using the wet process or dry process (Hashim et al 2005; Rusch et al 2003). Several types of fire retardant chemicals for wood products have been used including borax-boric acid, zinc borate, mono ammonium hydrogen phosphate, ammonium sulphate and nitrogen phosphate mixtures (White and Sweet, 1992; LeVan and Winandy, 1990; Garba, 1999).

In this study, the mechanical and physical properties of flame retardancy of MDF made from rubberwood fibers using the dry process was investigated. Three types of fire retardant chemicals were used namely zinc borate, sodium aluminate and aluminum trihydrate (ATH). The ATH is widely used as fire retardant additives for plastics and elastomers (Brown and Herbert, 1992).

2. Methods

Experimental MDF of dimension 21.2 x 21.2 x 0.5 cm and target density of 0.7gm/cm^3 were made using a small scale laboratory press. The boards were made from thermo mechanical processed rubberwood (*Hevea brasiliensis*) fibers free from resin obtained from MDF mill in Malaysia. The adhesive used were phenol formaldehyde and urea formaldehyde at 15% resin level based on oven dry weight of the boards.

Flame retardant chemicals used were sodium aluminate, zinc borate, and aluminum trihydrate. Four concentrations of flame retardant treatment were used; 10%,15%, 20% and 30% based on the oven dried weight of fibers along with control without flame retardant chemicals. For zinc borate and sodium aluminate, they were incorporated in the resin mix during blending. For ATH application, the chemicals were scattered evenly onto the fibers manually. A resin is then incorporated with the treated fibers in the blender. The press time was 10 minutes at 180°C with a pressure of 12N/mm^2.

A total of 4 panels were made for each concentration along with the control. The boards were then conditioned to standard procedure of 65% relative humidity with temperature of 20°C prior to testing.

Bending strength (MOR) was carried out according to ISO 16978(2002) with modification of size use 120 mm x 20 mm x 5 mm. The evaluation of internal bond strength (IB) was carried out in accordance with ISO 16984 (2002. Thickness swelling and water absorption of MDF were done according to ISO 16983 (2002). For each test, there were 8 replicates and 3 samples from each panel. The cyclic test was carried out in accordance with ISO 16987 (2002). The boil test was carried out in accordance with ISO 16998 (2002). A gelling time of the mixture of fire retardant chemical and UF resin was carried out to investigate whether the fire retardant chemicals interfere with the resin in 100°C distilled water. The formation of adhesive film and its cure was further conducted using phenol formaldehyde resin. Phenol formaldehyde resin and flame retardant chemicals were coated on the same glass plate and cure at a temperature of 50°C for 2 minutes. The cured film was examined by light microscope and image analyzer to find out the nature of the film cured. SEM-EDAX Falcon System was also employed to confirm the presence of flame retardant chemicals.

3. Results and Discussion

The results of the mechanical and physical properties studied for each type of flame retardant chemicals together with control are presented in Table 1-3. The results after being normalized are shown as percentage of control values in Figures 1-12.

For flame retardant MDF bonded with phenol formaldehyde resin, a general significantly increase in MOR values for all boards when the concentration of the flame retardant chemicals increase compared with the control (Table 1 and Figure 1).

It was shown that an incorporation of 30% ATH has the highest normalized MOR values compared with the control.

For flame retardant MDF bonded with urea formaldehyde resin a reverse trend is seen where as the concentration of flame retardant chemicals increased, the MOR value decreased (Table 2 and Figure 2). The analysis of variance for MOR between treatment showed no significant difference in MOR value at $p=0.05$. This lack of significant difference between treatment suggests that MOR was not affected by the treatment for boards bonded with urea formaldehyde resin.

Mechanical properties of cyclic and boil test after conditions could be used to determine the relative effect of fire retardant chemicals and levels (Reference). The MOR values after cyclic test showed a general decrease as the concentration of the flame retardant chemicals decrease for flame retardant MDF bonded with either phenol formaldehyde or urea formaldehyde resin with effect more severely seen for the flame retardant MDF bonded with phenol formaldehyde.

Table 1 and Figure 4 illustrate the effect of flame retardant treatment on internal bond strength (IB) for MDF bonded with phenol formaldehyde resin and Table 2 and Figure 5 illustrate the effect of flame retardant treatment for MDF bonded with urea formaldehyde resin. The IB after cyclic for flame retardant MDF bonded with phenol formaldehyde resin is shown in Figure 6. For boards made using 10% flame retardant chemicals irrespective of types, no general trend in the effect of treatment was found in the values of IB and IB after cyclic tests for both flame retardant MDF made using PF and UF resin. As for the IB after cyclic the effect I similar as of the bending strength after cyclic. As the concentration of the chemicals increase however, a trend is seen in the progressively decrease in the IB values and IB after cyclic.

The results shows that the closest curing time to ammonium chloride (NH_4CL) and UF was the aluminum trihydroxide followed by sodium aluminate and zinc borate. This is important if the precure is short, the resin will have the tendency to cure before the application of pressure. For good compatibility between the resin and the fire retardant chemical, a continuous film with good cohesion will be formed. It can be seen that films made from phenolic resin and those made from the mixture of phenolic resin with sodium aluminate gave a fairly uniform cured film without any sign of phase separation. For film made from a mixture of phenolic resin and ATH showed a slight phase separation. The films made from a mixture of phenol formaldehyde and zinc borate showed visible sign of phase separation and cluster formation leading to discontinuity in the film. This account for the fact that MDF treated with ATH and sodium aluminate using Phenol formaldehyde resin have good IB after cyclic and boil compared with MDF treated with zinc borate.

The ANOVA showed that the interaction between fire retardant chemicals and resin was significant ($P < 0.00$) for all the properties evaluated. This indicated that the mean value of each level of fire retardant type depend on the type of resin used.

The results of swell, mass increase and residual swell after cyclic are shown in Table 1-3 and after being normalized as shown in Figure 7-12.

For thickness swell after 24 hours, flame retardant MDF bonded with phenol formaldehyde resin showed a progressive decrease in swell for all types of flame retardant chemicals. Flame retardant MDF treated with 30% zinc borate showed the lowest thickness swell. The same trend is also seen for flame retardant MDF bonded with urea formaldehyde resin. For thickness swell after cyclic, flame retardant MDF bonded with phenol formaldehyde resin, the results showed a progressively increase in swell as the amount of flame retardant chemicals increase irrespective of types of chemicals.

The results for water absorption corresponds well with the thickness swell where as the amount of flame retardant chemicals increase the water absorption also decrease irrespective of the types of chemicals which is equally true for both flame retardant MDF bonded with phenol formaldehyde resin, and urea formaldehyde resin and after cyclic for flame retardant MDF bonded with phenol formaldehyde resin (Table 1-3 and Figure 10-12).

It was known from the method of the production of flame retardant MDF carried out in this study, certain levels of the fire retardant chemicals were blended and penetrated into the fibers followed by the addition of resin. Therefore swelling and water absorption of the samples decreased with increasing levels of chemicals. This might be the possibility be the cause that avoid water from entering and caused the samples to swell.

4. Conclusions

Acknowledgements

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Table 1

Mechanical and physical properties of flame retardant MDF made using phenol formaldehyde resin

Types of flame retardant	%	MOR (N/mm^2)	IB (N/mm^2)	TS (%)	WA (%)
		Mean			
Control	0	11.56	0.4	35.55	54.29
		(4.11)	(0.01)	(16.60)	(24.98)
Sodium Aluminate	10	15.05	0.38	27.68	95.11
		(2.98)	(0.02)	(3.75)	(16.92)
	15	21.48	0.34	24.98	48.61
		(6.86)	(0.01)	(4.34)	(11.56)
	20	25.19	0.31	19.50	40.74
		(1.76)	(0.02)	(3.57)	(5.39)
	30	29.55	0.26	13.87	33.02
		(4.11)	(0.02)	(8.09)	(9.07)
Zinc borate	10	23.23	0.44	27.22	96.14
		(3.89)[a]	(0.04)	(2.06)	(15.79)
	15	25.05	0.35	26.35	48.78
		(2.19)	(0.02)	(3.81)	(3.97)
	20	28.14	0.33	22.82	38.85
		(2.62)	(0.01)	(3.11)	(9.89)
	30	33.59	0.26	13.06	27.46
		(2.80)	(0.02)	(8.05)	(3.06)
Aluminum Trihydrate	10	14.91	0.36	31.05	95.68
		(4.13)	(0.02)	(7.33)	(25.97)
	15	31.18	0.35	28.52	54.57
		(8.3)	(0.01)	(6.08)	(6.09)
	20	36.34	0.32	24.92	30.61
		(1.85)	(0.01)	(4.86)	(10.14)
	30	39.77	0.25	19.40	23.49
		(1.91)	(0.05)	(5.27)	(10.20)

[a]Numbers in parentheses are standard deviation

Table 2

Mechanical and physical properties of flame retardant MDF made using urea formaldehyde resin

Type of flame retardant	%	MOR (N/mm^2) Mean	IB (N/mm^2)	TS (%)	WA (%)
Control	0	20.32	0.65	33.84	58.46
		(6.16)[a]	(0.02)	(1.75)	(15.78)
Sodium aluminate	10	25.67	0.61	19.10	91.50
		(4.13)	(0.02)	(0.69)	(19.15)
	15	18.43	0.54	17.14	73.93
		(5.00)	(0.02	(1.53)	(22.02)
	20	15.51	0.52	16.96	60.30
		(1.05)	(0.02)	(10.15)	(14.78)
	30	13.60	0.48	13.78	32.11
		(0.75)	(0.01)	(13.89)	(12.80)
Zinc borate	10	20.99	0.57	28.98	77.78
		(3.20)	(0.02)	(3.41)	(7.80)
	15	18.17	0.54	16.68	69.23
		(6.71)	(0.02)	(0.95)	(15.62)
	20	17.36	0.52	14.08	67.74
		(0.80)	(0.02)	(8.05)	(9.36)
	30	15.73	0.47	11.95	50.52
		(0.70)	(0.04)	(6.95)	(13.62)
Aluminum Trihydrate	10	32.05	0.67	26.50	86.74
		(9.63)	(0.02)	(5.00)	(7.79)
	15	28.05	0.60	24.45	52.92
		(7.54)	(0.02)	(4.64)	(5.90)
	20	27.39	0.57	22.11	40.61
		(1.63)	(0.03)	(7.56)	(7.46)
	30	22.48	0.51	19.45	33.20
		(2.22)	(0.03)	(4.20)	(7.72)

[a]Numbers in parentheses are standard deviation

Table 3

Mechanical and physical properties Of flame retardant MDF after cyclic and boil test using phenol formaldehyde

Types of flame retardant	%	MOR (N/mm^2) (cyclic)	IB (N/mm^2) (cyclic)	TS (%) (cyclic)	WA (%) (cyclic)	IB (N/mm^2) (boil)
		Mean				
Control	0	20.55	0.27	21.48	130.33	0.16
		(5.00)[a]	(0.01)	(4.36)	(28.75)	(0.02)
Sodium Aluminate	10	6.56	0.25	37.67	121.36	0.17
		(1.20)	(0.01)	(8.46)	(23.68)	(0.01)
	15	6.17	0.24	44.64	121.60	0.14
		(1.03)	(0.01)	(15.98)	(36.93)	(0.02)
	20	4.45	0.22	65.07	148.52	0.12
		(1.52)	(0.01)	(10.75)	(19.43)	(0.02)
	30	3.05	0.17	99.37	160.94	0.08
		(0.57)	(0.01)	(13.25)	(15.41)	(0.01)
Zinc borate	10	9.52	0.26	47.96	110.11	0.17
		(2.98)	(0.02)	(7.96)	(13.82)	(0.01)
	15	9.01	0.21	68.24	158.52	0.15
		(1.02)	(0.01)	(7.65)	(25.33)	(0.02)
	20	8.74	0.18	81.27	202.24	0.13
		(1.68)	(0.01)	(12.56)	(15.65)	(0.01)
	30	7.76	0.15	90.39	216.78	0.10
		(1.85)	(0.02)	(10.39)	(40.70)	(0.01)
Aluminum Trihydrate	10	18.16	0.27	10.37	144.16	0.17
		(1.6)	(0.01)	(4.62)	(30.47)	(0.01)
	15	16.61	0.21	20.05	150.59	0.14
		(1.21)	(0.01)	(8.0)	(19.90)	(0.01)
	20	15.34	0.17	47.53	148.52	0.12
		(1.52)	(0.04)	(9.79)	(19.43)	(0.01)
	30	13.87	0.13	70.79	160.94	0.10
		(1.28)	(0.01)	(16.25)	(15.41)	(0.01)

[a] Numbers in parentheses are () standard deviation

Table 4 : Gelling time of various flame retardant and UF resin

Chemical	***Curing time (s)***
NH_4Cl+UF	2.15
NH_4Cl + UF + ATH	3.30
NH_4Cl+UF+SA	4.03
NH_4Cl+UF+ZB	6.48

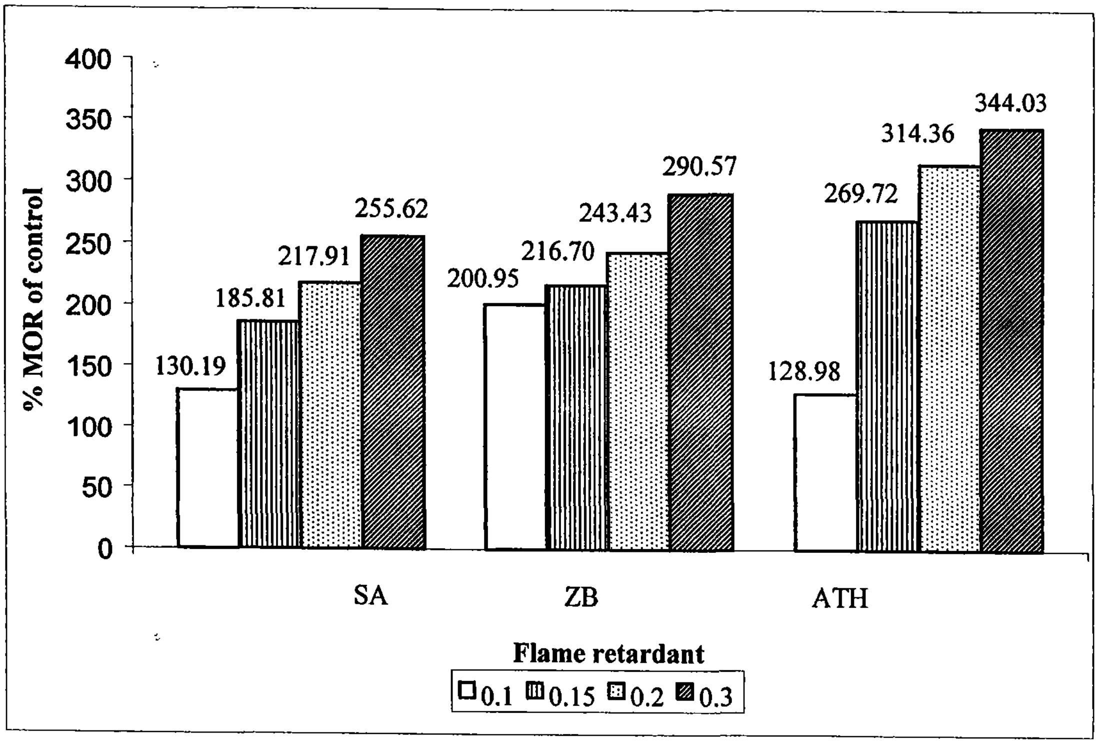


Fig. 1. MOR (normalized) of flame retardant MDF made using phenol formaldehyde resin.

SA- Sodium aluminate; ZB- Zinc borate; ATH- Aluminum trihydrate

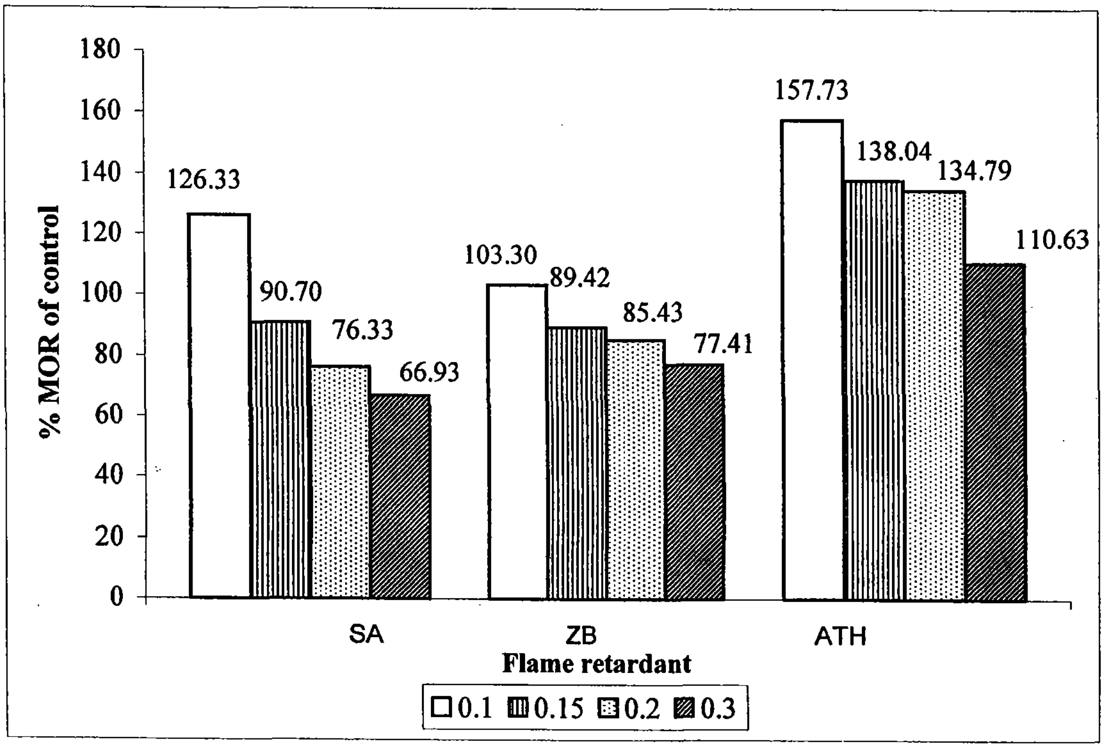


Fig. 2. MOR (normalized) of flame retardant MDF made using urea formaldehyde resin.

SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

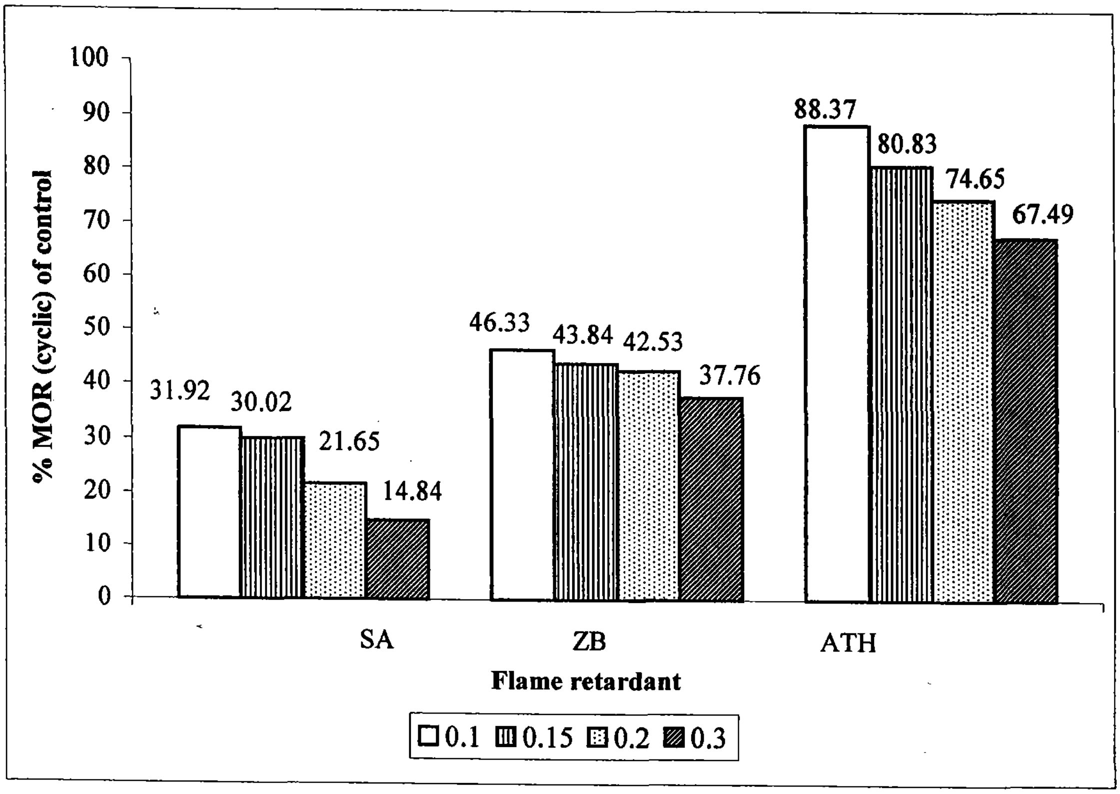


Fig. 3. MOR after cyclic test (normalized) of flame retardant MDF made using phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

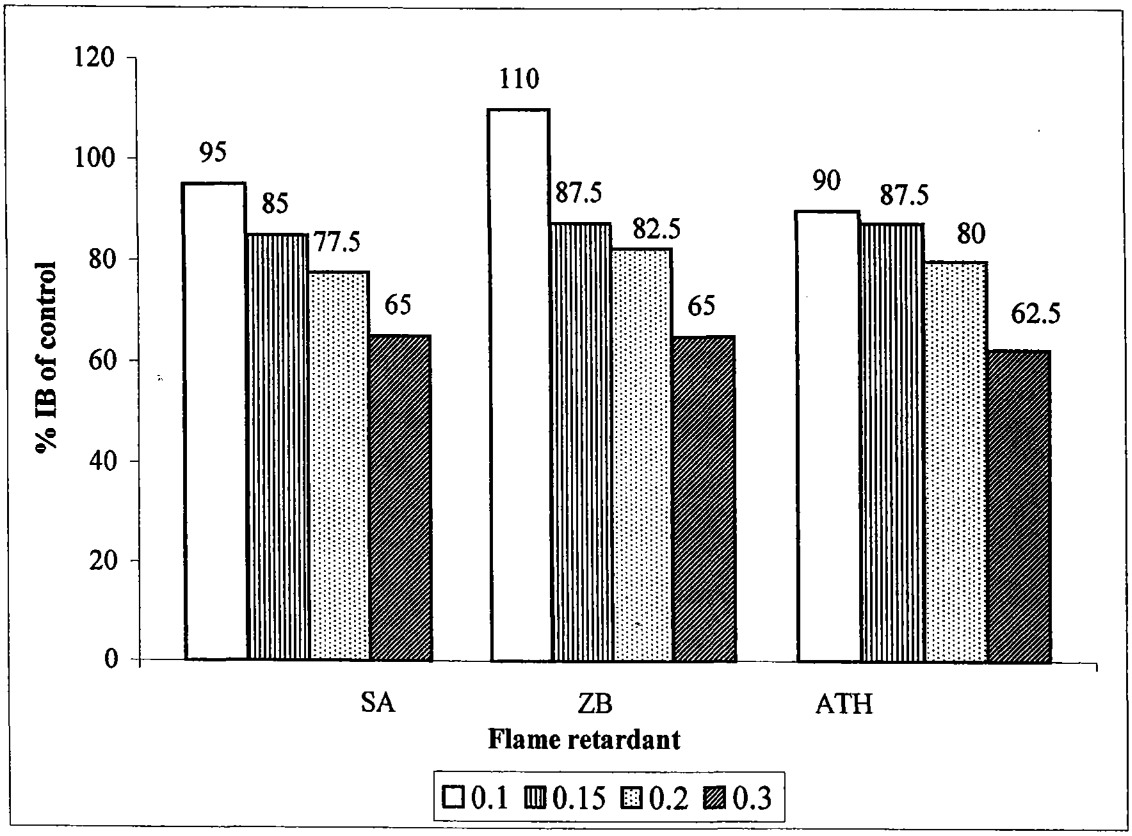


Fig. 4. Internal bond strength (normalized) of flame retardant MDF made using phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

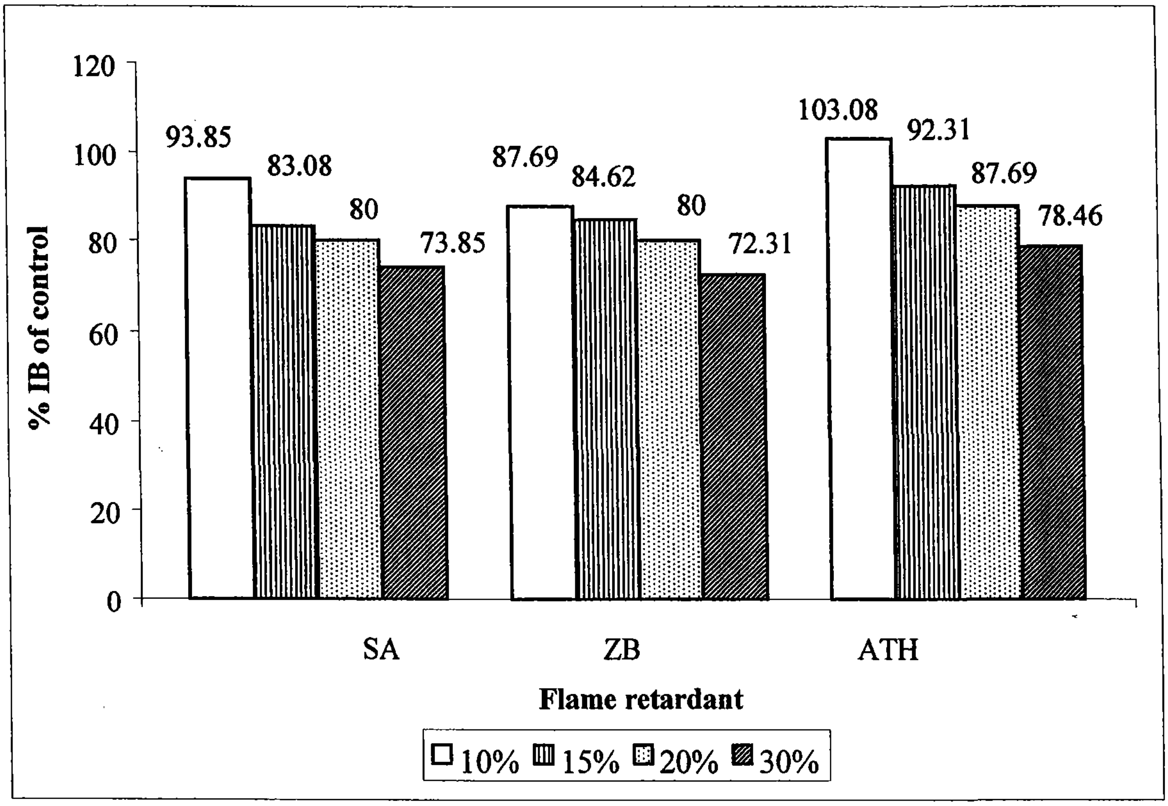


Fig. 5. Internal bond strength of Flame retardant MDF made from rubberwood fibres and Urea formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

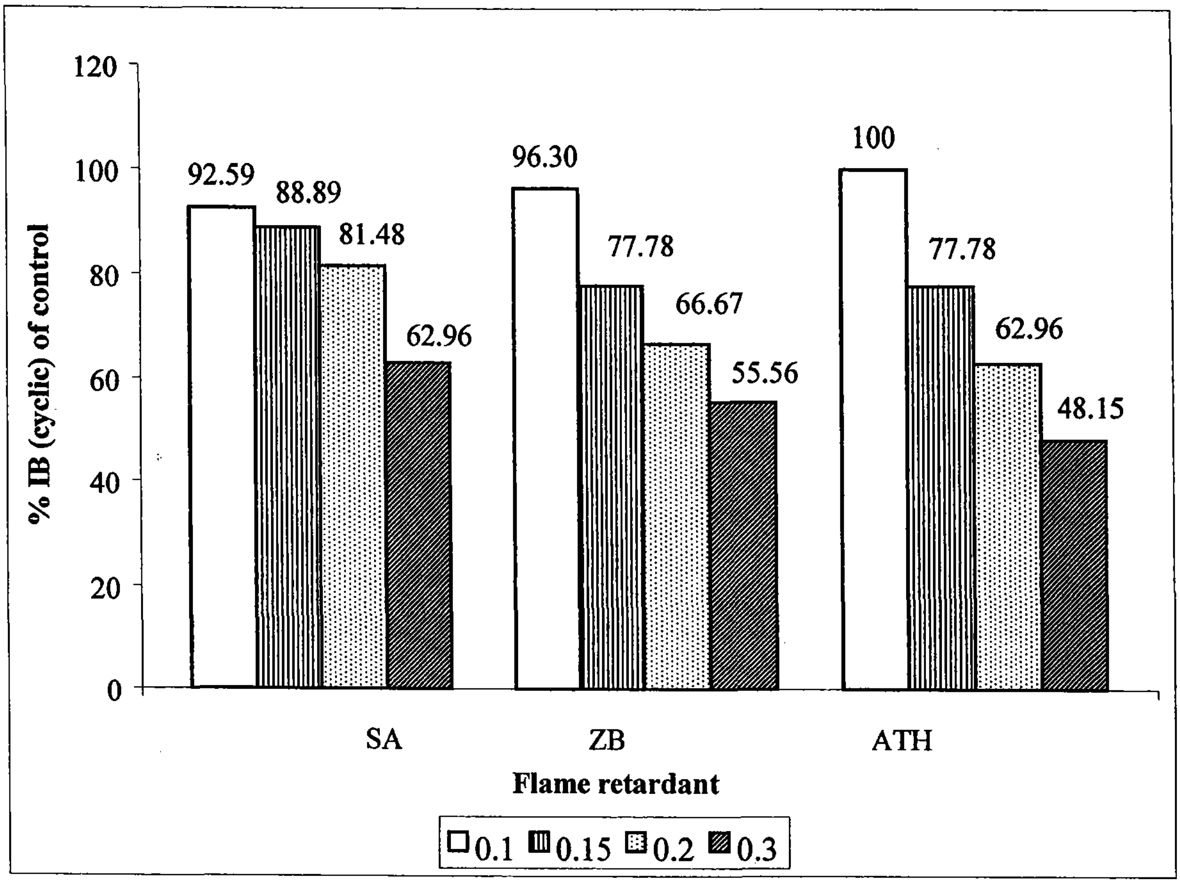


Fig. 6. Internal bond strength after cyclic test of Flame retardant MDF made from rubberwood fibres and Phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

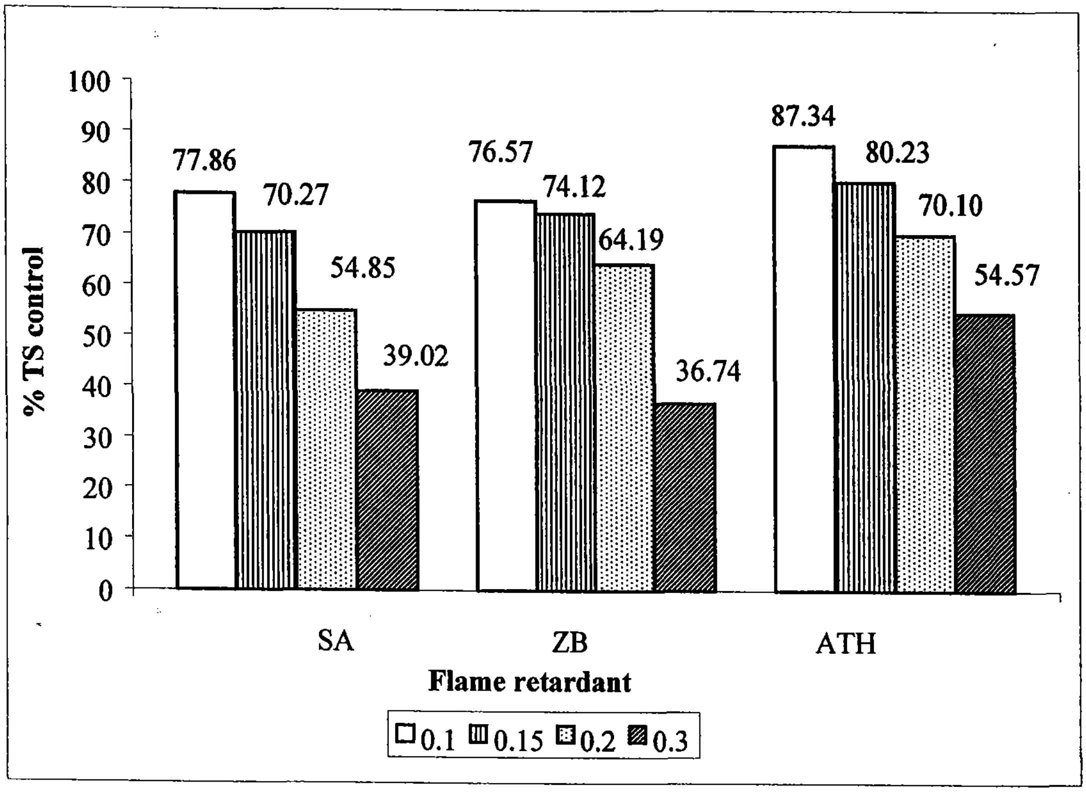


Fig. 7. Thickness swell of Flame retardant MDF made from rubberwood fibres and Phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

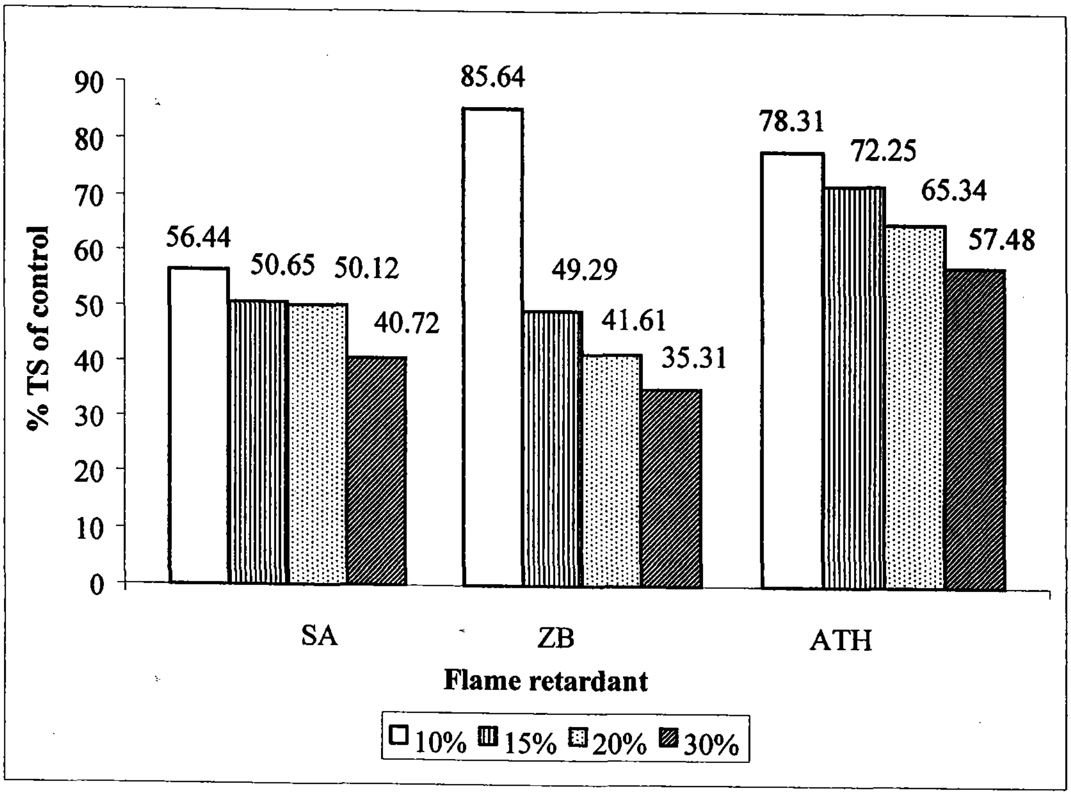


Fig. 8. Thickness swell of Flame retardant MDF made from rubberwood fibres and Urea formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

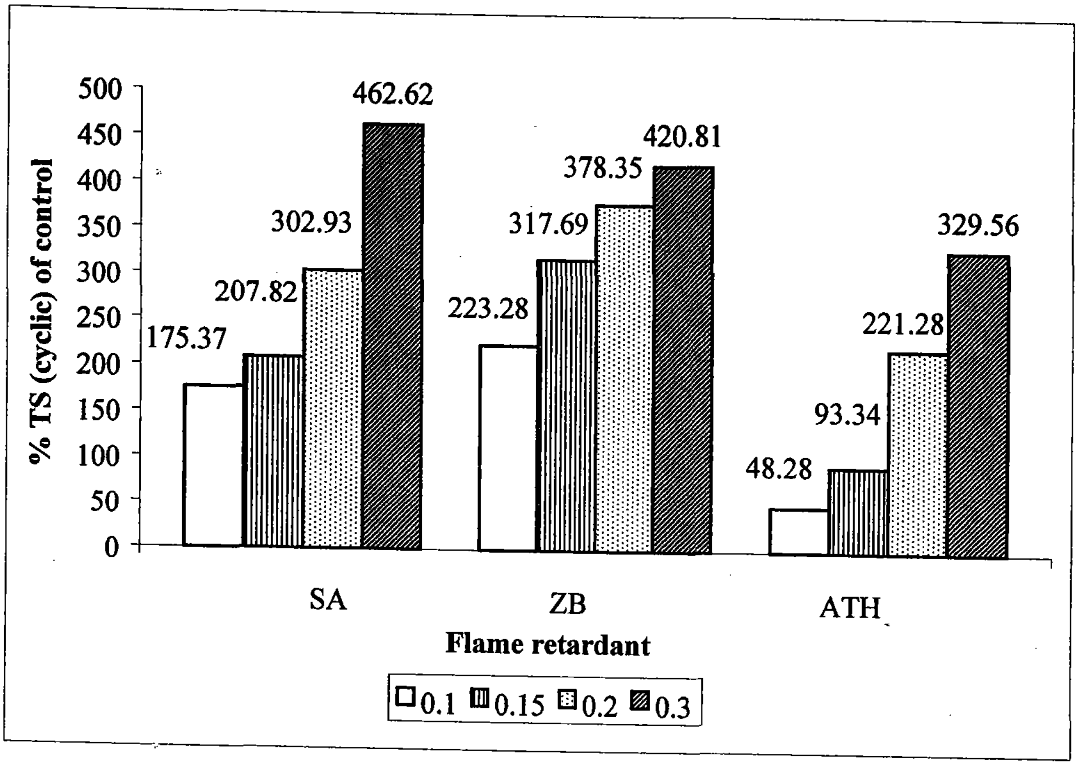


Fig. 9. Thickness swell after cyclic test of Flame retardant MDF made from rubberwood fibres and Phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

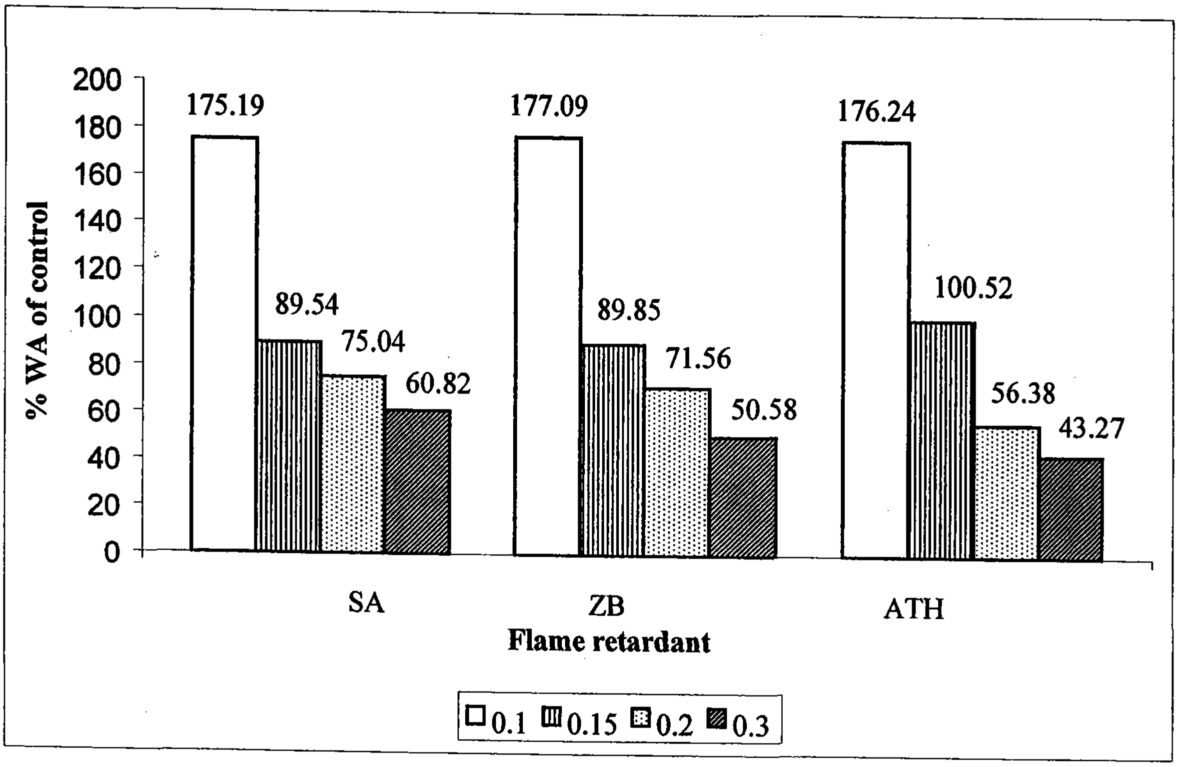


Fig. 10. Water absorption of Flame retardant MDF made from rubberwood fibres and Phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

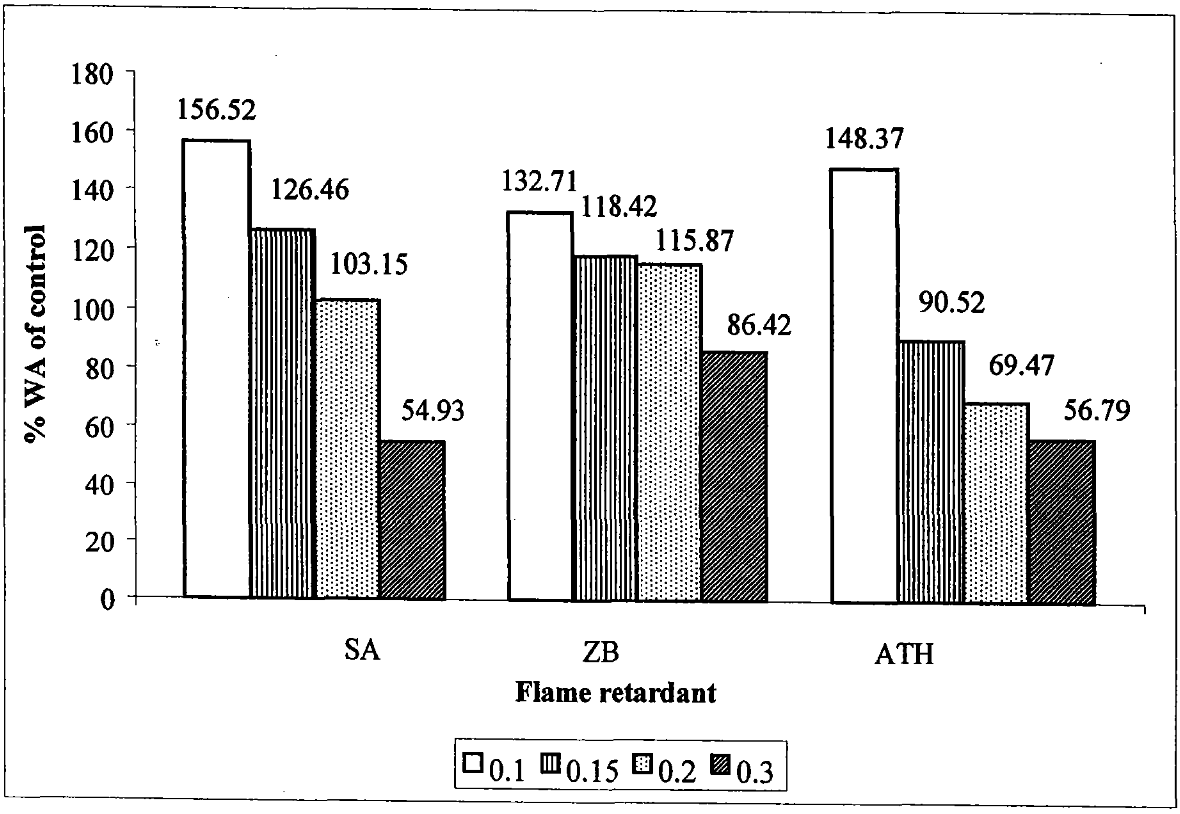


Fig. 11. Water absorption of Flame retardant MDF made from rubberwood fibres and Urea formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

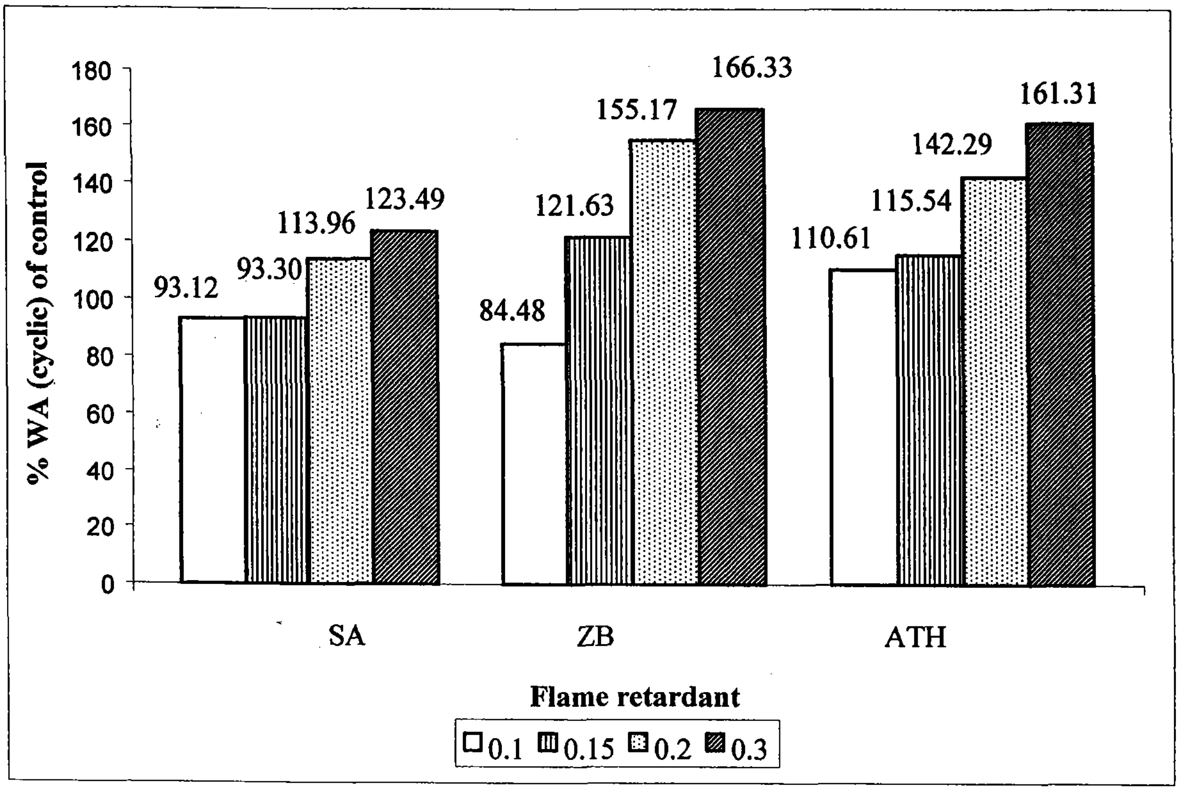
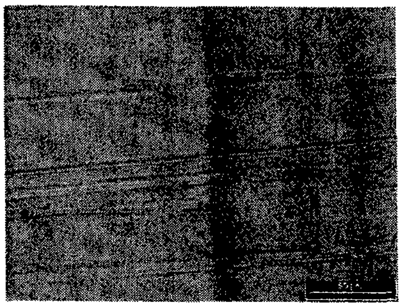
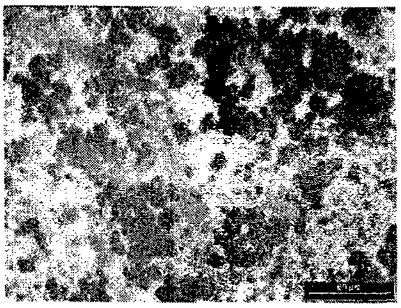


Fig. 12. Water absorption after cyclic test of Flame retardant MDF made from rubberwood fibres and Phenol formaldehyde resin.
SA – Sodium aluminate; ZB-Zinc borate; ATH- Aluminum trihydrate

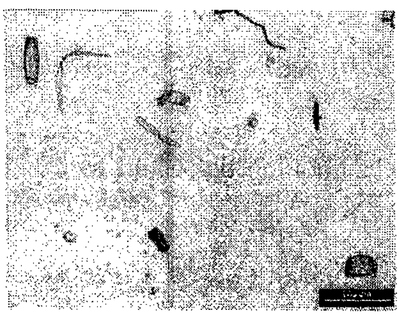
a. Cured film of phenol formaldehyde



b. Cured film of phenol formaldehyde and sodium aluminate



c. Cured film of phenol formaldehyde and zinc borate



d. Cured film of phenol formaldehyde and ATH

Fig. 13 Micrographs of cured film of various flame retardants with Phenol formaldehyde resin