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MOLD GROWTH ON WOOD-PLASTIC COMPOSITES

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Summary

Mold growth on building products has developed as an important consumer acceptance issue for wood/plastic composite decking. Very little information is available in the literature on mold susceptibility of wood-plastic composites (WPC). Basic WPC manufacturing variables (wood content, lubricant content and type, surface roughness, and moldicide type and content) were evaluated for their effect on the mold susceptibility of WPC manufactured using a lab scale extruder. Increasing the wood content, surface roughness, and lubricant content resulted in more mold growth on the composite. Incorporating moldicides (chlorothalonil or zinc borate) reduced the mold growth. These results may help manufacturers choose manufacturing variables to reduce mold susceptibility of their WPC products.

1. Introduction

Rapid production growth and consumer acceptance of wood-plastic composite (WPC) products have allowed WPC-based decking products to claim more than 10% of the current preservative treated wood decking market and is projected to reach +20% of the market by 2010 (Winandy et al 2004). Despite the growth and acceptance of WPC, there have been some growing pains involved in the process. Important issues that manufacturers are dealing with are photodegradation, decay of the wood component, and mold/algal growth on the composite surface. Minimal information about mold growth on WPC decking has been published, although anecdotal accounts indicate that this is a significant problem with real-world installations (Lang 2004, Manning 2004). However, we could only find a single paper (Dylingowski 2003) in the literature that dealt with mold susceptibility of WPC products. Dylingowski compared the efficacy of two moldicide additives in a model WPC material. The moldicide additives used were 4,5 dichloro-2-n-octyl-4-isothiazolin-3-one (DCOIT) biocide at a loading of 1,000 ppm and zinc borate at a loading of 10,000 ppm. The paper reported that the DCOIT biocide worked more effectively than the zinc borate at these loadings.

There are many manufacturing variables in the production of WPC decking. These include wood content, wood species, plastic type, lubricant type and content, processing temperature, other additives, etc. The purpose of this paper is to summarize some of the work we have been doing on how some of these manufacturing variables (specifically wood content, lubricant content and type, surface roughness, and moldicide type and content) can affect the mold susceptibility of WPC decking. This work is described in more detail in Vehring 2005.

2. Methodology

General Procedure for Manufacture of Composites

All WPCs were produced using 60-mesh maple wood flour (product 6010, American Wood Fibers, Schofield WI) and high-density polyethylene (HDPE) in a flake form (HP54-60 FLK BP, Solvay, Houston TX). The wood flour was dried for 15 hours at 102^{o} C prior to blending. WPC samples were prepared by dry blending oven-dried wood, plastic, and any additives in a stainless steel container (approximately 2 L) using manual agitation for one minute. An electrically heated Prep Mixer (C.W. Brabender, Type R.E.E.6) was then used. The two heating zones of the prep mixer were set at 200^{o} C (zone 1), and 185^{o} C (zone 2), and compounding speed was 35 rpm using cam type mixing blades. The material remained in the prep mixer until the DC amperage gauge stabilized at 5 amps (approximately 2 minutes). The material was then allowed to mix for an additional 2 minutes to ensure a homogeneous blend. Once blended, the material was removed and allowed to cool in a covered container. The cooled material was then ground using a Retsch Gmbh mill (Type SM1) with a screen size of 6.0 mm x 6.0 mm. Four batches of the desired blend were made and blended into a single batch prior to extrusion.

Ground WPC material was extruded using a C.W. Brabender 0.75-inch single screw laboratory extruder (Type 302) with a rectangular 5.0 mm x 25.0 mm die. For all studies except surface roughness, temperatures in the 4 heating zones were set to 185^{o} C at the hopper, 170^{o}, 165^{o}, and finally 150^{o} C at the die. The screw speed was set at 30 rpm for all the experiments, except for the surface roughness study.

Wood Content Variable

Four composite types were made consisting of 30, 50, 60, and 70% wood flour with no lubricants or other additives. The 60% wood flour composite was produced with a rough surface as well as a smooth surface. The rough surface of the 60% wood composite was achieved by increasing the die temperature to 170^{o} C and increasing the screw speed to 40 rpm.

Lubricant Type and Content Variable

Lubricants used in the composite manufacture were ethylene bis-stearamide wax (EBS, Dover Chemical) and zinc stearate (Doverlube Zn 20, Dover Chemical) at loadings of 2, 4, and 6% wt./wt. A 50/50 blend of EBS and zinc stearate was also used as a lubricant at 2, 4 and 6% wt./wt. loadings.

Fungicide Type and Content

The composite used in this experiment was made of 70% 60 mesh maple wood flour, using a 50/50 wt./wt. lubricant blend of 1.0% EBS wax and 1.0% zinc stearate. Two fungicides were used – chlorothalonil (CTL, Chlortram P-98M, Sostram Corp. at loadings of 0.5, 1.0, and 1.5%, and zinc borate (ZB, US Borax Corp.) at loadings of 1.0, 3.0, and 5.0%.

Mold Test Procedure

Mold susceptibility testing was conducted according to a modified form of ASTM D3273-94 – *Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber,* (American Society for Testing and Materials. 1994). A 46 X 61 X 53 cm mold chamber was constructed from ¼" poly(methylmethacrylate) sheets and bonded using dichloromethane and #6 ½" stainless steel screws. The soil in the chamber was suspended in a 40 X 55 X 5 cm wire mesh pan, lined with filter fabric. The soil was 25 mm deep and placed above 76 mm of water that was heated (25^o C) with an aquarium heater to raise the temperature of the chamber. An aquarium bubbler in the water increased the relative humidity of the air space within the chamber, and a 9 X 9 cm muffin fan (31 cfm) that is 25 mm above the soil circulated air and inoculum from the soil. Relative humidity in the chamber was approximately 100% and the air temperature was maintained at 25^o C. WPC specimens (five replicates) were suspended on stainless steel rods 76 cm above the soil. WPC specimens were not preinoculated.

Soil in the chamber was inoculated with a spore suspension of *Alternaria alternata* DR 406, *Aspergillus niger* ATCC 6275, *Aureobasidium pullulans* Forintek 132E, and *Cladosporium cladosporioides* ATCC 6721. Visual rating of one broad surface of the specimens the samples was done to reflect both growth density and coverage. A scale from 0-10 was used for the ratings with 0 meaning no fungal growth, and 10 meaning complete coverage. Mold ratings of 2 and less were hardly noticeable; 3-4 slightly noticeable; 5-7 very noticeable; 8-9 severe coverage; 10 was completely covered by dense mold fungi (Laks et al. 2002). Specimens were evaluated weekly for 8 weeks.

Statistical Analysis

Statistical analysis of the data was performed using Statistical Analysis Software, (The SAS System, V8 for Windows). Mean mold rating values were compared using Tukey's Studentized Range Test with an alpha of 0.05.

Results and Discussion

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Wood Content and Surface Roughness

Weekly mold coverage ratings for all composite types are shown in Figure 1. In general, mold susceptibility was proportional to wood content. The 30% wood content specimens showed only limited amounts of mold growth, having an average rating of 1 for weeks 3 through 8. A continuous film of plastic at the surface of the composite was observed, and is common in extruded composites (Stark 2003). Without a significant amount of wood at the surface to absorb moisture and provide nutrients, the mold was unable to colonize the samples as easily as the higher wood content samples.

The 50% wood content specimens showed limited amounts of mold growth at weeks 2 through 5 receiving a mean rating of 1. In subsequent weeks, the mean rating increased to 2. Again, limited wood at the surface of the composite inhibited the ability of the mold to grow.

The composite containing 60% wood with a smooth surface preformed relatively well, with a mean rating of 3 after 3 weeks, showing initial resistance to the mold. The composite was completely covered in light mold growth at the end of the 8-week rating, resulting in a mean rating of 5.

The 60% wood containing composite made with a smooth surface and the 60% wood composite made with a rough surface had statistically different mean ratings at 8-weeks. Close examination of the exposed rough surface WPC specimens showed that mold growth was denser in the fissures of the composite. This was likely due to more wood exposed within the fissures and/or more detritus collected in these locations, providing nutrient for fungus growth. The 70% wood content WPC samples were fully colonized by mold growth after 7 weeks of exposure, as were the 60% wood content, rough surface specimens.

Statistical analysis (Figure 1) of the mean ratings at week 8 showed that the 60% wood content rough and the 70% wood content samples were not significantly different. Both had a mean rating of 10. Similarly, the 20% and 30% wood content specimens had low mean ratings at 8 weeks that were not statistically different. The smooth 60% wood content specimens had a significantly different intermediate mean rating.

Lubricant Type and Content

Figures 2, 3, and 4 show the mold growth rates for 70% wood content composites made with EBS, zinc stearate, or the lubricant combination, respectively. The mold growth rate for the EBS-containing composites between weeks 1 and 2 was greater than that of the unlubricated material (Figure 2). It is possible that during production of the composite, the EBS hydrolyzed making a limited amount of low molecular weight amines available, which are easily consumed by the mold fungi promoting their growth. As the nutrients from the EBS are consumed, the growth rate slows, but the fungal mass continues to grow using nutrients available from the wood.

Figure 3 shows that the 6% zinc stearate loading resulted in a higher average initial mean rating compared to that of the other two lubricant loadings, as well as the unlubricated control. This indicates the zinc stearate supports mold growth when enough is added to the composite. However, by week 5, WPC specimens with 2, 4, and 6% zinc stearate had mean ratings of 10.

The lubricant blend gave varied results (Figure 4). Initially at two weeks, WPC with the 4% lubricant blend had a significantly higher mean mold rating than the 2% and 6% blends. This may have been the result of a thicker plastic layer forming on the surface of the 6% lubricant blend composite, which would have limited available nutrients for the fungi. However, by week 4 all WPC with 2, 4, or 6% lubricant blends had a mean rating of 10.

It is interesting to note that the blend of the two lubricants at the 2% and 4% loadings grew mold more rapidly than the zinc stearate or EBS by themselves at the same total loadings. Botros (2003) found that zinc stearate started to decompose at lower temperatures than other formulations that were tested, suggesting a chemical reaction between the zinc stearate and the coupling agent used in his work. It is possible that during the extrusion of the WPC material described in this work, the zinc from the zinc stearate catalyzed cleavage of the amide group in the EBS, leaving an amine as one of the byproducts of the reaction. Mold fungi are limited by the amount of available nitrogen in the food source they are consuming (Landecker 1996). Amine produced by the reaction of the two lubricants possibly provides sufficient fixed nitrogen, allowing for more rapid colonization of the composite.

Fungicide Type and Content

Figures 5 and 6 show mold testing results for WPCs manufactured with varied loadings of chlorothalonil and zinc borate, respectively. The anti-mold performance of the CTL is clear (Figure 5). There were substantial reductions in mold growth as the CTL loading increased from 0 to 0.5% to 1%. However, at 4 weeks, there was no significant difference between the composites containing 1.0% or 1.5% CTL. At these higher loadings, the mean mold ratings were low anyway (~3 at 8 weeks exposure), with only slightly noticeable mold coverage.

There was a very different response in mold susceptibility of the WPC made with zinc borate. The 1% ZB loading had no significant effect on mold growth compared to the untreated control. The 3% and 5% loadings effectively inhibited mold growth with a mean rating of 1 from week 4 to week 8. The results indicate that there is a critical performance threshold for ZB between 1% and 3% when tested under these conditions and with this particular WPC substrate.

4. Conclusions

Mold susceptibility of wood-polyethylene composites is highly dependent on manufacturing variables. In the work reported here, we evaluated wood content (specifically 60 mesh maple), surface quality, lubricant type and content, and moldicide type and content. Specific conclusions from this research are:

1. Wood loading is an important factor affecting mold growth. Increasing wood loading increases susceptibility staining from mold.
2. Surface quality of the composite is a major contributor to mold susceptibility. A relatively smooth surface minimizes exposed wood resulting in less mold growth. A rough surface increases wood exposure at the surface. The propensity for the surface to accumulate detritus that can support mold growth is also increased.
3. Lubricants, though necessary to plastics processing, can help to promote mold growth. The nature of the lubricant and its interaction with other formulation components can also affect mold susceptibility of the composite.
4. The addition of a fungicide into wood-plastic composites can reduce mold growth but is dependant on the type and loading of the fungicide. Chlorothalonil at 1.0 and 1.5%, and zinc borate at 3 and 5% were effective in limiting mold growth.

Other variables that were not evaluated in this work may also have an effect on mold susceptibility. Examples are wood species, thermoplastic type, compositional gradients, and density. More work is needed in order to fully understand the relationship between WPC properties and mold growth.

5. Literature

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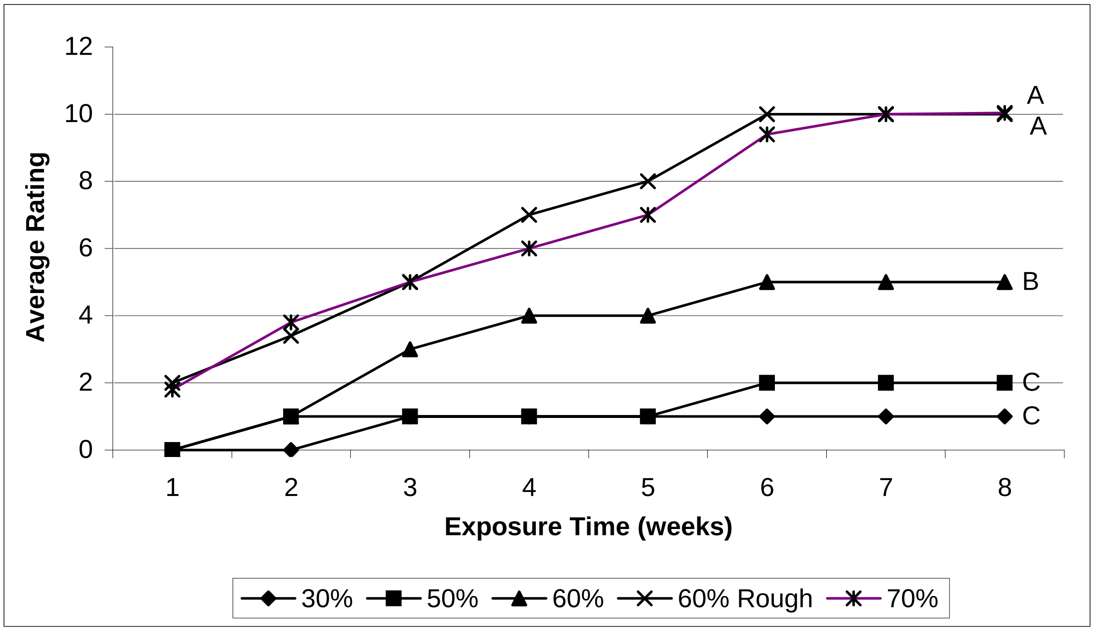

Figure 1: Average weekly mold ratings for smooth surface wood-plastic composites with wood loadings between 30 and 70% as well as 60% wood content rough surface samples. Means with the same letter designation at the 8 week exposure time are not significantly different at the 95% confidence level.

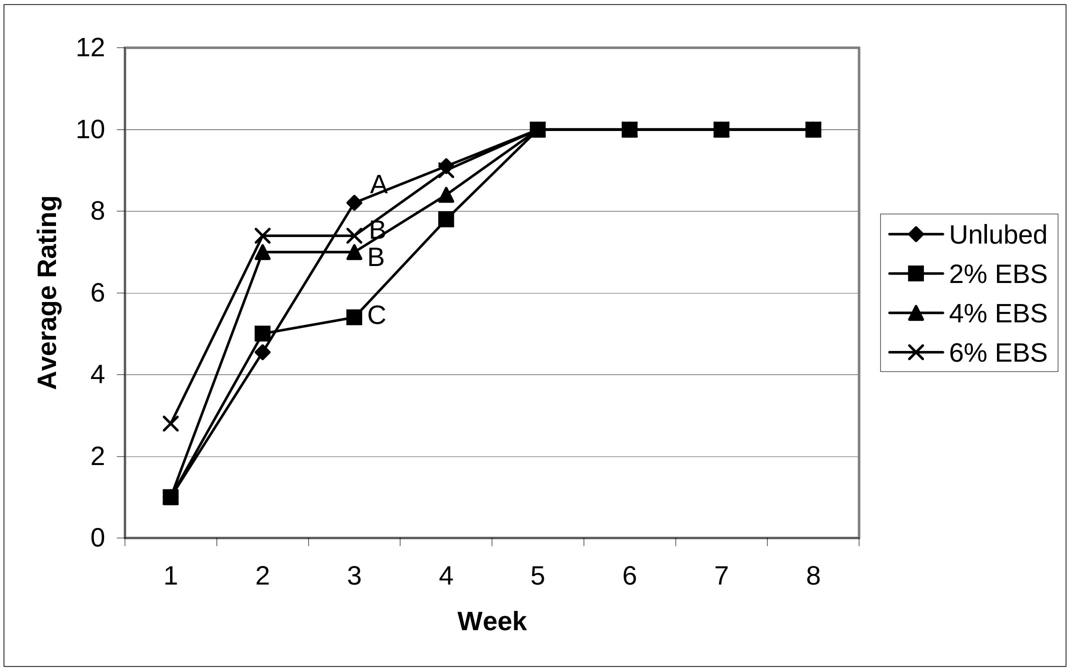

Figure 2: Comparison of average weekly mold ratings for 70% wood content WPCs containing EBS lubricant at 2, 4, and 6% loadings. Means with the same letter designation at the 3 week exposure time are not significantly different at the 95% confidence level.

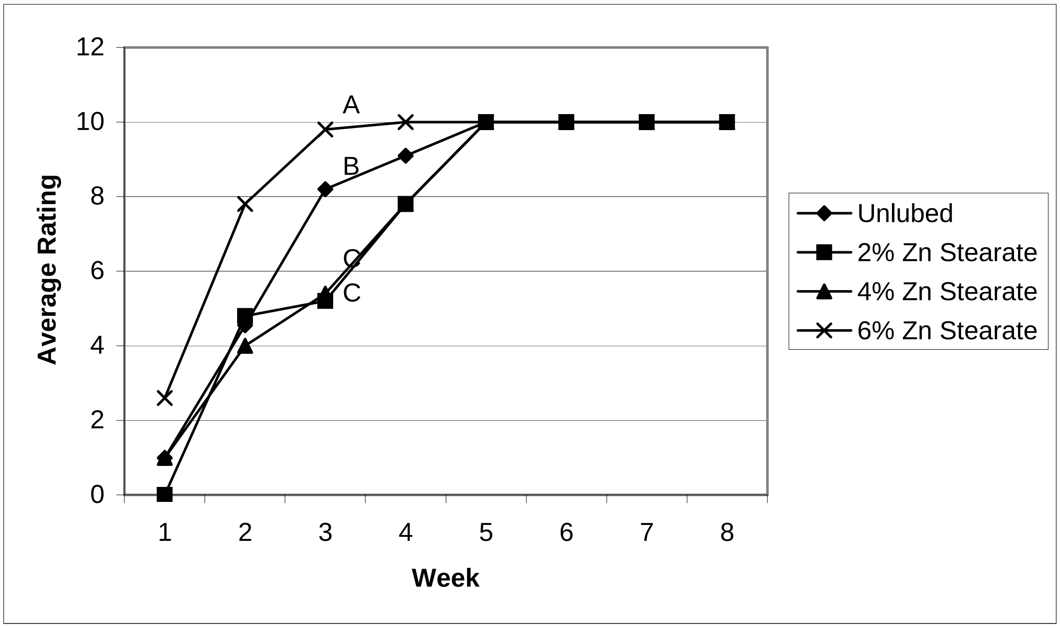

Figure 3: Comparison of average weekly mold ratings for 70% wood content WPCs containing zinc stearate lubricant at 2, 4, and 6% loadings. Means with the same letter designation at the 3 week exposure time are not significantly different at the 95% confidence level.

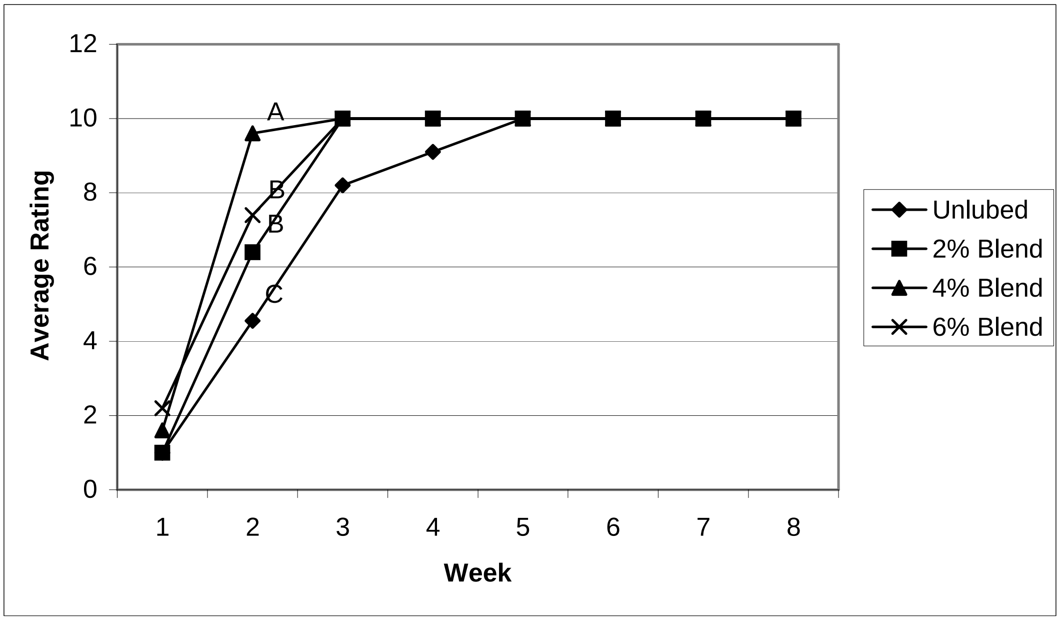

Figure 4: Comparison of average weekly mold ratings for 70% wood content WPCs containing a 50/50 blend of EBS and zinc stearate at 2, 4, and 6% loadings. Means with the same letter designation at the 2 week exposure time are not significantly different at the 95% confidence level.

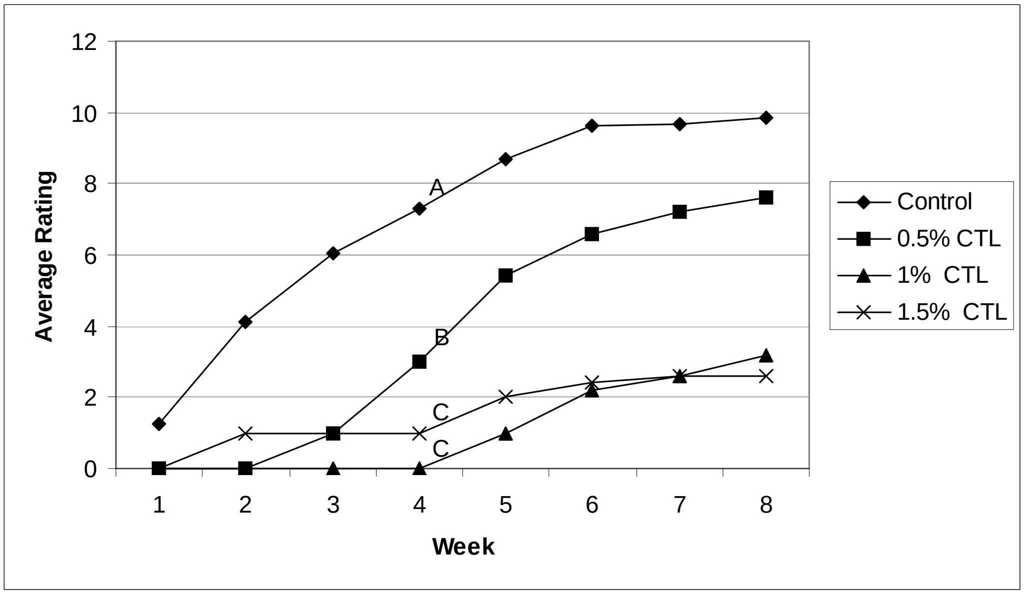

Figure 5: Visual weekly mold growth ratings for varied loadings of chlorothalonil containing composites made with a base composite of 70% wood and a 2% lubricant blend. Means with the same letter designation at the 4 week exposure time are not significantly different at the 95% confidence level.

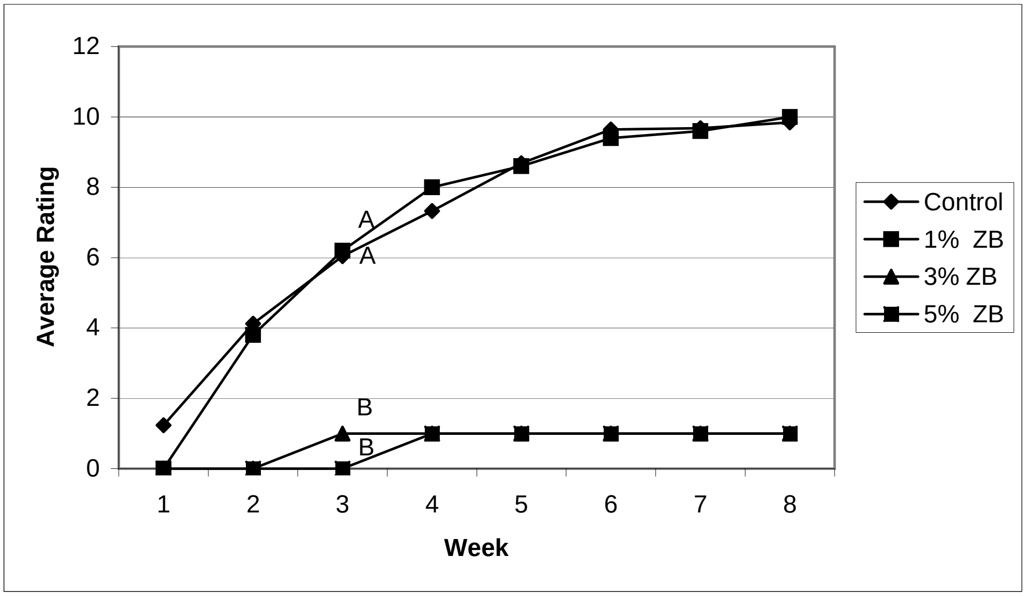

Figure 6: Visual weekly mold growth ratings for varied loadings of zinc borate containing composites made with a base composite of 70% wood, 28% plastic, and a 2% lubricant blend. Means with the same letter designation at the 3 week exposure time are not significantly different at the 95% confidence level.