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COMPARISON OF PESTICIDE EFFICACY AGAINST INSECTS AND MITES FOR GRAIN STORE STRUCTURE TREATMENT

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by

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Abstract

At present the control of invertebrate grain storage pests relies heavily on the use of organophosphate pesticides which are the only ones cleared in the UK for use in contact with stored cereals. However, there are no data available with which to compare the relative efficacy and residuality of pesticides against UK pests on a range of construction materials commonly used in storage facilities. The purpose of the laboratory study reported here was to investigate the relative efficacy of ten pesticides for the control of beetle and mite grain storage pests when used as treatments for grain store structures, and to assess their residual effectiveness over periods from one day up to six months after spraying.

The pesticides selected were five organophosphates, three pyrethroids, one carbamate and one organophosphate/ pyrethroid mixture, and represented those that are either already approved for use in UK grain stores or that could become so should approval be sought to widen their current use in food premises. The pesticides were sprayed onto squares of three types of substrate that are commonly used in grain store construction, namely wood, concrete and steel, and were applied at a rate equivalent to the label recommended field dose for each substrate type and pesticide. Batches of 25 beetles or mites were placed on each treated and untreated control substrate. The beetle species used were the saw-toothed grain beetle, *Oryzaephilus surinamensis*, the rust-red grain beetle, *Cryptolestes ferrugineus*, the grain weevil, *Sitophilus granarius*, the rice weevil, *Sitophilus oryzae*, the rust-red flour beetle, *Tribolium castaneum*, the foreign grain beetle, *Ahasverus advena* and the hairy fungus beetle, *Typhaea stercorea*. The mite species tested were the flour mite, *Acarus siro* and the cosmopolitan food mite, *Lepidoglyphus destructor*. Strains with high and low tolerance to pirimiphos-methyl were included for all species except *T. stercorea* and *A. advena*.

Recommendations for the structural treatment of grain stores to control beetle and mite pests, based on the results of these laboratory tests together with pesticide usage regulations in the UK, are:

1. For immediate treatment of infestations, use an organophosphate pesticide; pirimiphos-methyl, chlorpyrifos-methyl and etrimfos gave the best performances generally overall. Chlorpyrifos was also particularly effective against beetles on concrete but can only be used on surfaces that do not come into contact with food.

2. For longer-term treatment of areas that come into contact with food, use an organophosphate pesticide; fenitrothion performed best overall.

3. For longer-term treatment of areas that do not come into direct contact with food, use the pyrethroid permethrin. However, chlorpyrifos was more effective than permethrin against beetles on concrete.

Summary

At present the control of invertebrate grain storage pests relies heavily on the use of organophosphate pesticides which are the only ones cleared in the UK for use in contact with stored cereals. However, their continued use is under threat because of concerns about safety to humans and the environment, and increasing pest resistance. Some pesticide users are worried about operator exposure to pesticides and there is public concern about residues in food. Currently the Pesticides Safety Directorate is reviewing the use of all organophosphate pesticides, and the advice from MAFF is for farmers to avoid their use altogether unless there is no alternative. At the same time the demand for invertebrate-free grain continues, and it is often a legal requirement in the grain trade. Recently the control of post-harvest grain pests has become even more important following the designation in 1995 of those grain stores containing cereals intended for human consumption as food premises under the Food Safety Act; now all these grain stores are subject to inspection to ensure that adequate pest control measures are in force and are maintaining an appropriate level of control.

The UK cereal industry has responded to these concerns by setting up the Scottish Quality Farm Assured Cereals and the Assured Combinable Crops Schemes. These schemes are based on the principle that the industry will only use methods and products that are recognised as "Best Practice". With the change of status of most grain stores to food premises there is an opportunity for a wider range of lower toxicity pesticides, currently only available to the food industry, to be considered for use in grain stores.

However, at present there are no data available with which to compare the relative efficacy and residuality of pesticides against UK pests on a range of construction materials commonly used in storage facilities. The purpose of this study was to investigate the relative efficacy of ten pesticides for beetle and mite control when used as treatments for grain storage structures, and to assess their residual effectiveness over periods from one day up to six months after spraying.

The pesticides selected were five organophosphates, three pyrethroids, one carbamate and one organophosphate/ pyrethroid mixture, and represented those that are either already approved for use in UK grain stores or that could become so should approval be sought to widen their current use in food premises. The pesticides were sprayed onto squares of three types of substrate that are commonly used in grain store construction, namely wood, concrete and steel, and were applied at a rate equivalent to the label recommended field dose for each substrate type and pesticide. Batches of 25 beetles or mites were placed on each treated and untreated control substrate. The beetle species used were the saw-toothed grain beetle, *Oryzaephilus surinamensis*, the rust-red grain beetle, *Cryptolestes ferrugineus*, the grain weevil, *Sitophilus granarius*, the rice weevil, *Sitophilus oryzae,* the rust-red flour beetle, *Tribolium castaneum,* the foreign grain beetle, *Ahasverus advena* and the hairy fungus beetle, *Typhaea stercorea*. The mite species tested were the flour mite, *Acarus siro* and the cosmopolitan food mite, *Lepidoglyphus destructor.* Strains with high and low tolerance to pirimiphos-methyl were included for all species except *T. stercorea* and *A. advena.*

Recommendations for the structural treatment of grain stores to control beetle and mite pests, based on the results of these laboratory tests, are:

1. For immediate treatment of infestations, use an organophosphate pesticide; pirimiphos-methyl, chlorpyrifos-methyl and etrimfos gave the best performances generally overall. Chlorpyrifos was also particularly effective against beetles on concrete but can only be used on surfaces that do not come into contact with food.

2. For longer-term treatment of areas that come into contact with food, use an organophosphate pesticide; fenitrothion performed best overall.

3. For longer-term treatment of areas that do not come into direct contact with food, use the pyrethroid permethrin. However, chlorpyrifos was more effective than permethrin against beetles on concrete.

Possible reasons for the relative performance and residuality of each pesticide on the various substrates are discussed, and topics for further study are suggested to help explain the differences. Attention is also drawn to the difficulties the grain industry will face if further restrictions on the use of organophosphate pesticides are introduced.

INTRODUCTION

The 20 million tonnes of grain stored annually in UK farm and commercial stores (Anon., 1995a,b), together with the grain in processing premises, is at risk of infestation from invertebrate pests (Prickett, 1992;1994). The main primary insect pests which cause serious and damaging infestation include the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.), the rust-red grain beetle, *Cryptolestes ferrugineus* (Stephens), the grain weevil, *Sitophilus granarius* (L.) and the rice weevil, *Sitophilus oryzae* (Stephens). The rust-red flour beetle, *Tribolium castaneum* (Herbst), is a particular pest in flour mills. Secondary pests, usually associated with poor hygiene or mouldy grain and which may lead to rejection, include the foreign grain beetle, *Ahasverus advena* (Waltl) and the hairy fungus beetle, *Typhaea stercorea* (L.). The principal mite pests of storage premises are the flour mite, *Acarus siro* L. and the cosmopolitan food mite, *Lepidoglyphus destructor* (Schrank) (Wilkin and Thind, 1984; Prickett, 1992).

At present the control of invertebrate grain storage pests relies heavily on the use of organophosphate (OP) pesticides which are the only ones cleared in the UK for use in contact with stored cereals. For example, 15.8 tonnes of pesticide active ingredients, over 80% of which were OPs, were used in farm grain stores in Great Britain during the 1994/95 storage season (Norris and Garthwaite, 1997). However, their continued use is under threat because of concerns about safety to humans and the environment, and increasing pest resistance (Starzewski, 1991; Wildey *et al.*, 1998). Some pesticide users are worried about operator exposure to pesticides and there is public concern about residues in food. Currently all OP pesticides are under review by the Pesticides Safety Directorate, and advice from MAFF is for farmers to avoid their use altogether unless there is no alternative (Rooker, 1999). At the same time the demand for invertebrate-free grain continues, and it is often a legal requirement in the grain trade. Recently the control of post-harvest grain pests has become even more important following the designation in 1995 of those stores used to store cereals for human consumption as food premises under the Food Safety Act (Anon, 1990); now all these grain stores are subject to inspection to ensure that adequate pest control measures are in force and are maintaining an appropriate level of control.

The UK cereal industry has responded to these concerns by setting up the Scottish Quality Farm Assured Cereals and the Assured Combinable Crops Schemes (Anon, 1997, 1998). These schemes are based on the principle that the industry will only use methods and products that are recognised as "Best Practice". With the change of status of most grain stores to food premises there is an opportunity for a wider range of lower toxicity pesticides, currently only available to the food industry, to be considered for use in grain stores.

However, at present there are no data available with which to compare the relative efficacy and residuality of pesticides against UK pests on a range of construction materials commonly used in storage facilities. The purpose of this study was to investigate the relative efficacy of ten pesticides for beetle and mite control when used to treat grain store structures, and to assess their residual effectiveness over periods up to 6 months after spraying.

METHODS

Substrates

Pesticides were sprayed onto three types of substrate that are commonly used in grain store construction. The substrates used were :

(1) Plywood - 4 mm thick (confirmed as not treated with the fungicide pentachlorophenol).
(2) Galvanised steel - 3 mm thick.
(3) Concrete - 25mm thick (made to British Standard 5328: Part 1, 1997) as recommended for the construction of grain stores).

The substrates were supplied as 300 mm squares for the insect and 75mm squares for the mite bioassays. They were conditioned in a controlled environment at 20°C, 70% r.h. for at least two weeks before spraying.

Pesticides

Ten pesticides were selected after consultation with the Pesticide Safety Directorate and the Health and Safety Executive (Table 1), and represent those that are either already approved for use in grain stores or that could become so should approval be sought to widen their current use in food premises. The pesticides selected for study were five OPs (pirimiphos-methyl 25% emulsifiable concentrate (e.c), fenitrothion 20% micro-encapsulated (m-e), chlorpyrifos-methyl e.c., etrimfos e.c. and chlorpyrifos 20% m-e), three pyrethroids (permethrin 25% wettable powder (w.p.), deltamethrin2.5% + 2% bioallethrin suspension concentrate (susp. conc.) and alphacypermethrin 5.8% susp. conc.), one carbamate (bendiocarb 25% w.p.) and one OP/pyrethroid mixture (fenitrothion + permethrin + resmethrin ultra low volume liquid (u.l.v.l.)).

The substrates were sprayed in the laboratory with the appropriate pesticide at a rate equivalent to the label recommended field dose for each type of substrate (Table 1). Achieving accurate and consistent doses of pesticides is particularly difficult on porous surfaces such as concrete, so all the pesticides except the OP/pyrethroid mixture formulation were precision sprayed using a motor and rack laboratory sprayer developed at CSL and specially designed to give uniform deposits on substrates of the size used in our tests (Morgan and Pinniger, 1987). It produces sprays similar to those used in field applications where wetting or coarse sprays are specified. However, the OP/pyrethroid grain store product is formulated for use in special equipment as an ultra-low volume ready-to-use spray, and applying it with the laboratory sprayer would have given too high an application rate with the wrong droplet sizes. So this pesticide was applied using a compressor and carefully calibrated artist's airbrush with a, low-flow nozzle and needle assembly, the droplet size spectra of which had been determined previously using a Malvern Laser Particle Sizer.

Ageing of sprayed substrates

To establish the residual effect of the 10 pesticides substrates were tested one day, four weeks, 12 weeks and 24 weeks after spraying. To achieve this 12 replicates of each substrate were sprayed on one day (total: 36 blocks per pesticide). Three replicates of each substrate were used for each of the one day, one month, 3 months and 6 months experiments. These substrates were then held in a controlled environment at 20°C, 70% r.h. until needed. Substrates were left to dry for 24 hours after spraying prior to the 24 hour assessments.

Table 1. Pesticides used in experiments and the deposits applied to the different substrates.

Code	Pesticide	Active Ingredient	Deposit (mg ai/m^2) Wood	Steel	Concrete
P1	Actellic D[1,2]	Pirimiphos-methyl 25% e.c.	500	500	500
P2	Demise[2]	Fenitrothion 20% w/w m-e	240	240	240
P3	Reldan[1,2]	Chlorpyrifos-methyl e.c.	900	450	900
P4	Satisfar[1,2]	Etrimfos e.c.	1500	500	1500
P5	Empire 20[3]	Chlorpyrifos 20% w/w m-e	200	200	200
P6	Ficam W[3]	Bendiocarb 25% w.p.	96	96	96
P7	Coopex WDP[3]	Permethrin 25% w.p.	375	125	375
P8	Crackdown Rapide[3]	Deltamethrin 2.5% + 2% bioallethrin susp. conc.	37.5	12.5	37.5
P9	Fendona 6SC[3]	Alphacypermethrin 5.8% susp. conc.	14.5	14.5	14.5
P10	Turbair[2]	Fenitrothion+permethrin+resmethrin u.l.v.l.	20:40:4	20:40:4	20:40:4

[1] Approved for admixture to grain
[2] Approved for fabric treatment where food will touch treated surfaces
[3] Approved for fabric treatment where food will NOT touch treated surfaces

Beetle bioassays

Seven beetle species were selected as being typical of the pest fauna found in UK grain stores. Five of the species were represented by two strains, one with low tolerance and the other with high tolerance to pirimiphos methyl, the most commonly used insecticide in UK grain stores (Table 2). All beetles were adults of known age (see Table 2) but were not sexed, and were obtained from stock cultures maintained at CSL.

Table 2. Beetle species and strains used in experiments.

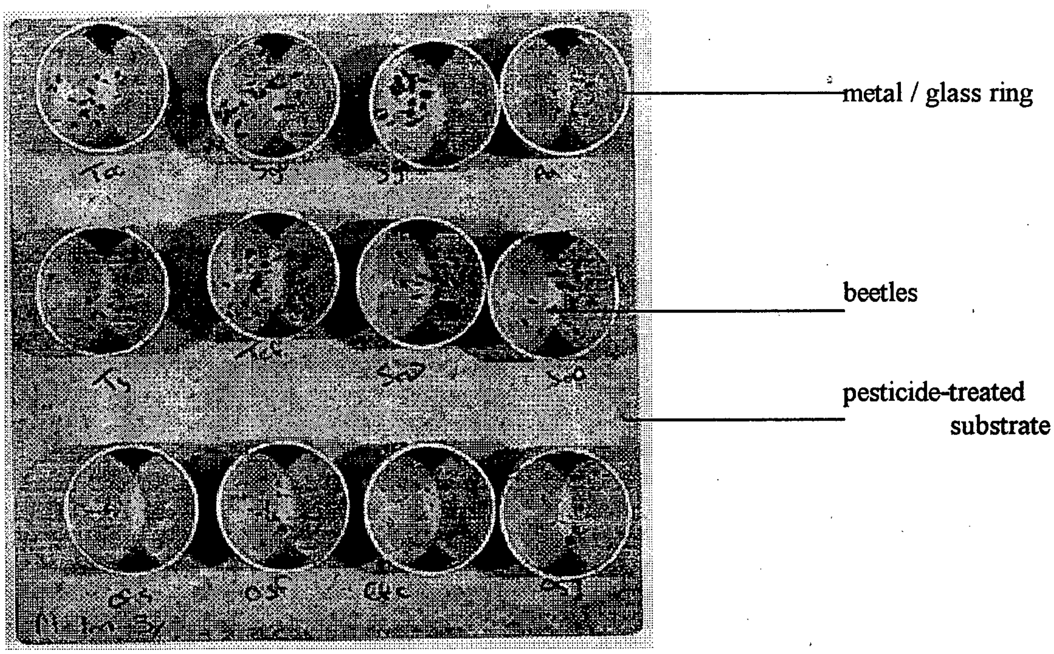
Species	Strain	Pirimiphos Methyl Tolerance	Age (Post-adult eclosion)
Oryzaephilus surinamensis	8518B Faceby (OsF)	Low	1-3 weeks
(Saw-toothed grain beetle)	9213 Tram (OsT)	High	1-3 weeks
Sitophilus granarius	Windsor Susceptible (SgW)	Low	2-4 weeks
(Grain weevil)	Gainsborough (SgG)	High	2-4 weeks
Sitophilus oryzae	Droxford (SoD)	Low	2-4 weeks
(Rice weevil)	A76 (SoA)	High	2-4 weeks
Cryptolestes ferrugineus	C124 (CfC)	Low	1-3 weeks
(Rust-red grain beetle)	9322 Stow (CfS)	High	1-3 weeks
Tribolium castaneum	FSSII (TcF)	Low	3-5 weeks
(Rust-red flour beetle)	CTC 12 (TcC)	High	3-5 weeks
Typhaea stercorea (Hairy fungus beetle)	Datchet (Ts)	Unknown	3-5 weeks
Ahasveras advena (Foreign grain beetle)	Susceptible (Aa)	Low	3-5 weeks

Twelve batches of 25 beetles of each species/ strain (total: 144 batches) were removed from culture and put into 75 x 25 mm glass specimen tubes. The inner lip of each tube had been painted with Fluon®, an aqueous suspension of polytetrafluoroethylene which, when dry, prevents insects climbing vertical surfaces. The beetles were left to condition for 24 hours at 20°C, 70% r.h.

Three replicates of each treated substrate were used for each bioassay. One untreated block of each substrate was used as a control. Twelve glass or metal beetle-retaining rings (outer diameter = 60 mm, inner diameter = 57.8 mm, height = 20 mm) were coated with Fluon® and placed on each substrate replicate (144 rings total per experiment). Figure 1 shows the arrangement of rings on one substrate block.

Beetles were transferred from the specimen tubes into the rings so that each ring contained twenty five beetles and each species /strain was represented in one ring per block (Figure 1). This was repeated so that a total of three treated blocks per substrate and one untreated block per substrate were set up. Each substrate was labelled with the appropriate experimental details and left at 20°C, 70% r.h. (12 hours light, 12 hours dark).

Figure 1: Position of retaining rings on substrates.

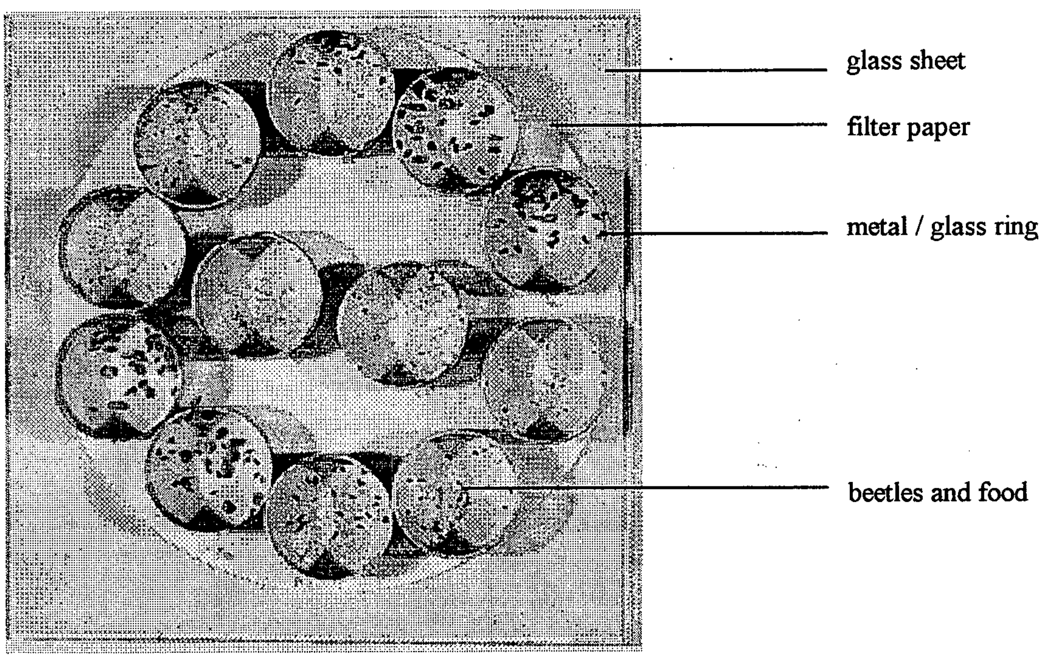


After 24 hours the beetles were transferred from the substrates on to clean filter paper to determine whether or not they would recover from exposure to pesticide. Beetles were removed from the ring using a pooter attached to a vacuum line, using as little suction as possible to prevent damage to the beetles. The ring was removed from the substrate, inverted and placed on a 12.5 cm diameter white filter paper which had been put onto a glass sheet (300 x 300 x 5 mm) (Figure 2). The insects were then transferred from the pooter into the ring. A small amount (<0.5 g) of food was placed into the centre of each ring to prevent the beetles dying of starvation during the recovery period. The type of food was the same as that used for rearing each species in the stock cultures:

- *Sitophilus granarius*: Kibbled wheat
- *Sitophilus oryzae*: Kibbled wheat
- *Oryzaephilus surinamensis*: Wheat middlings, rolled oats and yeast (5:5:1)
- *Cryptoplestes ferrugineus*: Wheat middlings, rolled oats and yeast (5:5:1)
- *Tribolium castaneum*: Wholemeal flour, yeast (20:1)
- *Ahasverus advena*: Wheat middlings, rolled oats and yeast (5:5:1)
- *Typhaea stercorea*: Wheat middlings, yeast (10:1)

Beetle mortality was assessed seven days after transfer to the recovery apparatus. Beetles were examined by eye and were counted as either alive, knocked down or dead. Alive was defined as showing no signs of having been affected by the pesticide. Knocked down was defined as being immobilised by the pesticide. Dead was defined as showing no movement after being gently blown on and gently prodded with a fine paint brush.

Figure 2: Beetles on filter paper during recovery period.



Mite bioassays

For each species of mite two strains were used, one with high tolerance (9258/2 and 4016/2 for *A. siro* and *G. destructor*, respectively) and one with low tolerance (9266/1 and G6 for *A. siro* and *G.* destructor, respectively) to pirimiphos-methyl, chlorpyrifos-methyl and etrimfos. All mites were adult females aged 4-10 days and obtained from standard cultures maintained at CSL..

Developing an arena to retain mites securely on substrates such as concrete with uneven surfaces proved particularly challenging. Several different methods were tried before the following technique was found to be successful. The test arenas consisted of two substrate blocks, with an EPDM (E-A-P International) 'washer' with an internal diameter of 33mm placed between the two treated surfaces to create a chamber 2mm deep in which to place the mites. The arenas were held together using clips in the case of the plywood and steel. For the concrete, the weight of the top substrate block was sufficient to hold the 'washer' in place and prevent mite escape. Three treated and three control replicates were set up for each species and strain at 20°C and 70% r.h., with 25 mites in each replicate. The control substrate blocks were also allowed to condition to 70% rh for a period of one week prior to the 1 day assessments. After 72 hours mortality was assessed by examining the mites under a binocular microscope. The mites were considered dead if they were shrivelled and showed no movement in response to a gentle touch with a single-hair paint brush. Mites were considered alive if they exhibited repeated identical movement with or without stimulation from the paint brush. During the 72 hour counts mites were removed from the substrates which were then placed in a controlled environment room at 20°C and 70% r.h. to age until the next assessment.

RESULTS

A. Beetles

The main results for each pesticide are summarised below. Mean percentage mortalities for all the bioassays are presented as histograms with standard error bars in Appendix 1. Knock down was recorded only rarely and so beetles in this condition were recorded as alive for the purpose of this report. Mean percentage mortalities across all control experiments were usually below 10% and only rarely exceeded 15%, except in *A. advena*. The reason for this is not known but it may have been linked to the very short adult longevities reported in some strains of this species (Jacob, 1996).

Pirimiphos-methyl. Pirimiphos-methyl achieved good control on wood during the one day test. However, during the one month test pirimiphos-methyl failed to kill 100% of all species and strains except for *A. advena*. In general, control declined over time. On steel pirimiphos-methyl achieved good control for all species and strains in the one day and one month tests. However, with the exception of *A. advena*, mortality declined in subsequent tests and 100% mortality was not achieved in the 3 or 6 month tests for any of the species and strains. In general, mortality declined over time on concrete, although for *A. advena* all tests resulted in 100% mortality. Pirimiphos-methyl on concrete achieved particularly poor control for both strains of *O. surinamensis* and for the low tolerance strain of *S. granarius*.

Fenitrothion. Generally fenitrothion provided good control on wood and steel, except for the high tolerance strain of *O. surinamensis*. On concrete excellent control was achieved for all species and strains in all tests.

Chlorpyrifos-methyl. Chlorpyrifos-methyl performed well on wood during the one day tests, achieving 100% mortality for all species and strains. Control was still good at one month, although mortality declined in the low tolerance strain of *O. surinamensis*. Control was very poor during the 3 month tests except in *A. advena* and *T. stercorea*, and as a result no 6 month tests were done. On steel one day tests all achieved 100% mortality for all species and strains. This declined at one month for all strains except *A. advena* and the low tolerance strain of *S. granarius*. Mortality was extremely low at 3 months and the tests were halted at this point. On concrete, although 100% mortality was achieved for all species and strains in the one day tests, control was very poor in the one and 3 month tests. No 6 month tests were performed.

Etrimfos. On wood 100% control was achieved in one day tests with etrimfos for all species and strains. Mortality declined rapidly in the one and 3 month tests, and no 6 month tests were done. On steel Satisfar achieved 100% mortality for all species and strains in day 1 tests. Control was good for most species in the one month tests, with the exception of *T. stercorea*, but mortality declined sharply in the 3 month tests. No 6 month tests were done. On concrete mortality was high in the one day tests (100% except for the high tolerance strain of *S. granarius*). Mortality declined rapidly at one month and was negligible by 3 months, so no further tests were done.

Chlorpyrifos. Mortality was high for most species and strains in all tests with chlorpyrifos on wood. The exceptions were the two *O. surinamensis* strains where mortality was low and fluctuated over time. Both strains showed an increase in mortality between the one day and one month tests, as did the high tolerance strain of *S. granarius,* although it was not possible to explain this phenomena with the data available. Results on steel were very similar to those on wood. Mortality was high for all species and strains in all tests on concrete (100% except for *O. surinamensis* at 6 months).

Bendiocarb. For bendiocarb on wood 100% mortality at one day was achieved for six strains but mortality declined rapidly at one month with only *A. advena* achieving 100% mortality. Mortality at 3 months was very low and no 6 month test was done. The results for bendiocarb on steel were particularly interesting. Generally, good mortality was achieved in the one day and one month tests with mortality declining at 3 months (*O. surinamensis* 9213 Tram and *S. granarius Gainsborough* had generally lower mortality in all tests). However, *O. surinamensis*, *S. granarius* and *T. castaneum* all showed a pattern of an increase in mortality between one day and one month followed by a decline in mortality at 3 months. Although no explanation for this is available from our data, Fletcher and Axtell (1993) reported an increase in mortality at 3 months to bendiocarb on galvanised metal in the bed bug *Cimex lectularis*. On concrete mortality at one day was low (100% mortality in *A. advena* and *C. ferrugineus* only) and declined rapidly at one and 3 months.

Permethrin. Mortality was 100% in all tests on wood with permethrin except for the high tolerance strains of *S. granarius* at 3 months and *S. oryzae* at 1 day. Mortality was high for most species and strains in all tests on steel. The high tolerance strain of *S. oryzae* showed an increase in mortality between day one and one month followed by a decline between 3 and 6 months. A similar, although less extreme, response occurred in *T. castaneum* CTC12, a strain which previously showed broad cross-resistance to synergised pyrethrums and OPs (Lloyd and Ruczkowski, 1980). On concrete mortality was high for the first three tests except for *S. granarius* and the high tolerance strain of *S. oryzae* A76. There was a decline in mortality at 6 months in seven strains although mortality remained at 100% for the other five strains.

Deltamethrin + bioallethrin. On wood mortality was around 100% with deltamethrin + bioallethrin for all species and strains except for the high tolerance strains of *S. oryzae* A76 and, to a lesser extent, *T. castaneum*. Again, an increase in mortality was noticed between the one day test and the one and 3 month tests in the former, and between the one day and one month tests in the latter. On steel mortality was close to 100% in all tests for *A. advena, O. surinamensis, S. granarius* and the low tolerance strain of *S. oryzae*. Lower mortality was achieved *with T.*

stercorea and the low tolerance strain of *T. castaneum*. *C. ferrugineus* together with the high tolerance strains of *S. oryzae* and *T. castaneum* all showed an interesting pattern of mortality. Generally, there was an increase in mortality from one day to one month and a subsequent decline in mortality at 6 months. On concrete mortality was 100% for all tests on *A. advena*, *C. ferrugineus*, *O. surinamensis* and the low tolerance strain of *S. granarius*. For most other strains there was a decline in mortality at 6 months. The exception to this was the high tolerance strain of *S. oryzae* where mortality was below 60% for all tests.

Alphacypermethrin. On wood treated with alphacypermethrin mortality at one day was 100% except for *T. castaneum*. Patterns of mortality for the other tests were more complicated. *C. ferrugineus*, *T. stercorea* and the low tolerance strain of *S. granarius* exhibited decreasing mortality over time. However, *O. surinamensis*, *T. castaneum*, the high tolerance strain of *S. granarius* and the low tolerance strain of *S. oryzae* showed a decrease in mortality between the one day and one month tests followed by an increase at 3 months and a subsequent decrease in the 6 month tests. The high tolerant strain of *S. oryzae* had very low mortality in all tests. On steel mortality was at or around 100% for most species in all tests except for *T. stercorea* and the high tolerance strain of *S. oryzae*. There were some fluctuations in response in the low tolerance strains of *C. ferrugineus* and *S. oryzae*, and the high tolerance strains of *O. surinamensis* and *S. granarius* but these effects were very small. On concrete 100% mortality in all tests was achieved for *A. advena*, the high tolerance strain of *O. surinamensis* and the low tolerance strain of *S. granarius*. Good control at or near 100% for the first three tests followed by a decline in mortality at 6 months was achieved in *C. ferrugineus* and *T. castaneum*, and in the low tolerance strains of *O. surinamensis* and *S. oryzae*. Mortality in *T. stercorea* and the high tolerance strain of *S. granarius* declined steadily over time. Mortality was very low in the high tolerance strain of *S. oryzae* with no mortality recorded at 3 months.

OP/pyrethroid u.l.v.l. On wood sprayed with the OP/pyrethroid u.l.v.l. mixture, mortality at one day was poor with only 100% achieved for *A. advena*. Mortality declined rapidly over time so the 6 month tests were not done. Although mortality was slightly higher on steel than on wood, 100% at one day in *A. advena* and at one day and one month inthe low tolerance strain of *S. oryzae* it was still poor and declined rapidly over time. Again, no 6 month tests were done. On concrete mortality was poor at one day with no 100% control achieved in any species or strain, and declined rapidly over time. No 6 month tests were done.

B. Mites

Mean percentage mortalities for all the bioassays are presented as histograms with standard error bars in Appendix 2. Mean percentage control mortalities were usually below 15% and rarely rose above 20%, except on concrete where mean control mortalities were often 10-20% higher than on wood and steel. The reasons for this are not clear but possible causes could include the alkaline nature of the concrete and the desiccant effect of any fine concrete dust remaining in cracks and crevices on the surface of the substrate. It was noted that in some but not all tests with particularly high control mortalities the mites were often covered in fine cement powder.

Pirimiphos-methyl. During the one day test, pirimiphos-methyl gave 100% mortality in all four strains on steel, but on wood the tolerant strain of *L. destructor* showed a mortality of less than 100%, and on concrete, only the low-tolerance strain of *A. siro* had a mortality of 100%. Mortalities declined at the one month and longer tests, especially on concrete. By 6 months mortalities below 50% were recorded in every strains on all substrates.

Fenitrothion. 100% mortality was not achieved for either strain of *A. siro* on any substrate even at the one day test. More than 75% mortality was achieved in all but one of the tests with *L. destructor.*

Chlorpyrifos-methyl. During the one day test, chlorpyrifos gave 100% mortality for all strains on each substrate. Thereafter it declined rapidly over time, particularly on concrete.

Etrimfos. Etrimfos also gave 100% mortality for all strains on each substrate during the one day test. At the one month test 100% mortality was achieved for all four strains on steel; on wood it gave 100% mortality for *A. siro* and greater than 80% for *L. destructor*. Good control was maintained at 3 and 6 months, particularly on wood, but control was poor on concrete.

Chlorpyrifos. At the one day test, chlorpyrifos gave 100% mortality in all four strains on steel and concrete, and on wood three of the four strains showed 100% mortality, with the tolerant strain of *L. destructor* again showing a mortality of less than 100%. Even by six months post-treatment, chlorpyrifos still remained effective on all three substrates, giving mortalities in the range 80-100%.

Bendiocarb. Bendiocarb gave poor control of *A. siro* on all substrates even in the one day test. For *L. destructor* mortalities approaching 100% were achieved on wood and steel but not concrete. Six month tests were not conducted.

Permethrin. Mortalities above 80% were achieved for *A. siro* on all substrates even after six months. However, control for *L. destructor* was poorer.

Deltamethrin + bioallethrin. Control of all strains was generally poor with this pesticide and no six month tests were done.

Alphacypermethrin. Mortality was below 80% in all tests with alphacypermethrin and no six month tests were conducted.

OP/pyrethroid u.l.v.l. No tests with this pesticide achieved 100% mortality, and by the 3 month test mortality was below 50% in all except one test.

C. Best pesticide performances against beetles and mites.
The best pesticides for beetle and mite control on each substrate are summarised in Table 3. The rankings were based on an index of mortality for all strains at each pesticide ageing period. For example, a pesticide achieving 100% mortality for all strains in all tests would score an index of 1200 while another pesticide giving 0% mortality in all tests would score a zero.

Table 3. Best pesticide performances against beetles* and mites† on different substrates.

	1 day	1 month	3 months	6 months
Steel	Pirimiphos-methyl*† Chlorpyrifos-methyl*† Etrimfos*† Chlorpyrifos†	Permethrin* Etrimfos† Chlorpyrifos†	Permethrin* Etrimfos† Chlorpyrifos†	Permethrin*† Chlorpyrifos†
Wood	Etrimfos*† Chlorpyrifos-methyl†	Permethrin*† Etrimfos† Chlorpyrifos†	Permethrin* Etrimfos† Chlorpyrifos†	Permethrin* Etrimfos† Chlorpyrifos†
Concrete	Chlorpyrifos-methyl*† Chlorpyrifos*† Etrimfos†	Chlorpyrifos*† Fenitrothion*	Chlorpyrifos*† Fenitrothion* Permethrin†	Chlorpyrifos*† Fenitrothion* Permethrin†

DISCUSSION

Recommendations for beetle control

The results show that when treating grain store structures, best practice is dependent on both the construction materials and on the length of time that protection is required. When treating wood and steel etrimfos and chlorpyrifos-methyl gave the most effective control in the short term; indeed the four most effective pesticides in the short term were all OP compounds, indicating that OP pesticides should be recommended for treating existing infestations.

For longer-term treatments the pyrethroid permethrin was more effective. However, pyrethroids were ineffective at controlling insects on concrete, a common building material in grain stores especially for floors. There is a further problem with recommending permethrin because, aside from the OP/pyrethroid u.l.v.l. mix, none of the pyrethroids tested are currently approved for application to surfaces in contact with food. Thus, pyrethroids can only be recommended for use as part of best practice in areas where no food destined for human consumption is stored.

In general, reasonable control was achieved on wood. *T. castaneum* and the high tolerance strain of *S. oryzae* on substrates treated with deltamethrin + bioallethrin, and *O. surinamensis*, *T. castaneum*, the high tolerance strain of *S. granarius* and the low tolerance strain of *S. oryzae* on substrates treated with alphacypermethrin all showed unexpected increases in mortality in the later stages of experiments. This pattern of mortality has been noted by previous workers who suggested that it might be due to pyrethroids binding with the cellulose of the wood, thus denying insects access to the pesticide. Over time this binding breaks down and the active ingredient becomes available again to the insects with a subsequent rise in mortality (Webb and Lloyd 1979; Pinniger, 1983; J. Chambers, pers. comm).

Mortality on steel was generally higher than on the other substrates, probably because it is non-absorbent and absorbency can adversely affect pesticide performance (Burkholder and Dicke, 1966; Parkin, 1966; Chadwick, 1985; Jain and Yadav, 1989; Giga and Canhao, 1991; Gudrups and *et al.*, 1994). However, this does not explain why mortality in *O. surinamensis* and the high tolerance strain of *S. granarius* increased between the one day and one month tests when exposed to chlorpyrifos. Similar results were recorded in the high tolerance strains of *S. oryzae* and *T. castaneum* to permethrin and deltamethrin + bioallethrin, and in *C. ferrugineus* to deltamethrin + bioallethrin.

It is unlikely that any binding mechanism could be responsible for this phenomenon (J. Chambers, pers. comm.). In the case of chlorpyrifos there may have been a delayed release of active ingredient to the substrate and the insects from the micro-encapsulated formulation. However, similar results were not noticed in fenitrothion, another pesticide with a micro-encapsulated formulation. Close examination of the substrates after application of these compounds revealed a mottled effect on the steel which suggests that some areas of the substrate may have remained free of active ingredient immediately after spraying. Although these areas on the substrate were small (approx. 1-2 mm diameter) this may have reduced insect exposure sufficiently to lower mortality (Pinniger and Wildey, 1979; Barson *et al.*, 1992; Cox *et al.*, 1997). It is possible that these compounds became effective shortly after the initial test period of one day after spraying perhaps due to migration across the surface making the dose more even.

Generally results on concrete were poorer than on other substrates. This may be explained by the nature of the concrete surface in contact with the pesticide. Many workers have noted that the alkaline nature of concrete tends to hydrolyse pesticides, especially OPs (Parkin, 1966; Okwelogu, 1968; Mensah et al., 1979; Williams *et al.*, 1982; Chadwick *et al.*, 1987; Jain and Yadav, 1989; Giga and Canhao, 1991; Gudrups *et al.*, 1994). Similar effects have been observed with formulations of permethrin (Chadwick, 1985). The high persistence of fenitrothion and chlorpyrifos may be due to their micro-encapsulated formulation.

The poor level of control achieved by the OP/pythethroid ultra low volume formulation (Turbair) deserves further examination. The failure of this pesticide could be a result of the methodology used in these tests. All other pesticides were applied using a rack and motor sprayer (Morgan and Pinniger, 1987) which used conventional, commercially available spray heads and nozzles and reproduces very accurately the spraying rates used under practical conditions. However, this particular pesticide could not be applied in this way because it has its own novel delivery system., so an artists' airbrush was used instead. Every attempt was made to reproduce the delivery pattern of the novel delivery system and it is considered unlikely that the application method caused the low mortality. Another possibility could be the low amount of active ingredient contained in this particular formulation which is a mixture of fenitrothion: permethrin: resmethrin applied at a rate of 20:40:4 mg /m^2, respectively. This application rate is much lower than the comparable rates for the fenitrothion formulation Demise (240 mg / m^2) and the permethrin formulation Coopex WDP (375 mg / m^2 on wood and concrete, 125 mg / m^2 on steel). Even allowing for possible synergistic effects between the OP (fenitrothion) and the pyrethroids (permethrin and resmethrin), the delivered dose of active ingredient may still be too low to achieve higher control.

In summary the following recommendations can be made for beetle control :

- If beetles are known to be present the use of an OP pesticide is recommended. On the basis of our tests etrimfos performs best on wood; pirimiphos-methyl, chlorpyrifos-methyl and etrimfos perform best on steel.

- If applying a longer-term treatment on areas that come into contact with food an OP must be used under current pesticide regulations. In our tests, fenitrothion had the best residual effect on wood and steel.
- If applying a longer-term treatment on areas that do not come into contact with food then, on the basis of our results, permethrin is recommended for wood and steel, and chlorpyrifos for concrete.

Recommendations for mite control.

Mite infestations usually comprise more than one species, and in fact it would be highly unusual to see only one species of mite in an infestation (Griffiths *et al*, 1976; Jeffrey, 1976). Thus, recommendations for 'best practice' summarised here are for storage mites generally rather than for particular species. The most desirable outcome from these tests is a 100% mortality rate. Mites can breed rapidly under optimum conditions and a few survivors can increase their numbers dramatically over the course of the six months ageing period used in this study (Boczek, 1991).

It might be expected that the effectiveness of a pesticide would reduce over time but this did not always happen during the present study. Pirimiphos-methyl and chlorpyrifos-methyl generally behaved as expected on all three substrates, with a decline in efficacy over time. There were occasional increases in mortality for individual strains, but on the whole they followed the expected pattern. The reduction in efficacy happened more quickly on concrete than on steel and wood, possibly due to the alkaline nature of the concrete increasing the rate of chemical degradation of OPs as discussed earlier.

With fenitrothion, however, some strains showed an increase in efficacy from one day through to three months, followed by a decrease at six months, while other strains showed an initial decrease at one month, followed by an increase at three months with another reduction at six months. With etrimfos, there was a small decline in efficacy on steel and wood over time, but on concrete the decrease was more pronounced, particularly in the two *A. siro* strains. For chlorpyrifos, mortality remained high throughout the six month ageing period which was unexpected because OP pesticides are not usually considered to possess a long residual life. As suggested earlier this could be due to the micro-encapsulated formulation of chlorpyrifos which, as well as controlling the rate of release of the active ingredient, might also serve to protect it from the adverse conditions found on concrete (Wege *et al*, 1999). However, the fenitrothion product also had a micro-encapsulated formulation but exhibited no clear pattern to changes in efficacy over time.

Bendiocarb demonstrated an increase in efficacy over time for *A. siro* on all three substrates. The same was true to some extent for *L. destructor* with slight increases on steel and wood. On concrete, after an initial decrease in efficacy at one month, there was an increase at three months. With permethrin, there was generally an increase in efficacy over time on all three substrates; with deltamethrin + bioallethrin and alphacypermethrin there was the same pattern as with permethrin on concrete, that is an initial increase at one month followed by a reduction at three months. There was an exception in the case of deltamethrin + bioallethrin on steel where the expected general decrease in efficacy over time occurred for three of the four strains. In the case of the OP/pyrethroid u.l.v.l. mix the trend was the expected decrease in efficacy over time for all three substrates, although occasional increases in mortality were seen at one month post-spraying.

As has been mentioned already, on non-porous surfaces such as steel, the residual activity of a treatment is thought to be greater than on porous wood and concrete surfaces because the pesticide penetrates into the substrate. However, for the mites in the current study the data were less clear-cut. For example, the results for pirimiphos-methyl and etrimfos both agree with the proposition that non-porous surfaces show a greater residual activity. At one month post-spraying the mortality rates on steel and wood were far greater than on concrete for the majority of the strains tested. However, for two strains mortality was less on steel than on concrete at the one month post-spraying test. The two strains in question have both demonstrated tolerance to chlorpyrifos-methyl; however, they have also demonstrated tolerance to pirimiphos-methyl and etrimfos, so they would be expected to show similar trends depending on how each individual pesticide was behaving. Also, similar increases in mortality over time were seen on steel as on the other two substrates, as discussed previously possibly due to pesticide migration over the steel after spraying.

To summarise, on the basis of our tests the following recommendations can be made for mite control :

- To treat a mite infestation immediately the use of an OP pesticide is recommended : pirimiphos-methyl, chlorpyrifos-methyl, chlorpyrifos and etrimfos.
- For longer-term treatment the pyrethroid permethrin can be recommended on steel and concrete. On plywood, it is only at one month post-spraying that this pesticide gives adequate mortality of all four strains tested (*i.e.* >80%).
- However, only pirimiphos-methyl, chlorpyrifos-methyl, etrimfos, chlorpyrifos and permethrin are approved for use as fabric treatments where food will come into contact with the pesticide, and only the first three for admixture to grain.
- For areas where food will come into contact with the pesticide, there is no pesticide available to give a residual effect either to six months post-treatment on steel or to one month post-treatment on concrete.

Overall recommendations for beetle and mite control

Recommendations for the structural treatment of grain stores to control beetle and mite pests, based on the results of these laboratory tests together with pesticide usage regulations in the UK, are:

- For immediate treatment of infestations, use an organophosphate pesticide; pirimiphos-methyl, chlorpyrifos-methyl and etrimfos gave the best performances generally overall. Chlorpyrifos was also particularly effective against beetles on concrete but can only be used on surfaces that do not come into contact with food.
- For longer-term treatment of areas that come into contact with food, use an organophosphate pesticide; fenitrothion performed best overall.
- For longer-term treatment of areas that do not come into direct contact with food, use the pyrethroid permethrin. However, chlorpyrifos was more effective than permethrin against beetles on concrete.

General remarks

The aim of this study has been to provide recommendations in support of best storage practices to guide farmers, storekeepers and processors on the most effective pesticides to use in their circumstances. It should be noted that the recommendations for beetle and mite control described above are based on laboratory tests designed as far as practical to reflect conditions in grain and food stores. Actual pesticide performance under farm and food storage conditions may be affected to some degree by factors such as temperature, relative humidity and pest resistence levels in different geographical areas. However, by performing our tests under carefully controlled conditions comparisons between the performances of different pesticides can be made more accurately. The tests were conducted using insects and mites considered to correspond most closely to the pest fauna of UK grain stores, both in terms of the species found there and their tolerance to pesticides. Pesticides were sprayed onto materials chosen as representative of those commonly used in the construction of UK grain stores.

Also, it should be remembered that these recommendations are based on the current regulatory situation. This is subject to change as product licences come up for renewal. For example, after this project commenced, Reldan (chlorpyrifos-methyl) had its maximum residue limit reduced from 5 to 3 mg/kg and its withholding period has been increased to eight weeks. Additionally, Satisfar (etrimfos) appears to be no longer available commercially in the UK.

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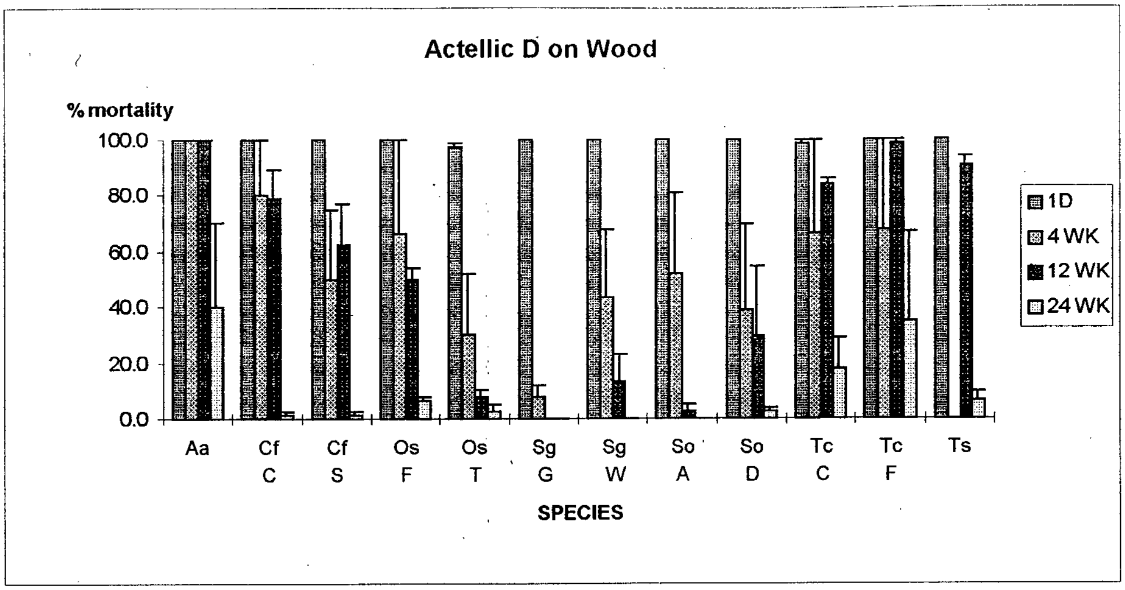
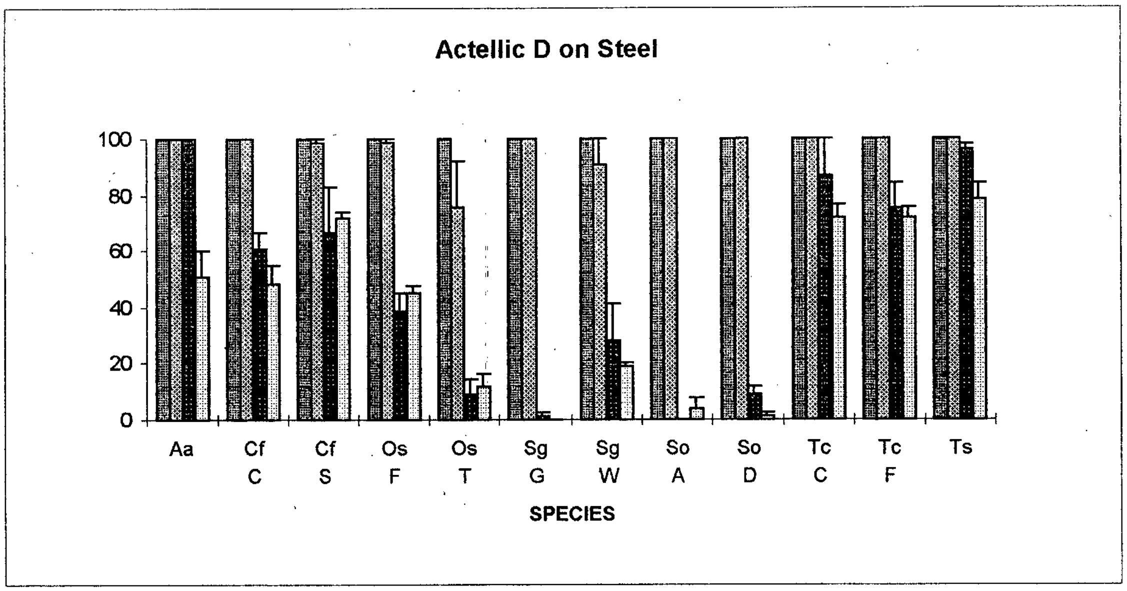
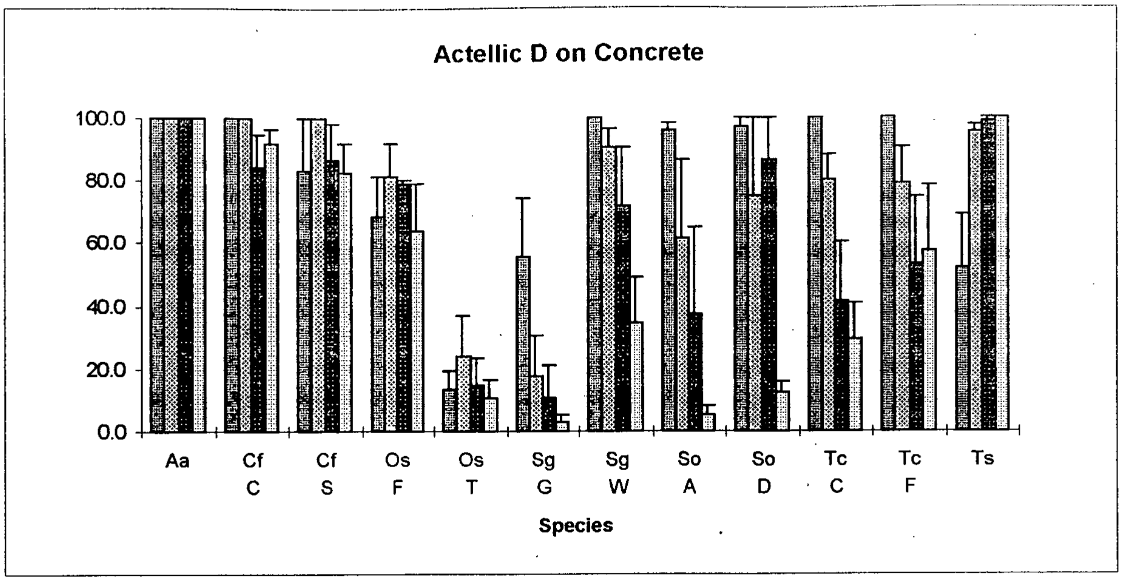
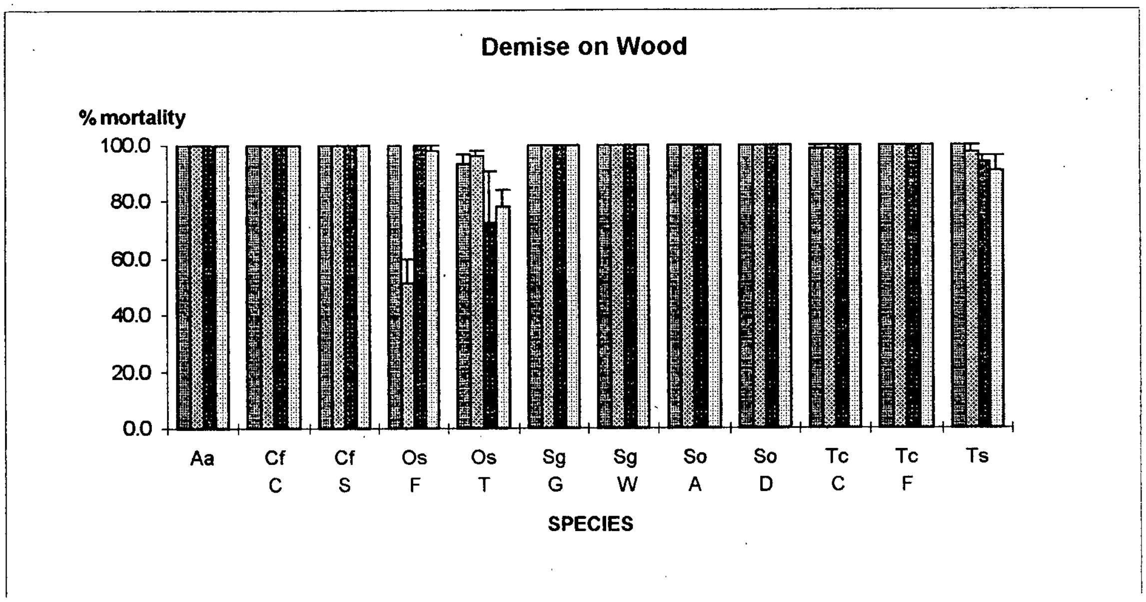
Appendices

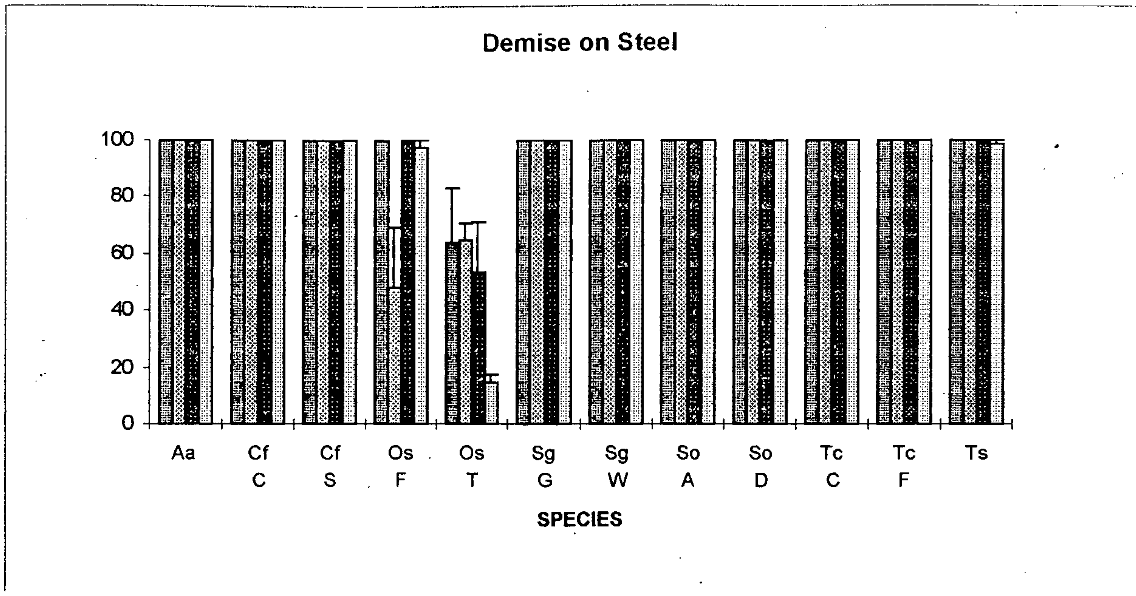
Appendix 1: Histograms of mean % mortality of 12 insect species/strains on ten pesticides.


Actellic D on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
1D
4 WK
12 WK
24 WK
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES


Actellic D on Steel
100
80
60
40
20
0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES


Actellic D on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species


Demise on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES


Demise on Steel
100
80
60
40
20
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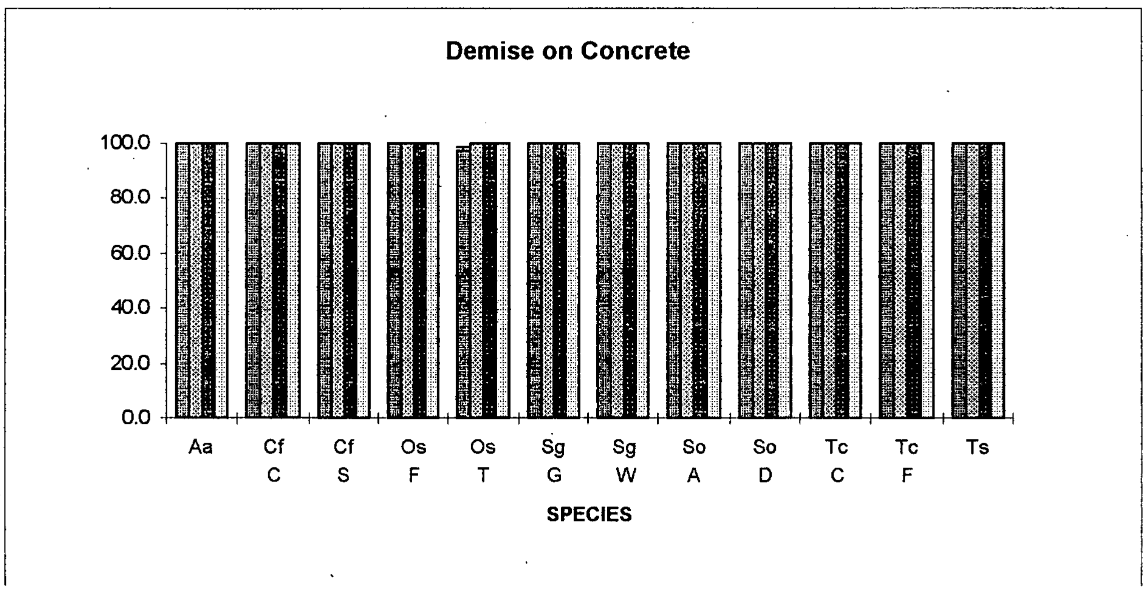
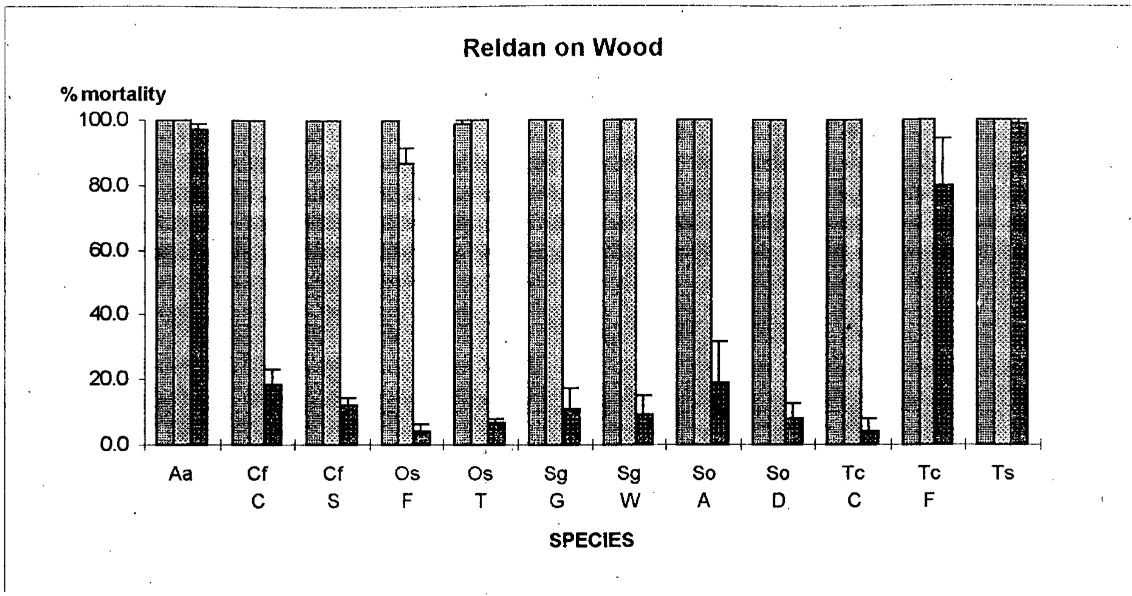
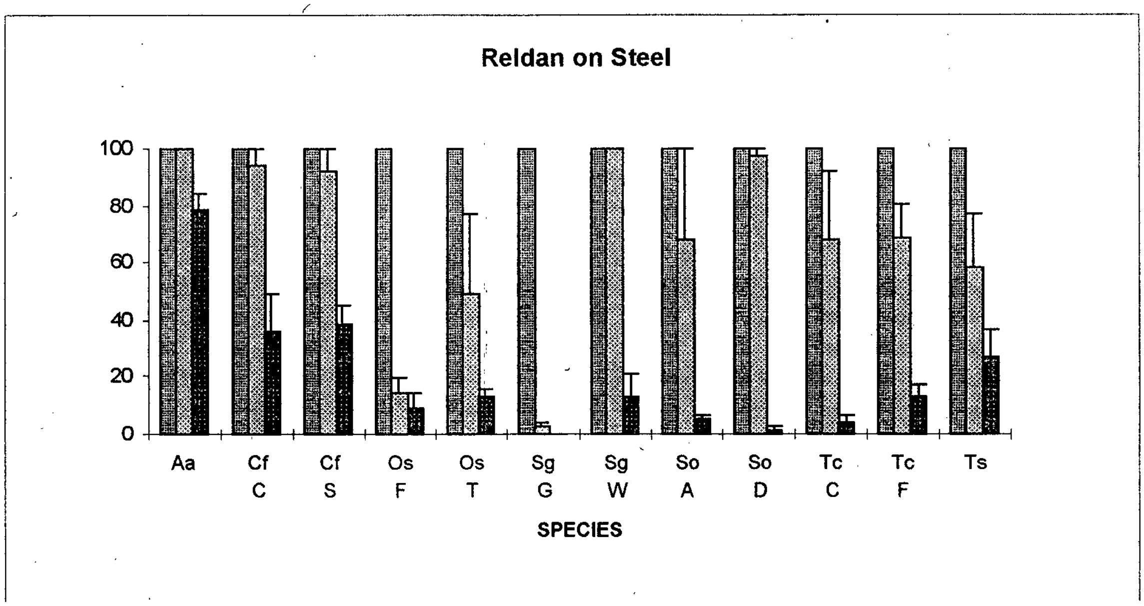
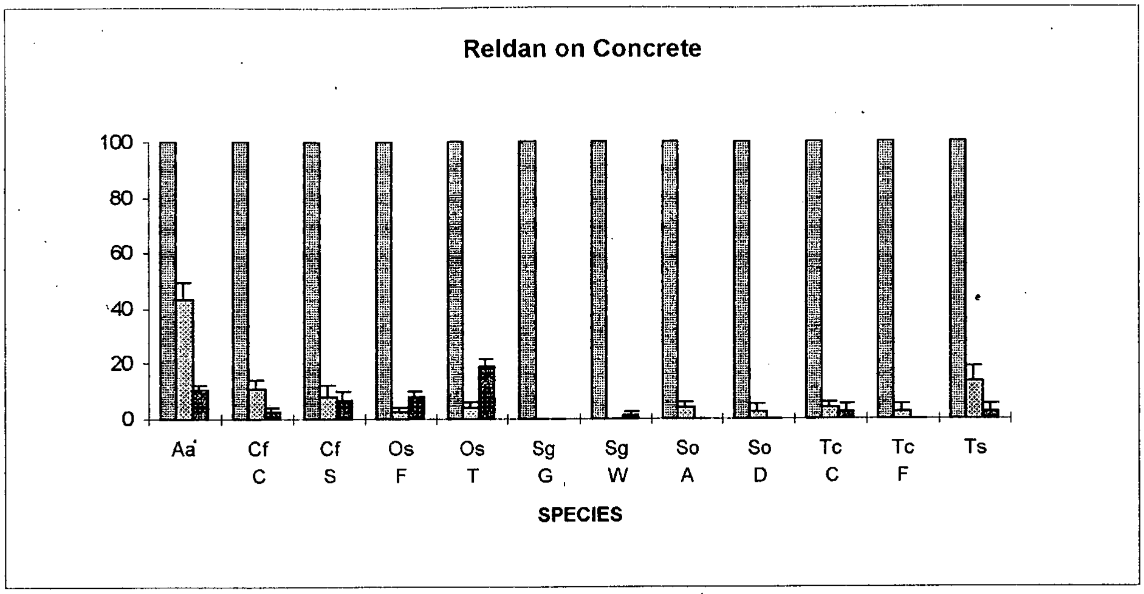
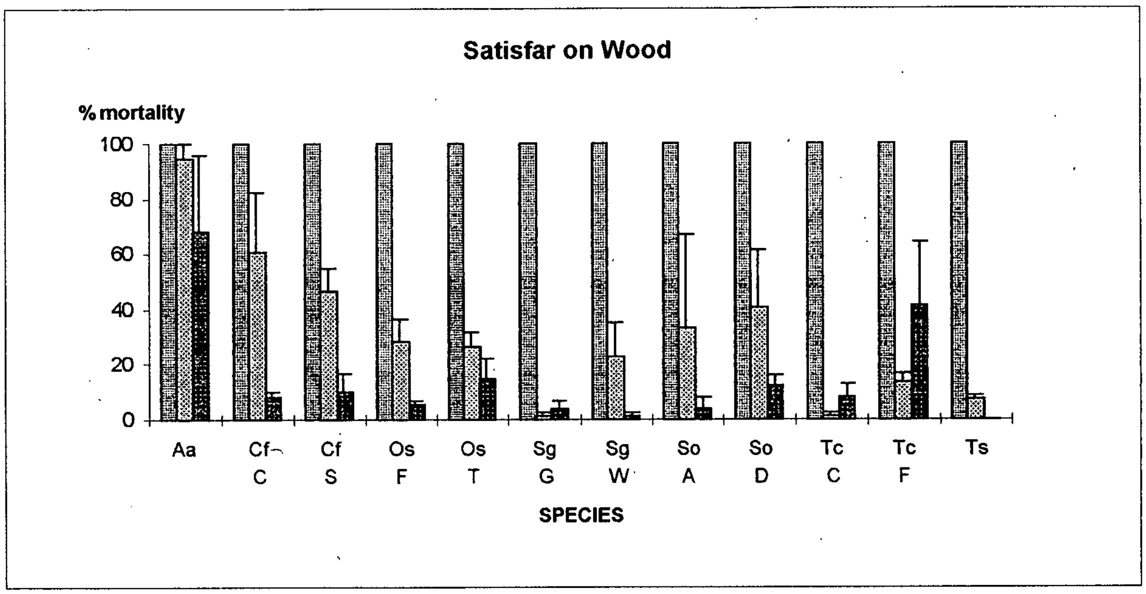
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

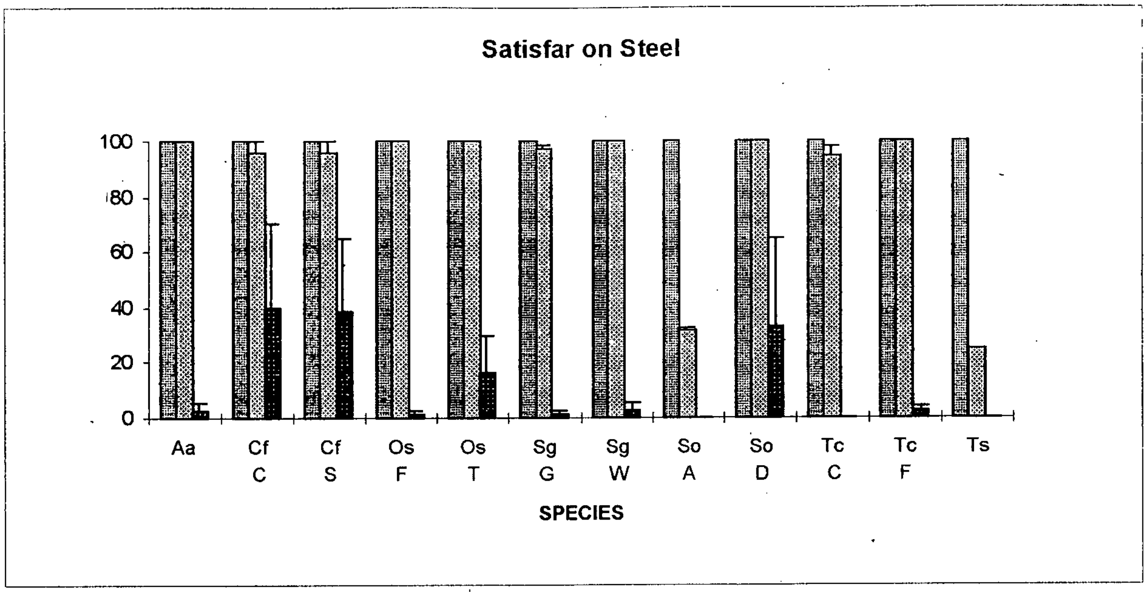

Demise on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

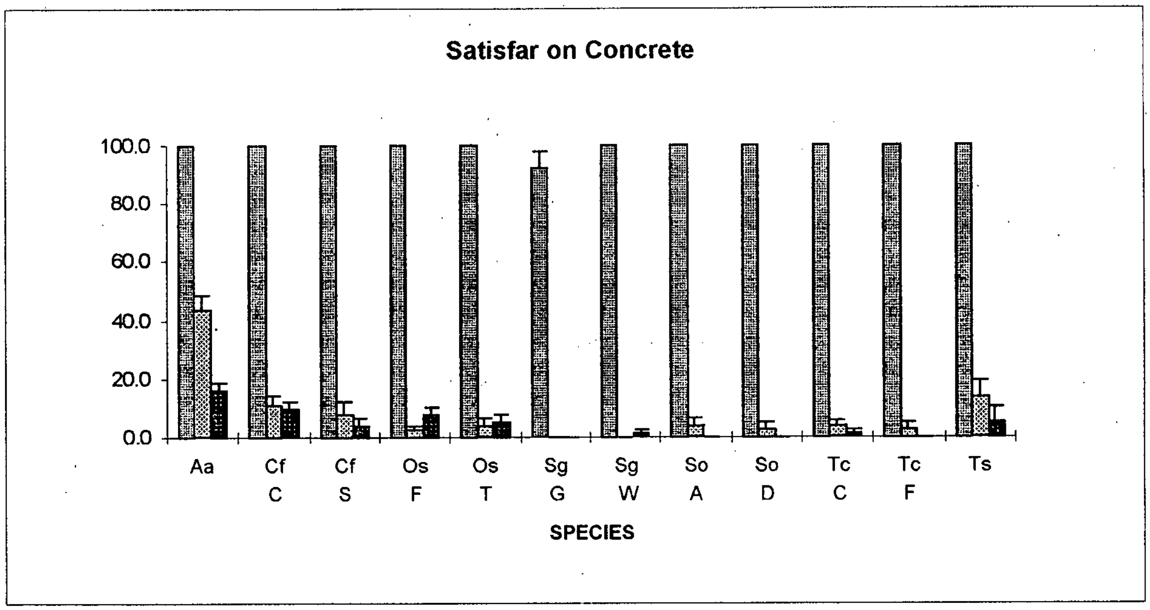

Reldan on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

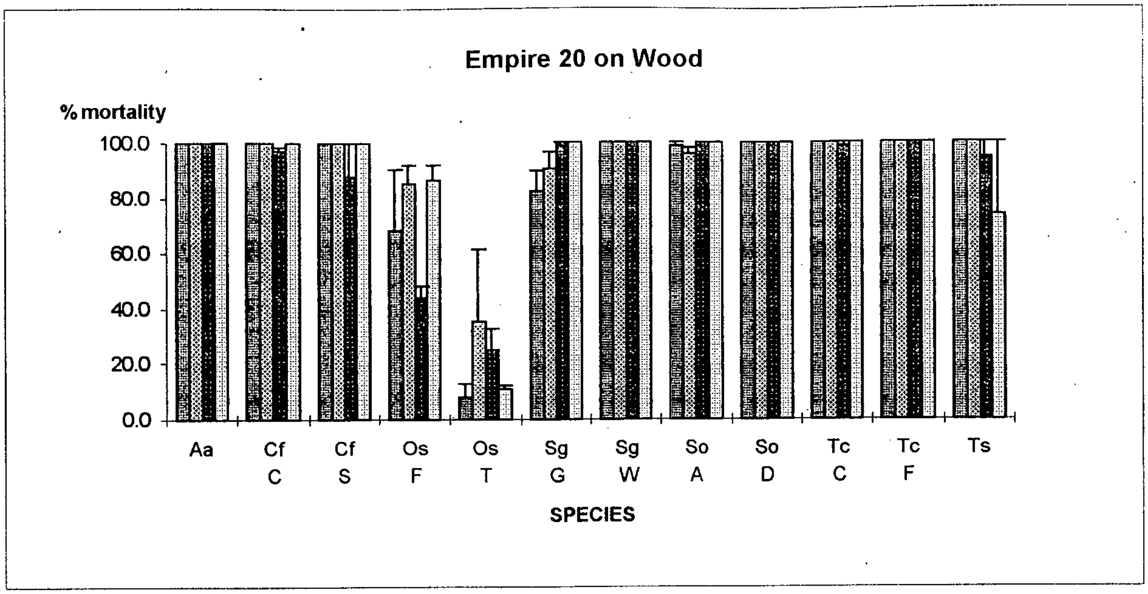

Reldan on Steel
100
80
60
40
20
0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

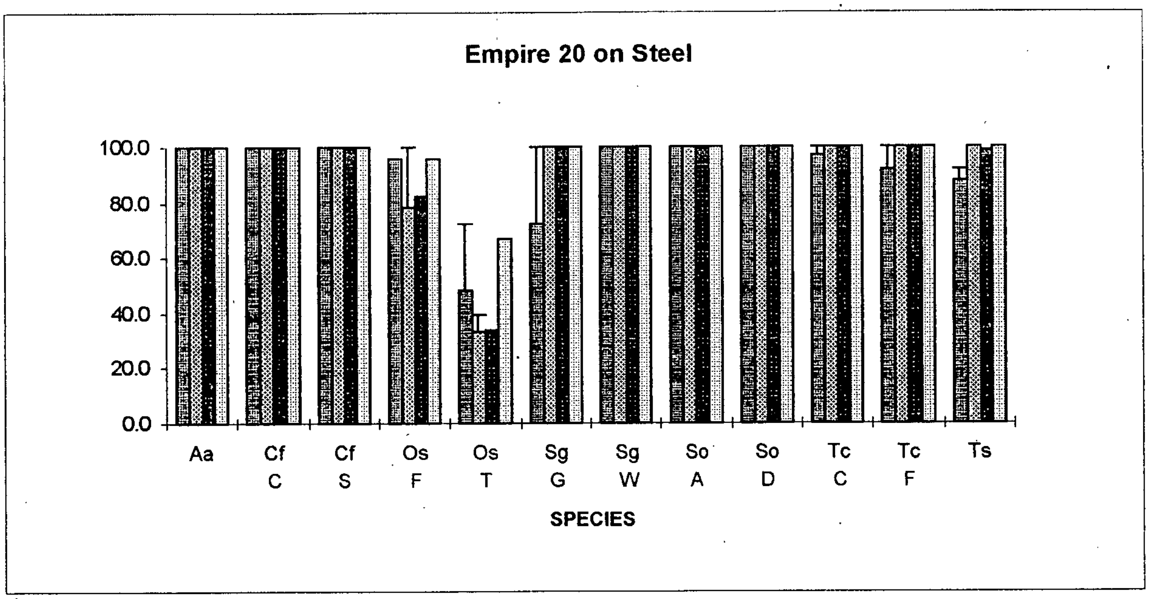

Reldan on Concrete
100
80
60
40
20
0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

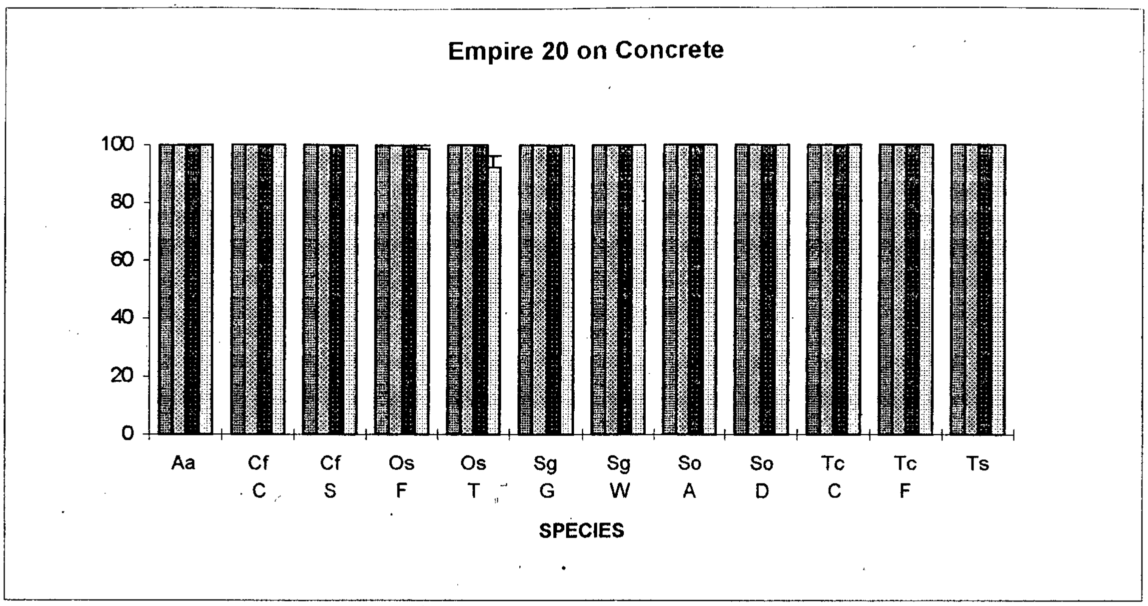

Satisfar on Wood
% mortality
100
80
60
40
20
0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

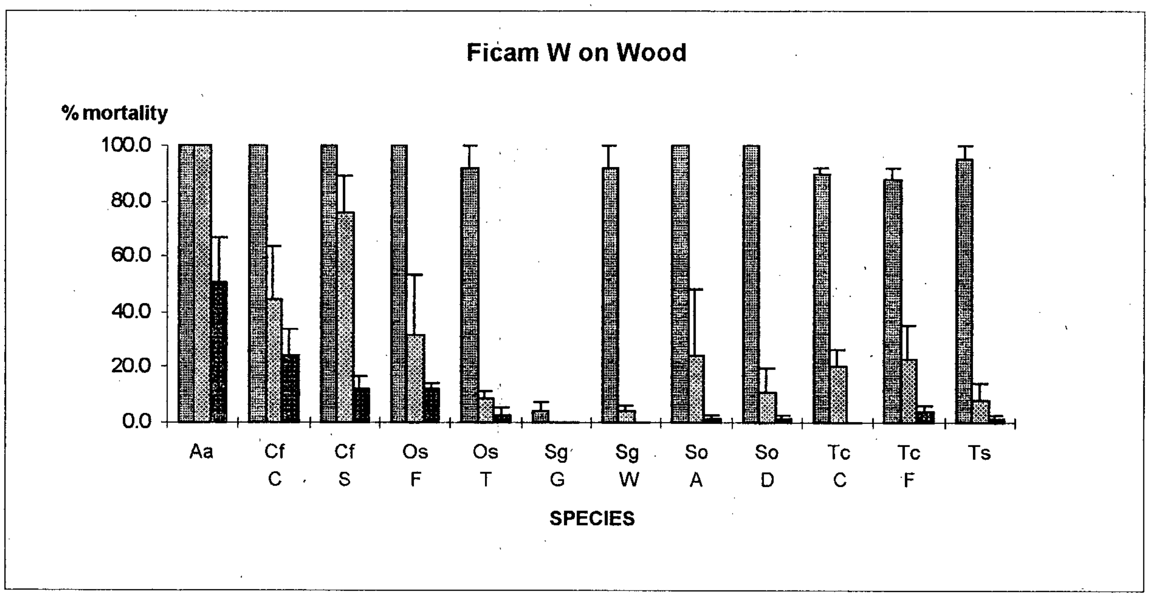

Satisfar on Steel
100
80
60
40
20
0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

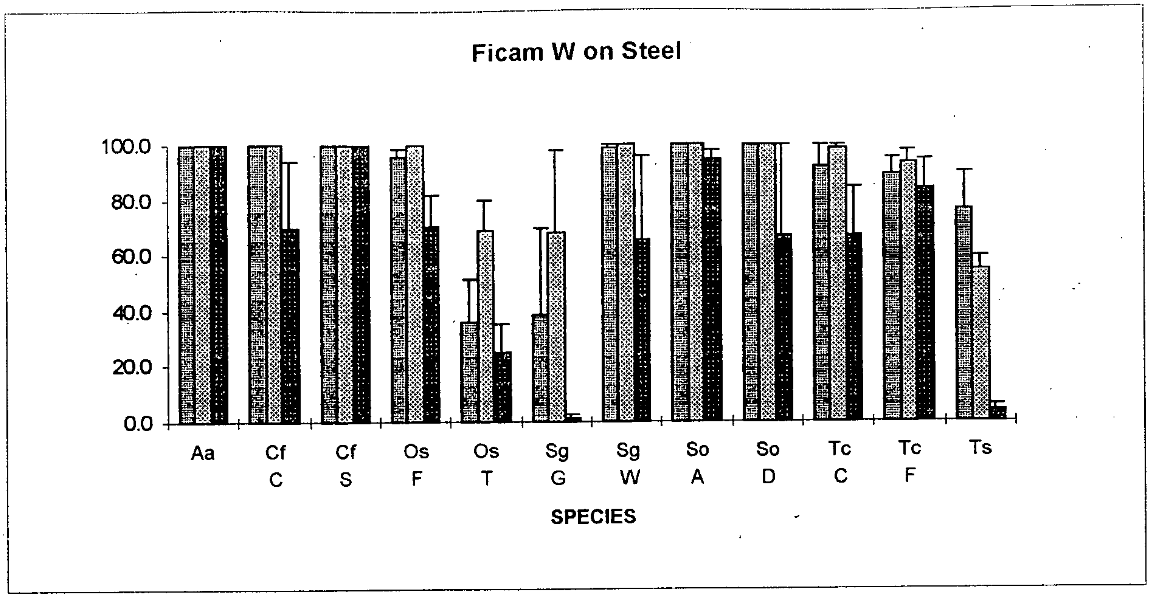

Satisfar on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

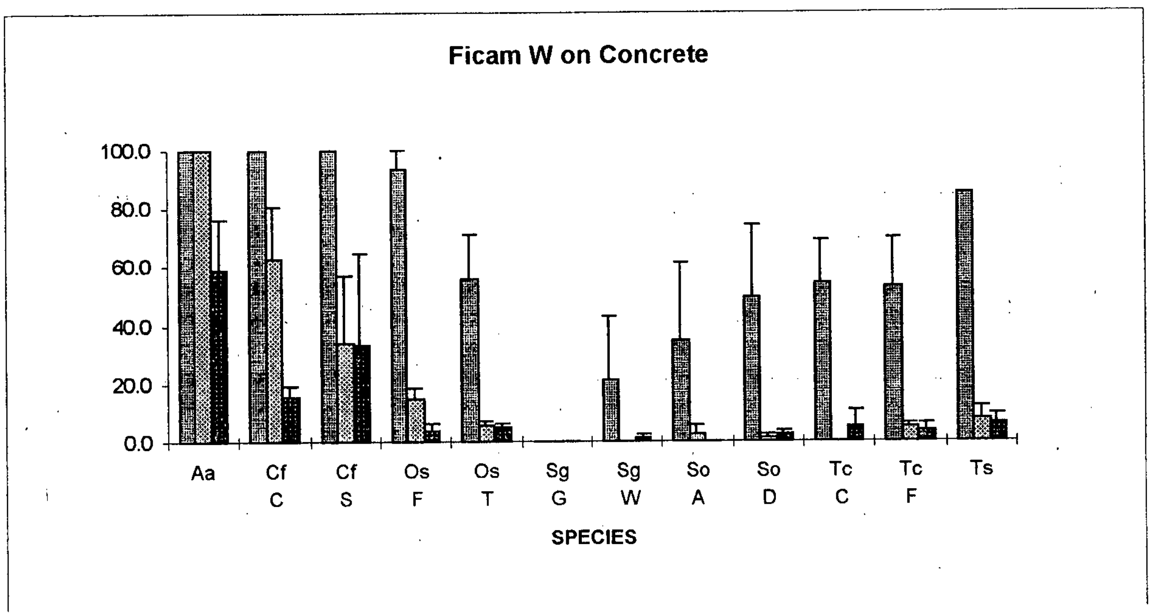

Empire 20 on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

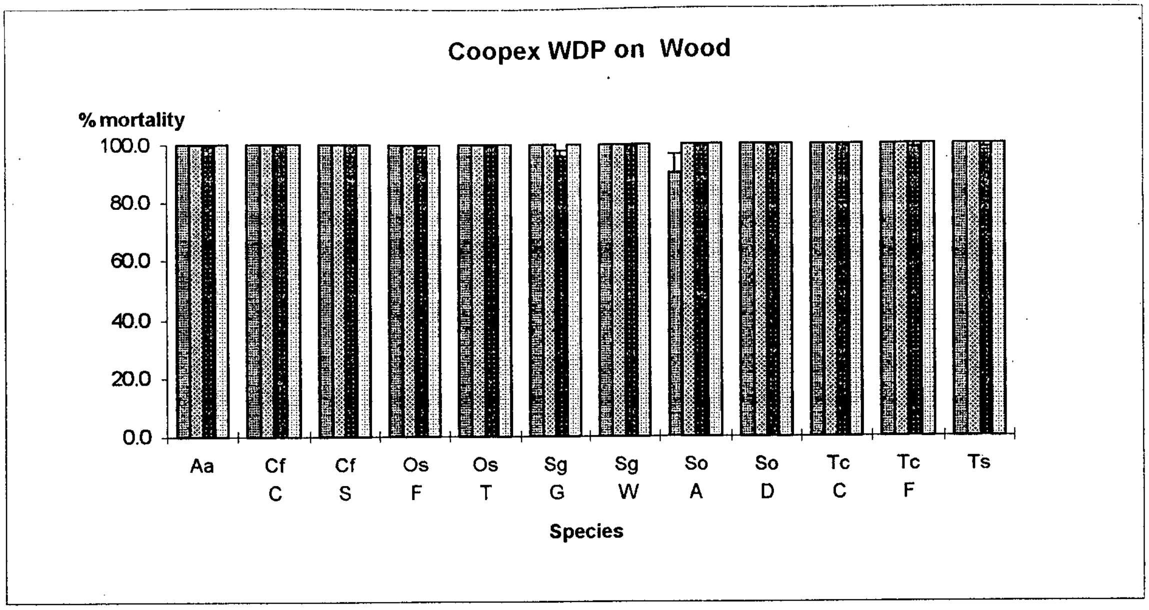

Empire 20 on Steel
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

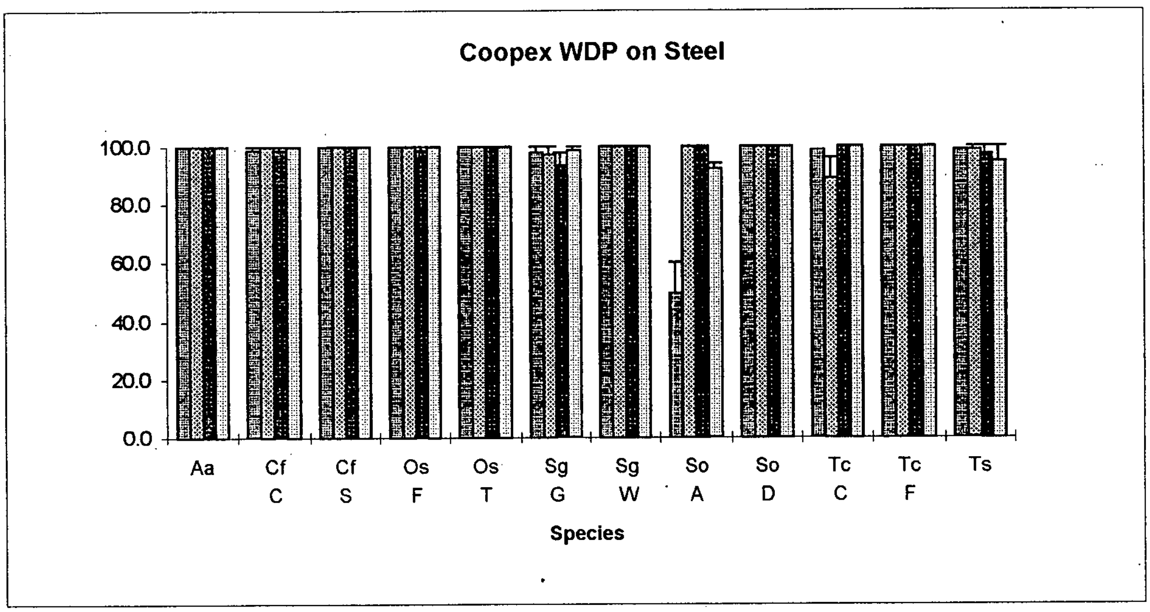

Empire 20 on Concrete
100
80
60
40
20
0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

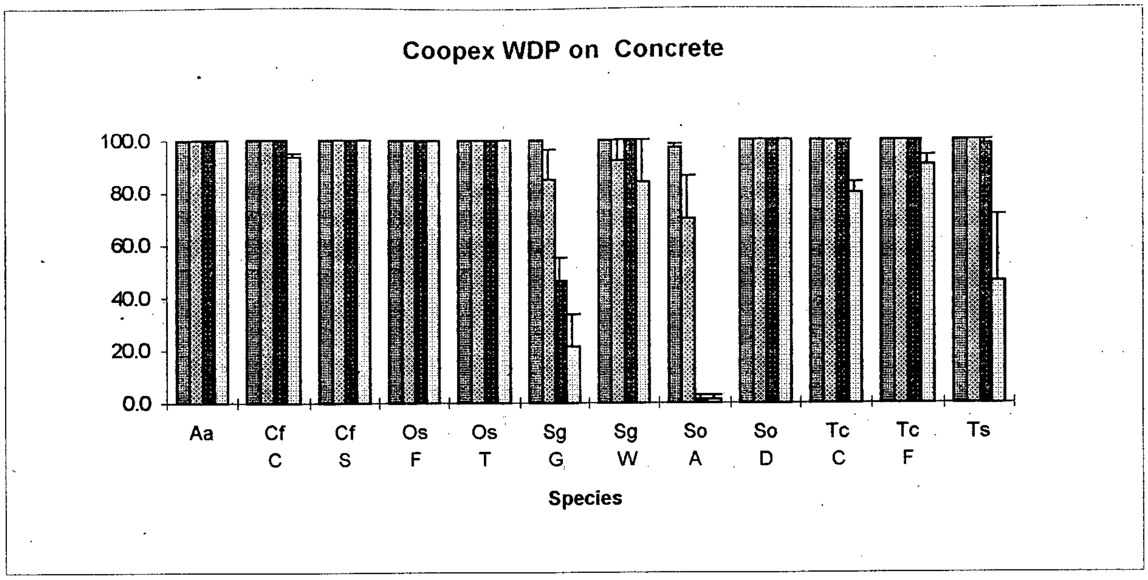

Ficam W on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

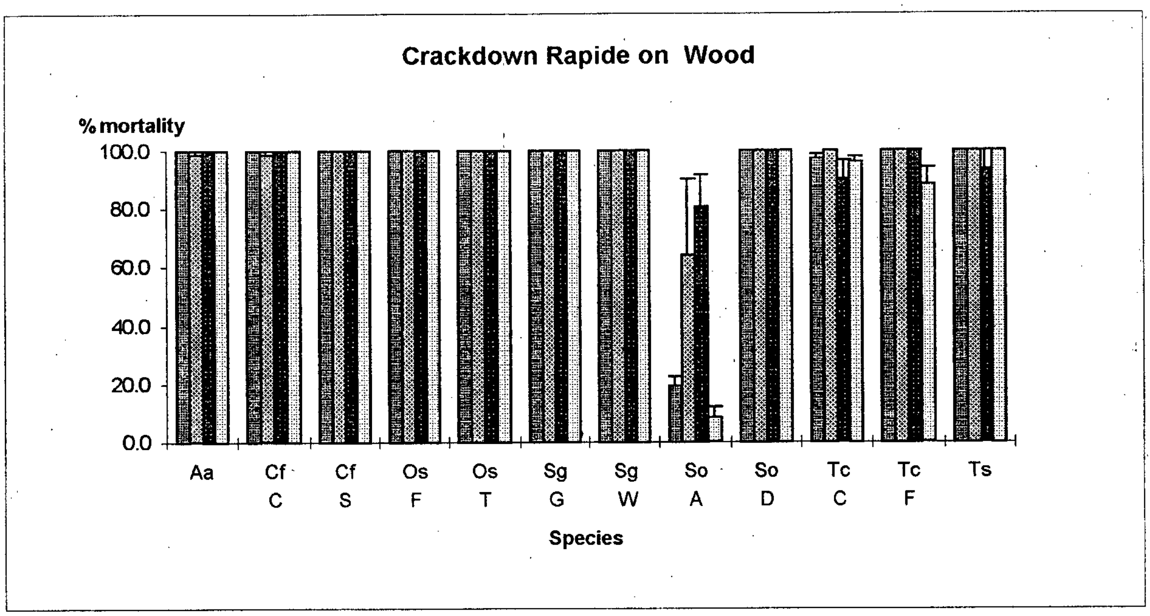

Ficam W on Steel
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

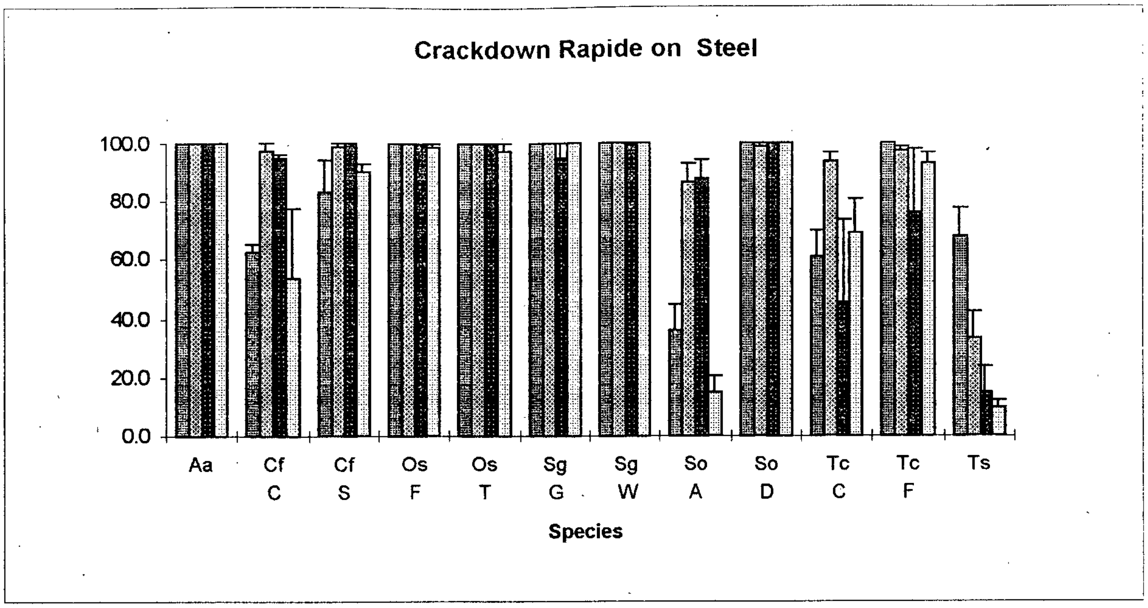

Ficam W on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
SPECIES

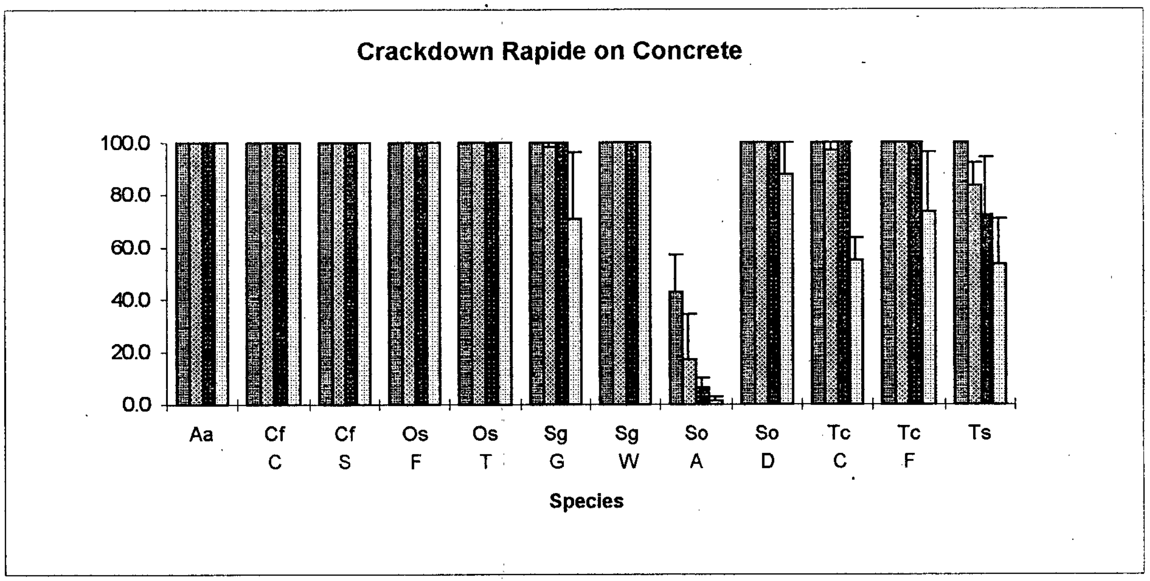

Coopex WDP on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

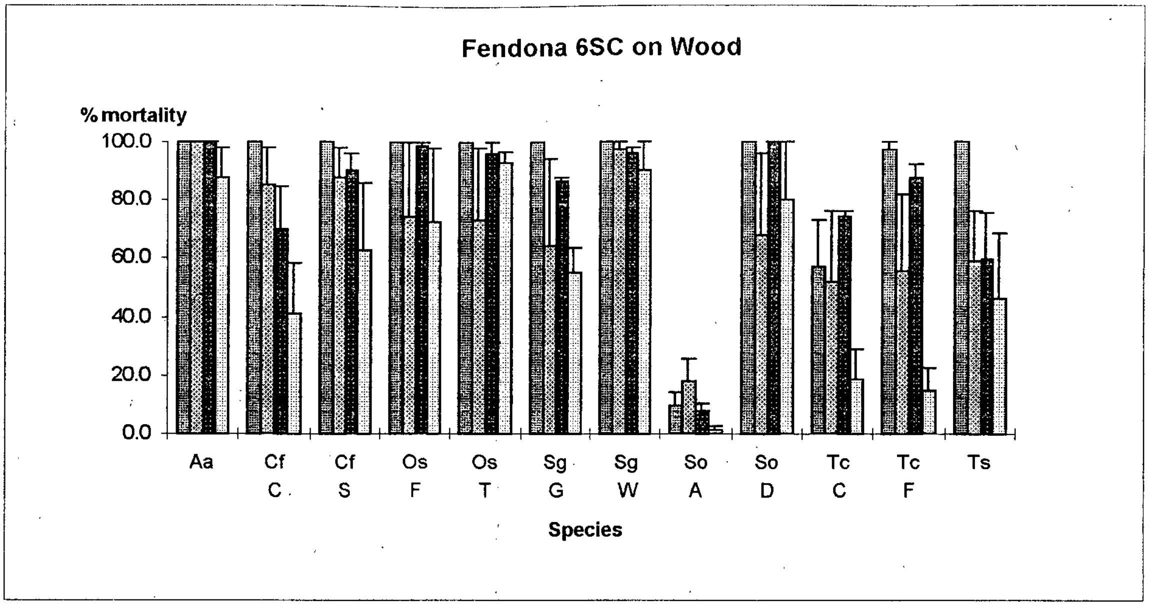

Coopex WDP on Steel
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

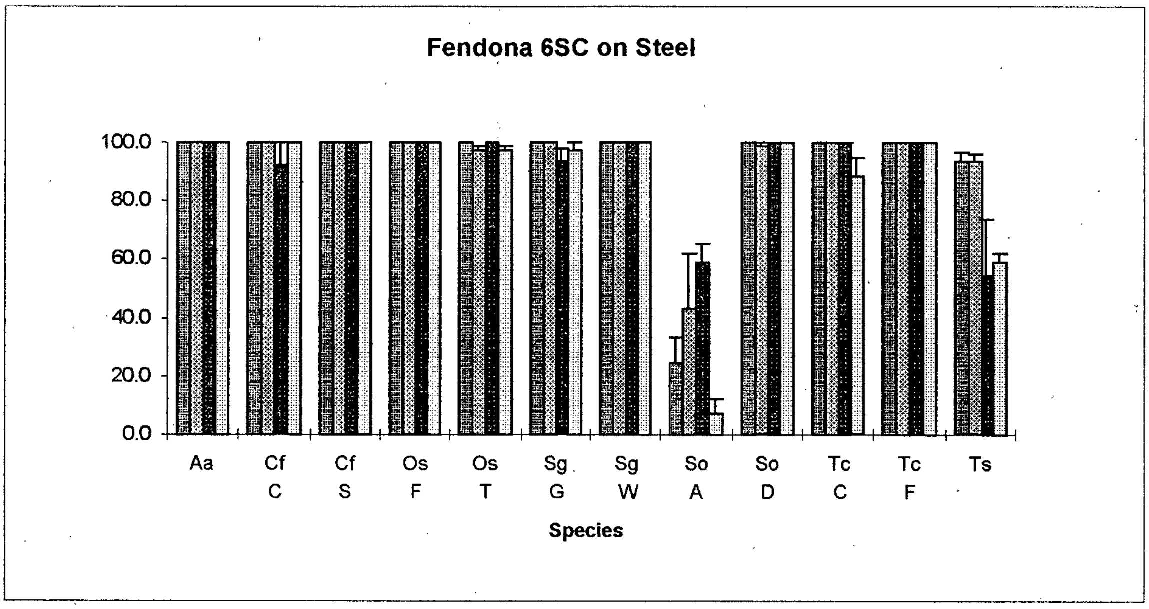

Coopex WDP on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

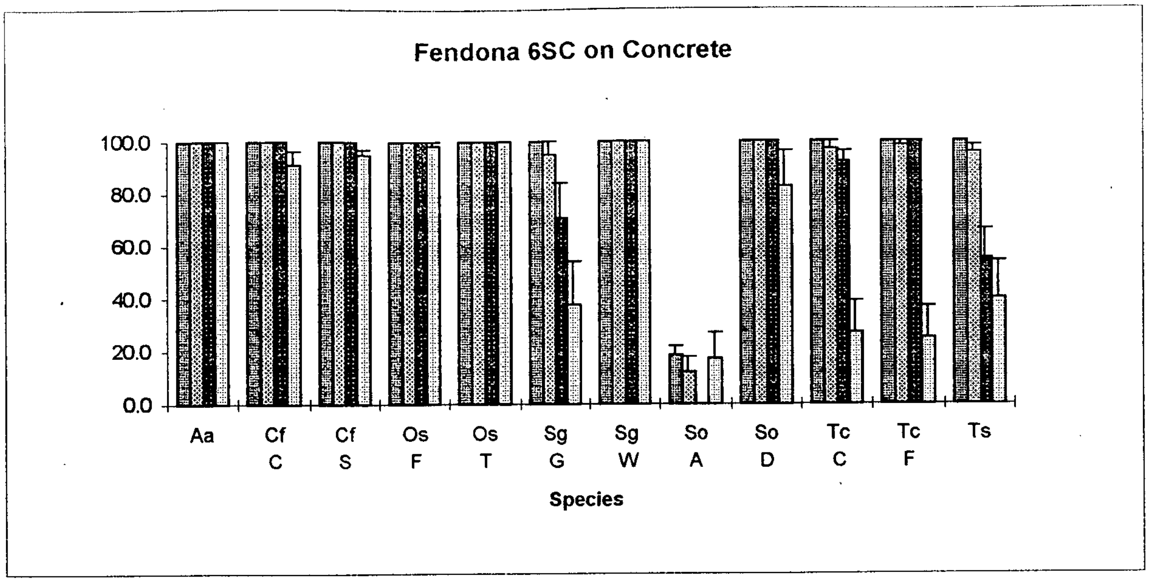

Crackdown Rapide on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

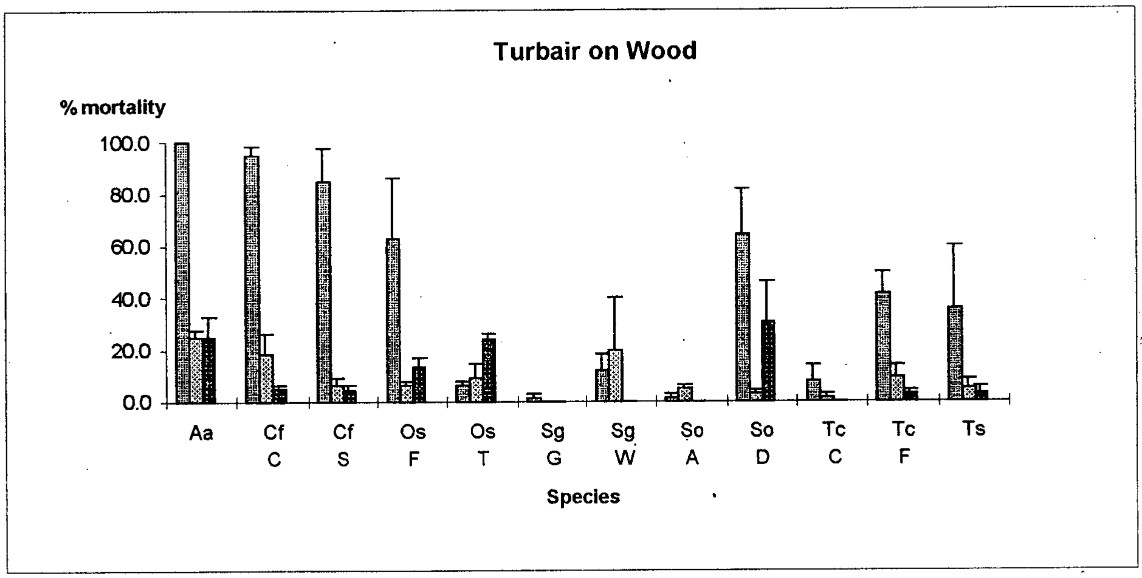

Crackdown Rapide on Steel
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

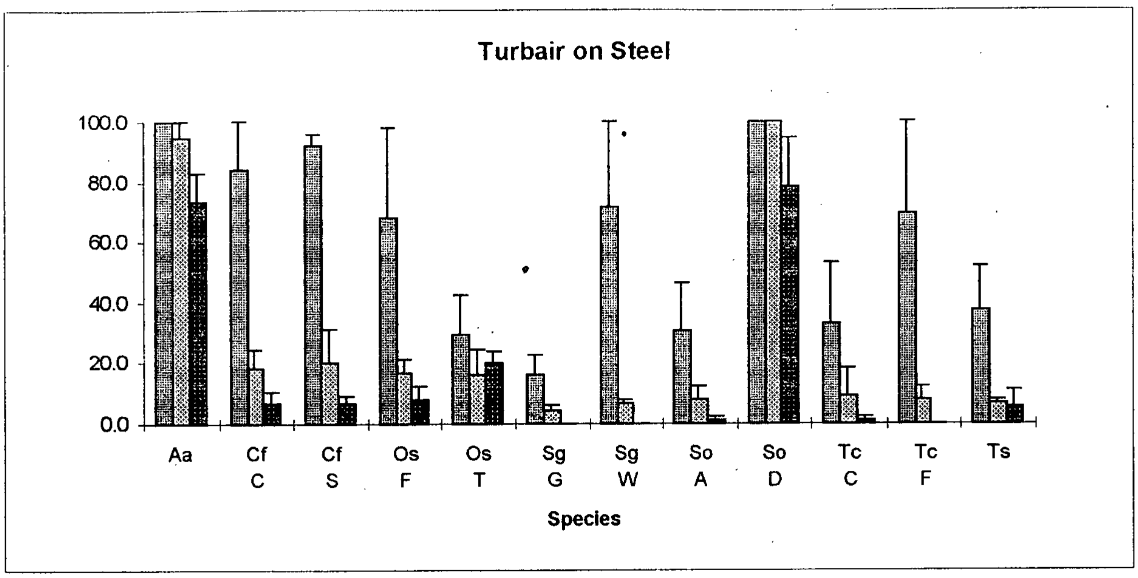

Crackdown Rapide on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

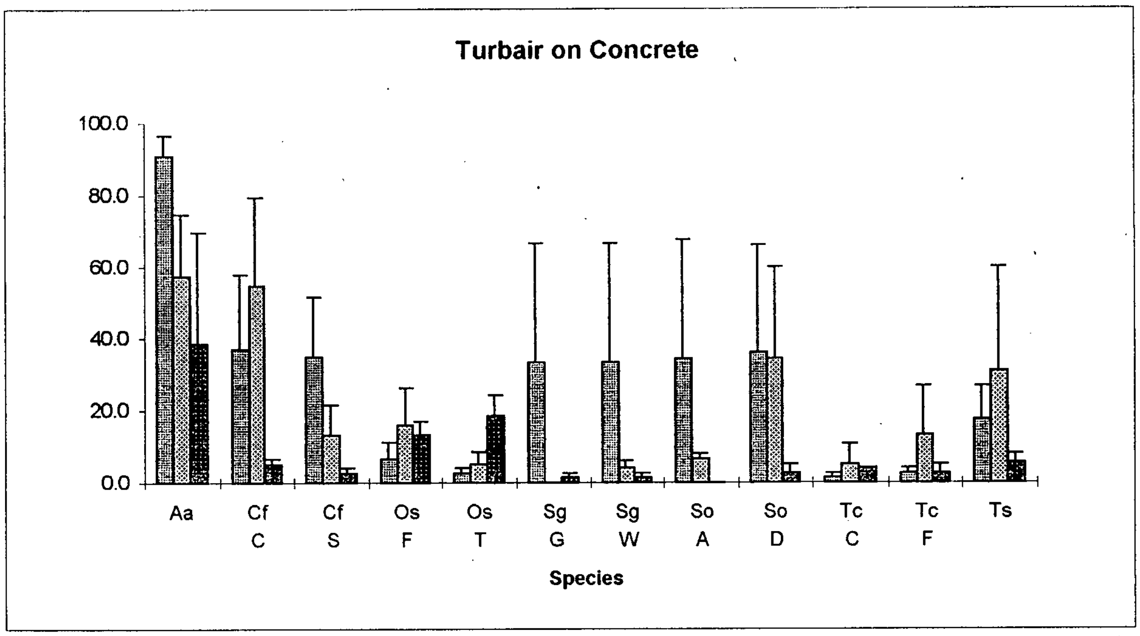

Fendona 6SC on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species


Fendona 6SC on Steel
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species


Fendona 6SC on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

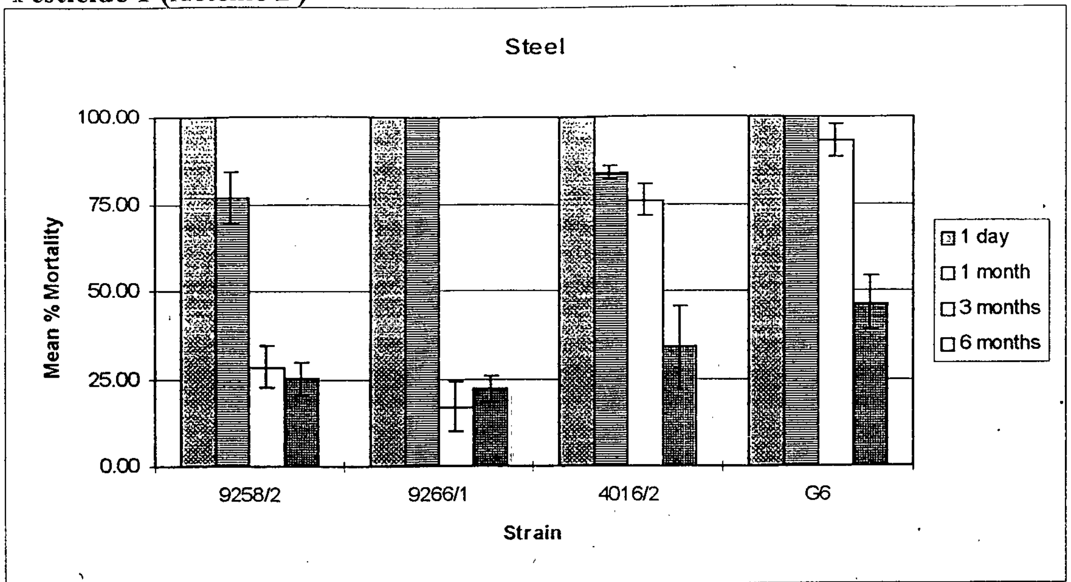

Turbair on Wood
% mortality
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

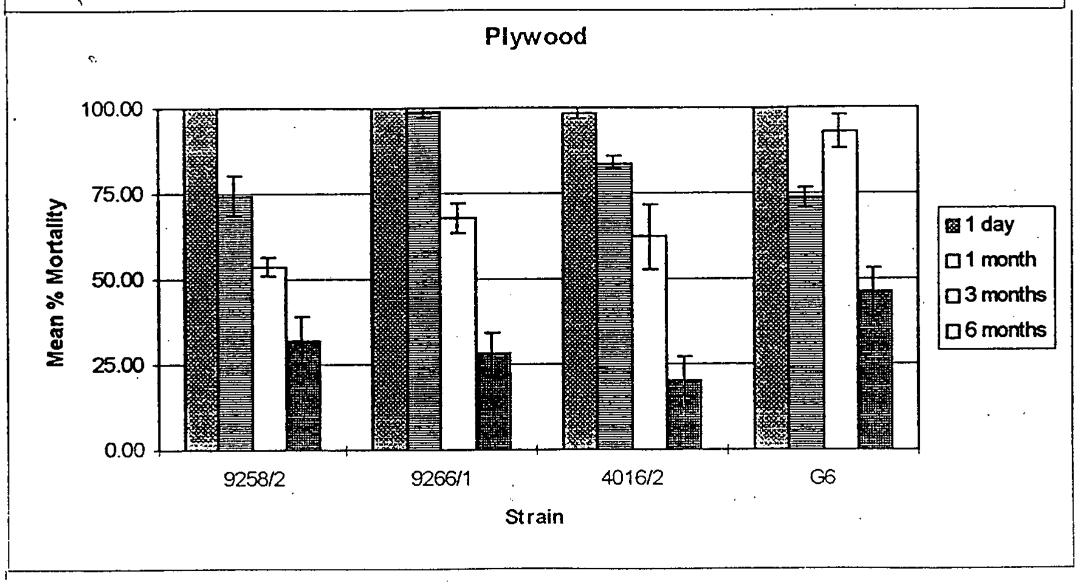

Turbair on Steel
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

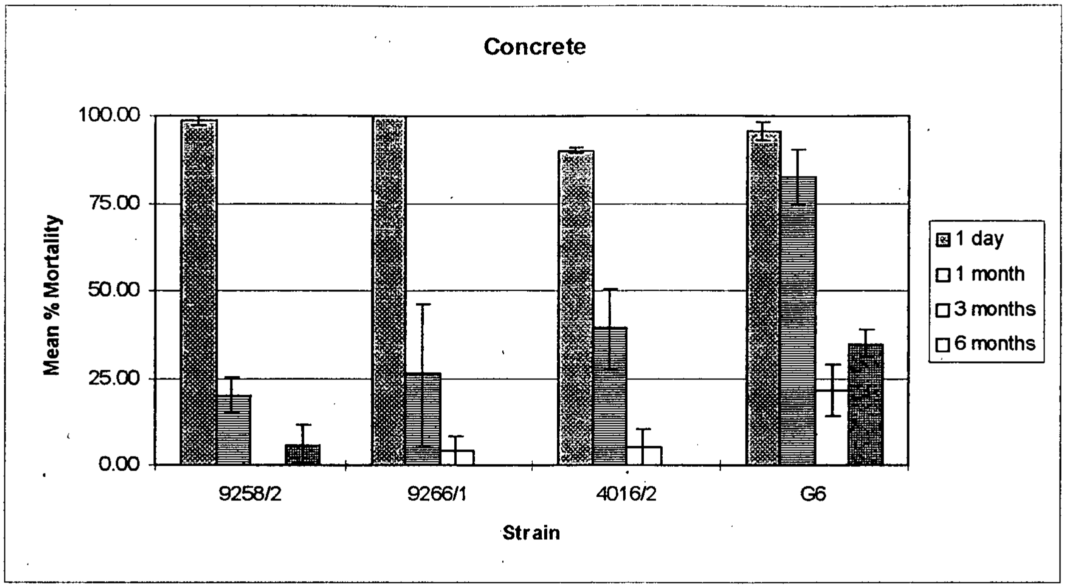

Turbair on Concrete
100.0
80.0
60.0
40.0
20.0
0.0
Aa
Cf C
Cf S
Os F
Os T
Sg G
Sg W
So A
So D
Tc C
Tc F
Ts
Species

Appendix 2. Histograms of mean % mortality for 4 species/strains of mites on ten pesticides.

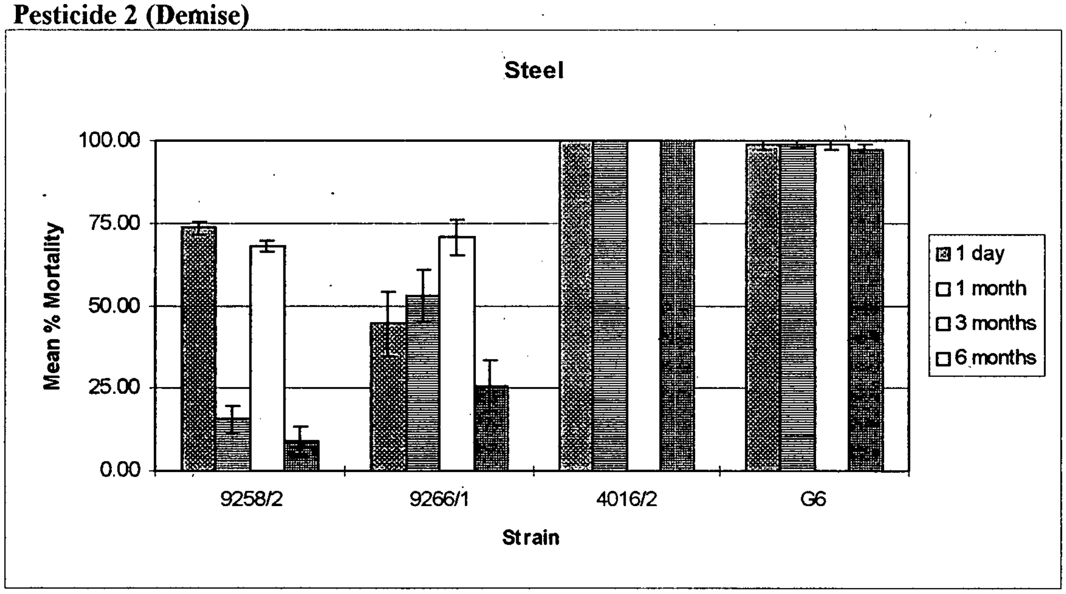
Pesticide 1 (Actellic D)

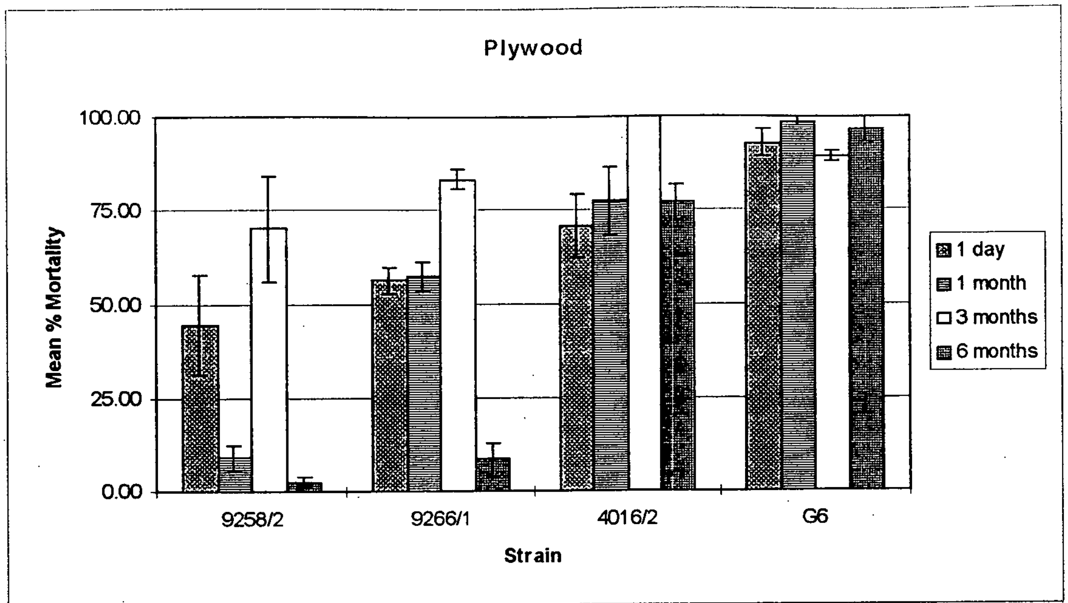


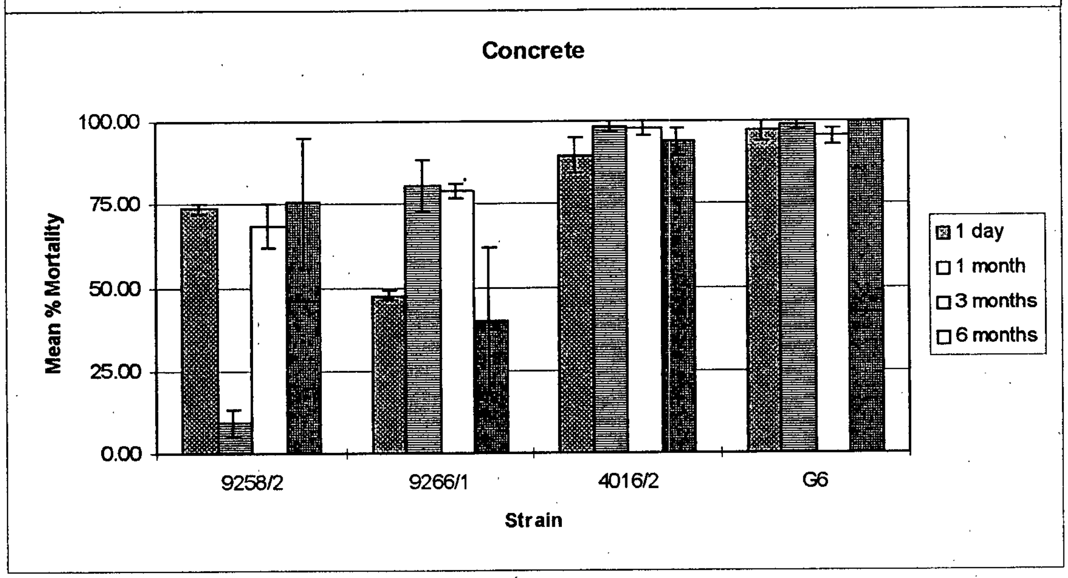




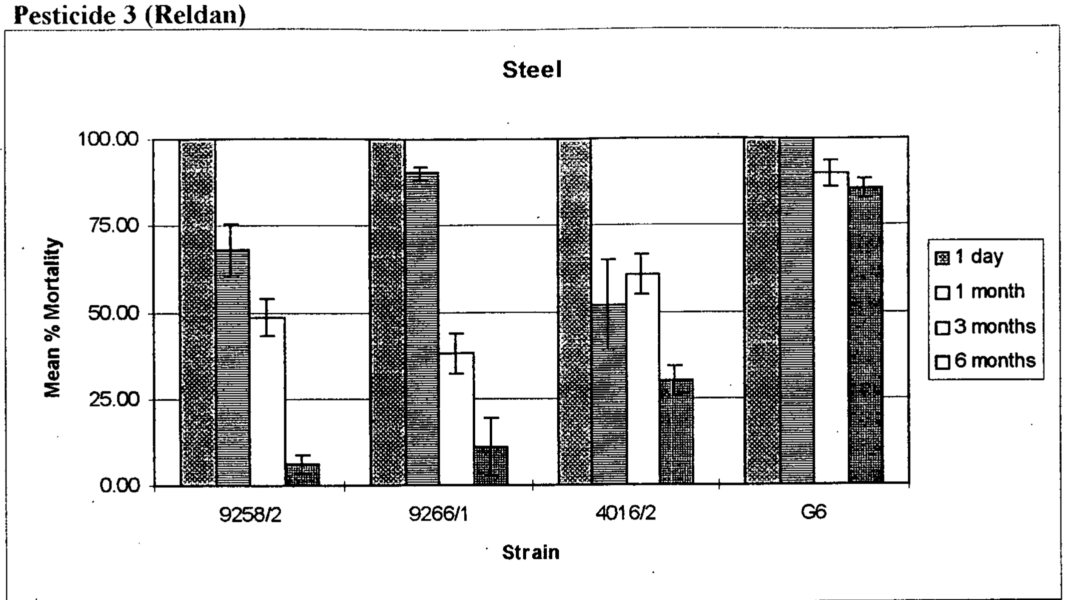
Pesticide 2 (Demise)

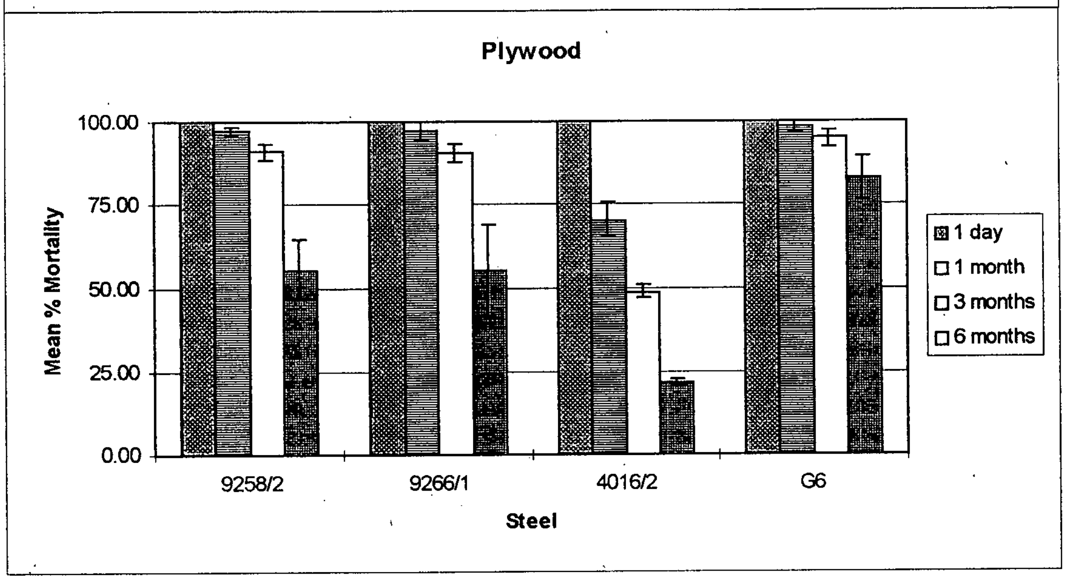


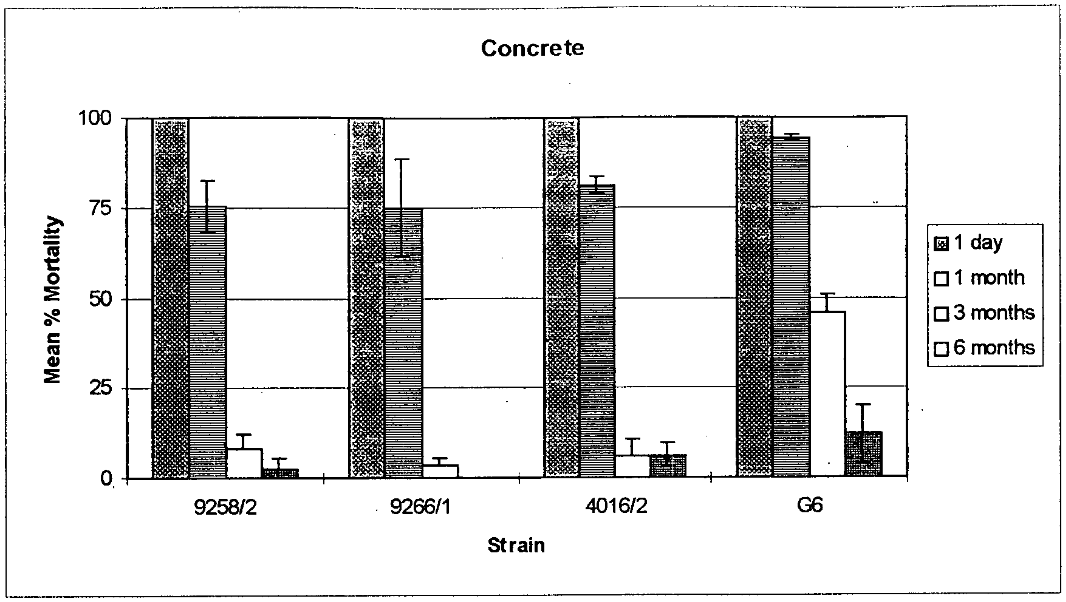

Plywood
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months


Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months

Pesticide 3 (Reldan)

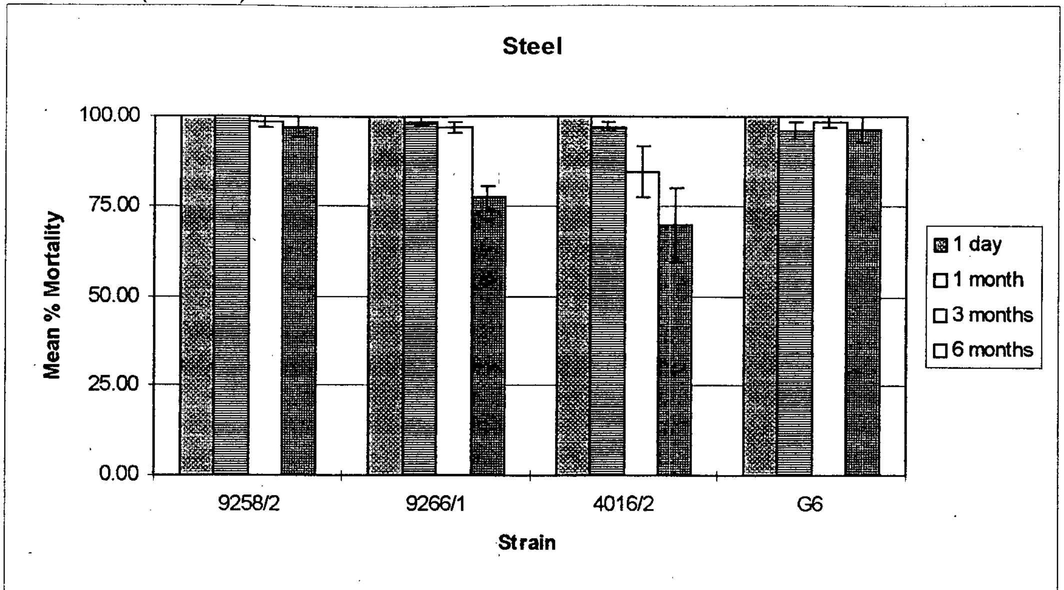


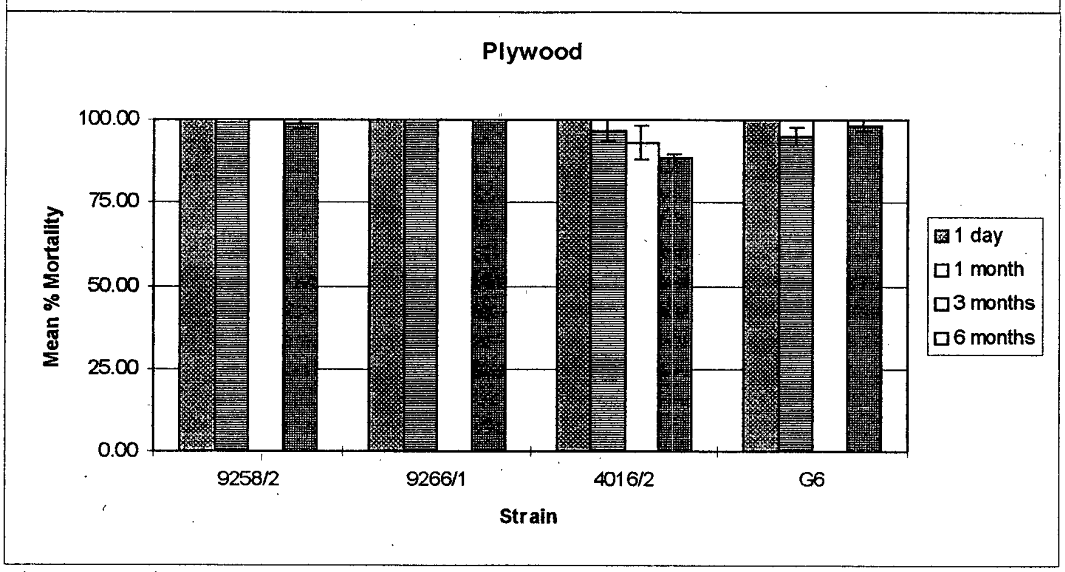


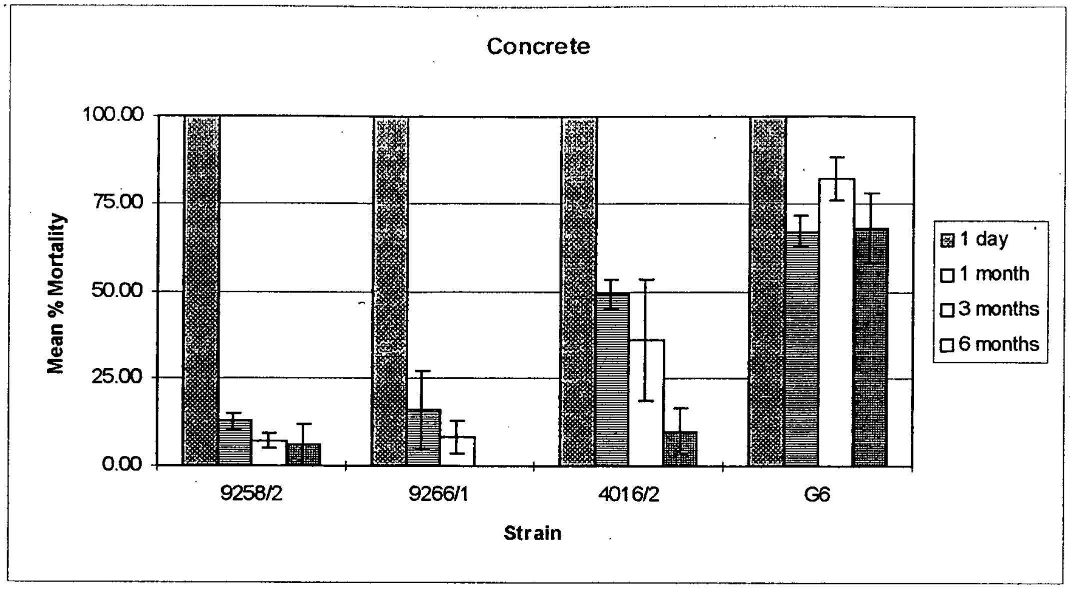


Concrete
100
75
50
25
0
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months

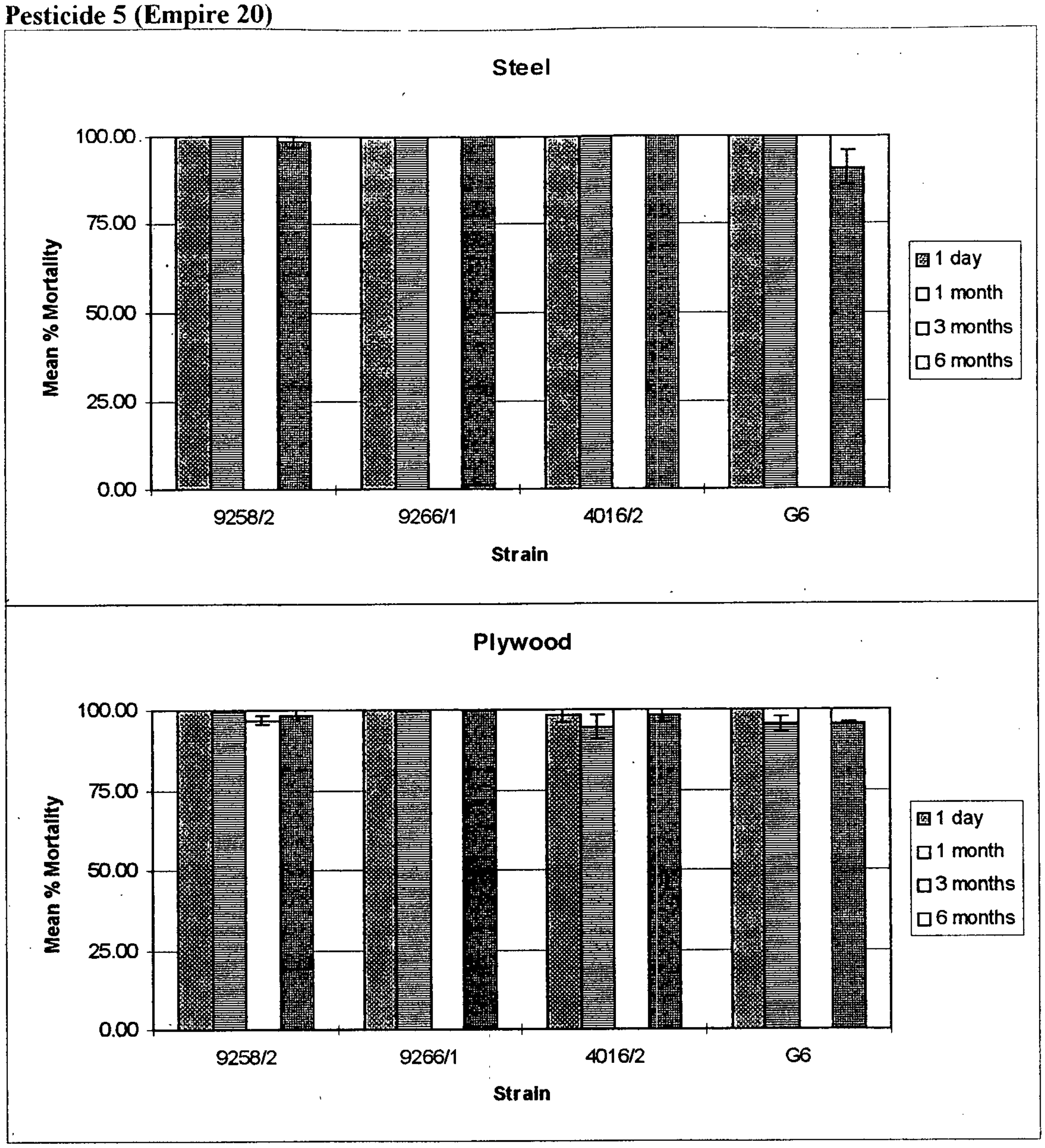
Pesticide 4 (Satisfar)

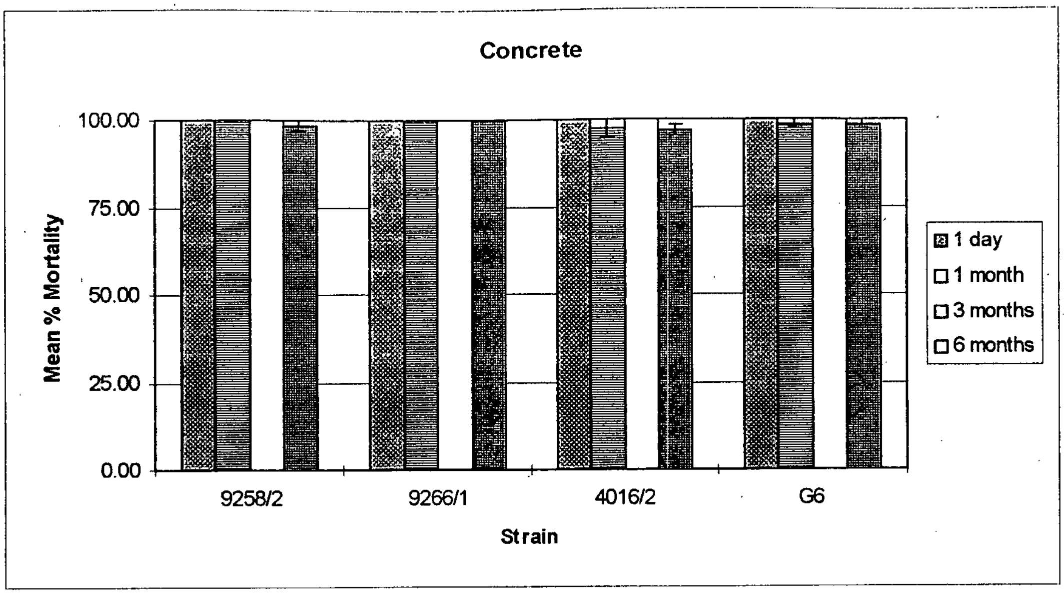




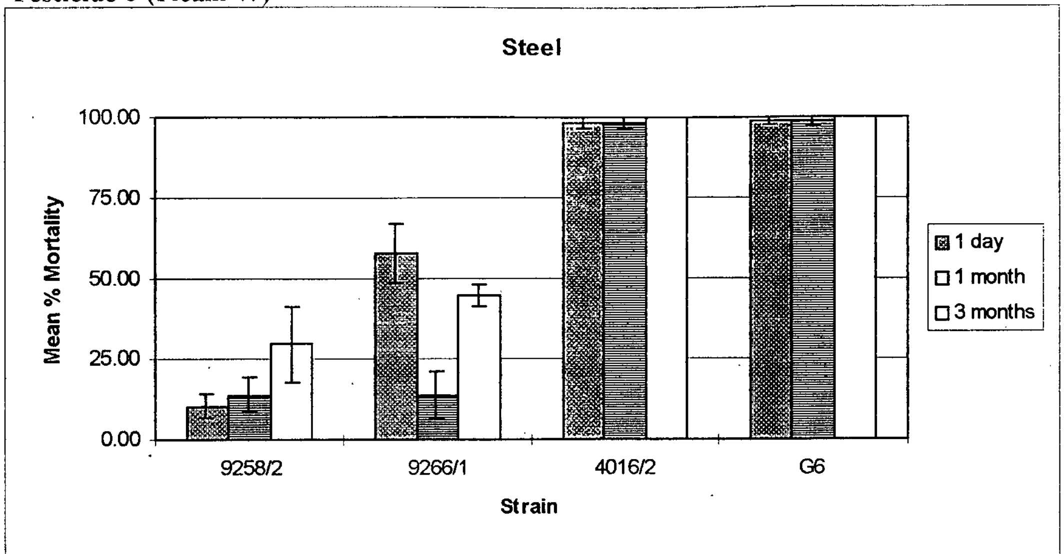

Concrete
Mean % Mortality
100.00
75.00
50.00
25.00
0.00
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months

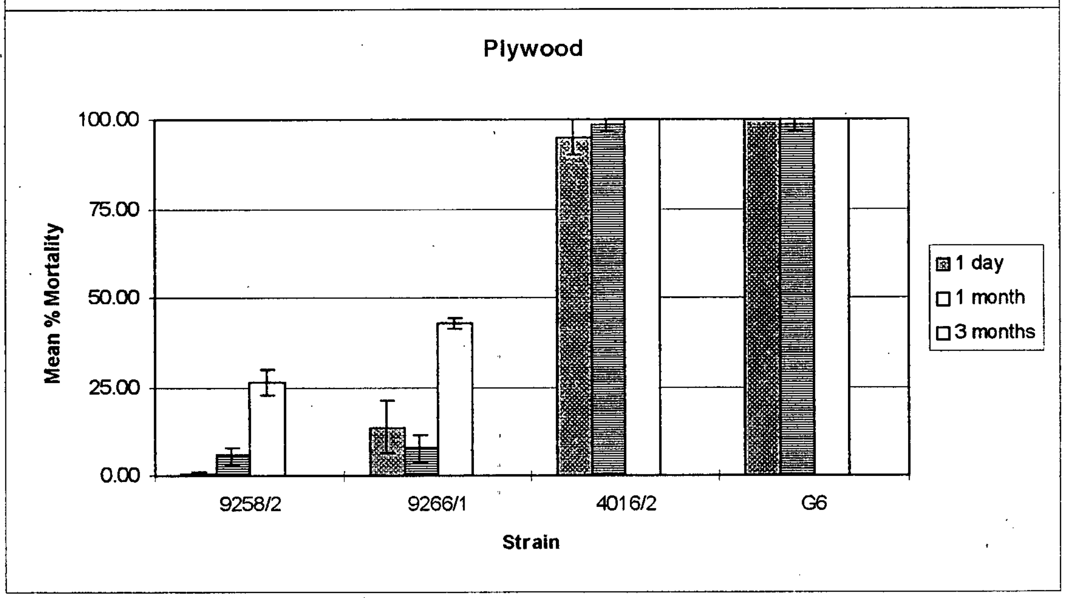
Pesticide 5 (Empire 20)

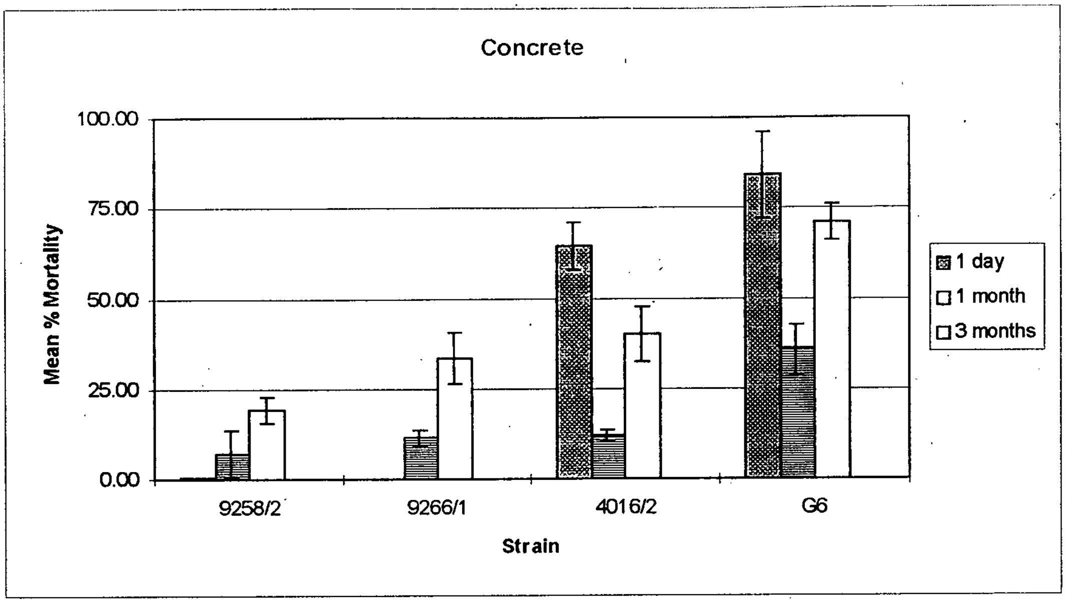



Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months

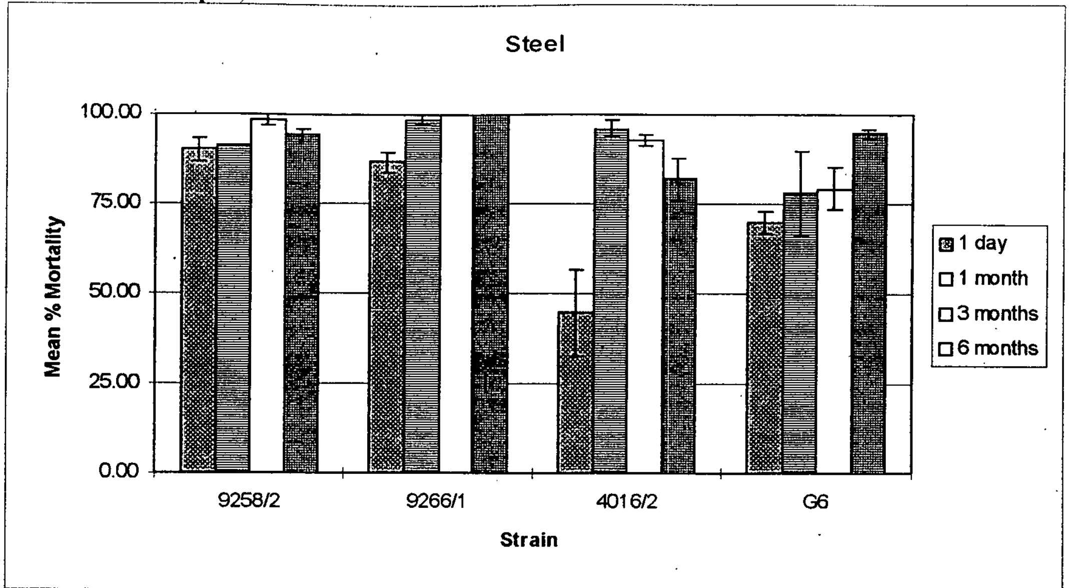
Pesticide 6 (Ficam W)

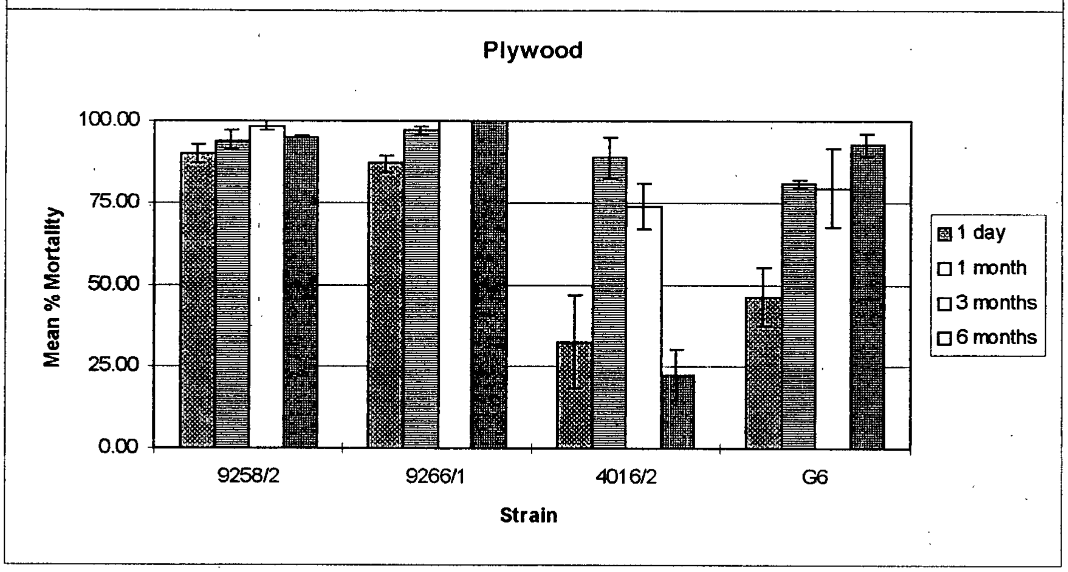


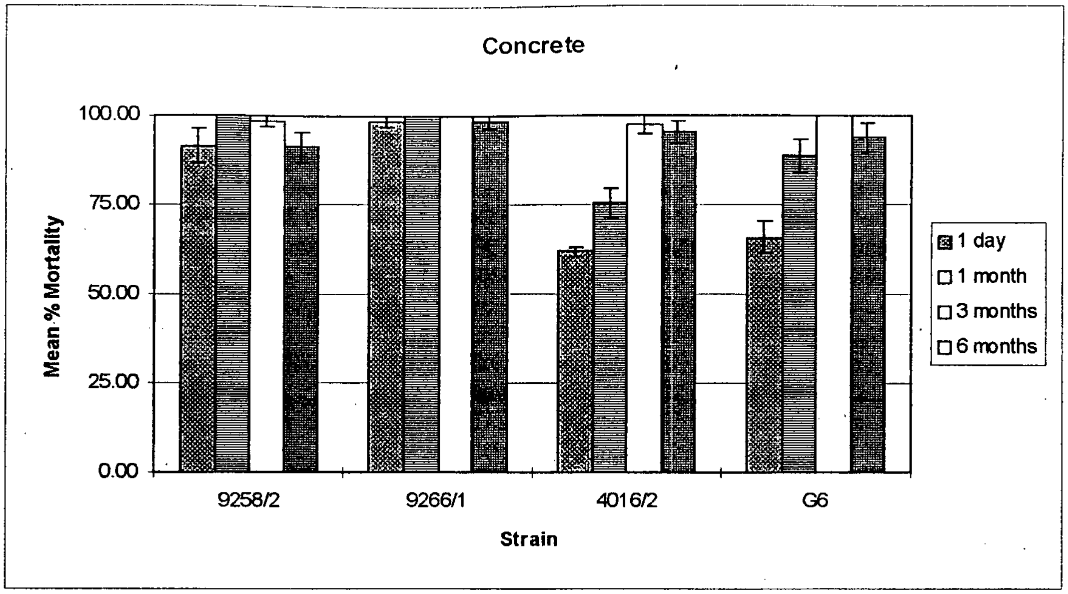



Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months

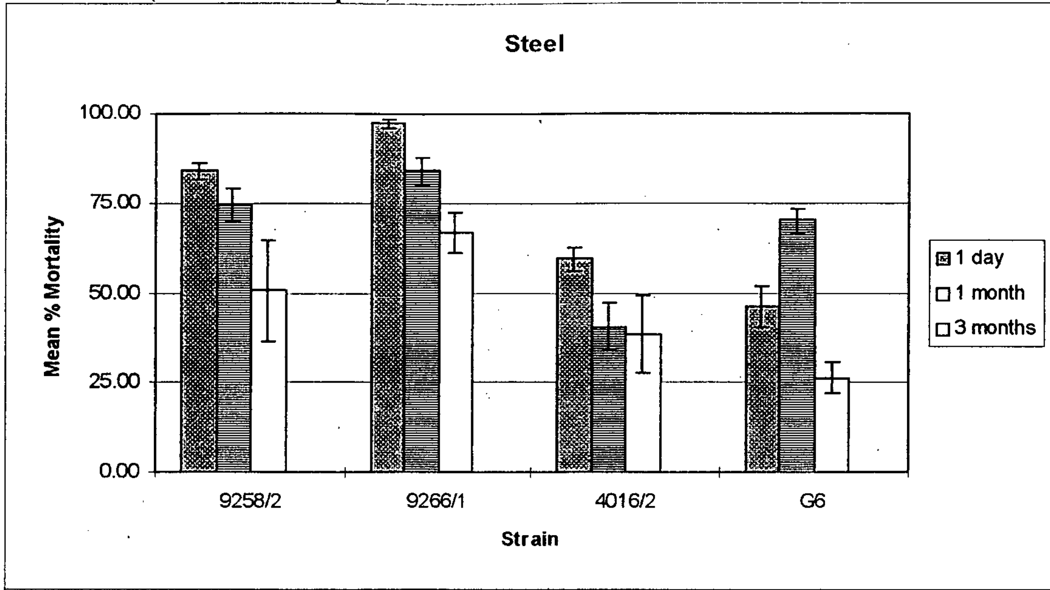
Pesticide 7 (Coopex)

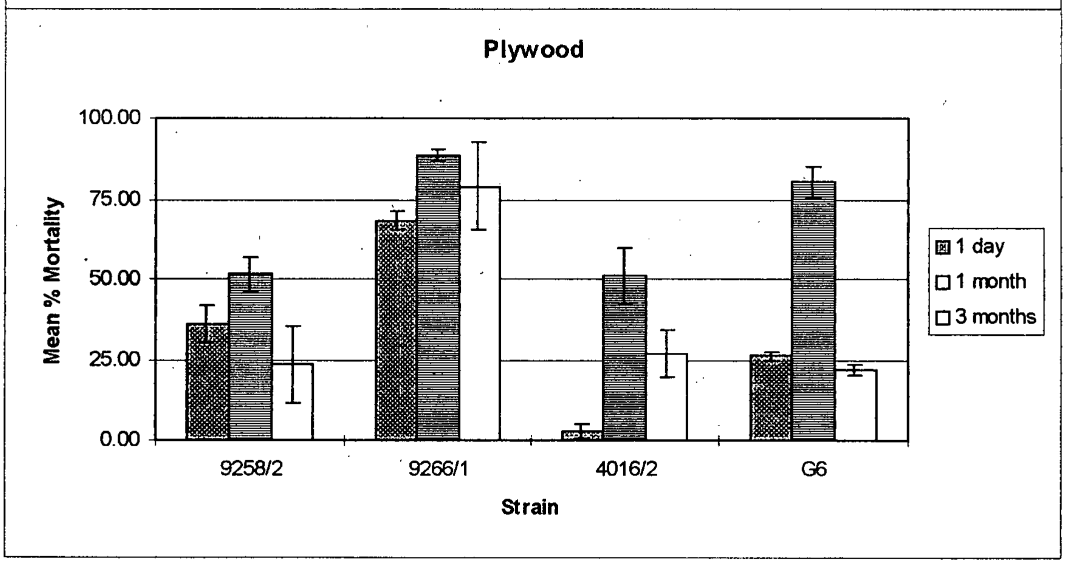


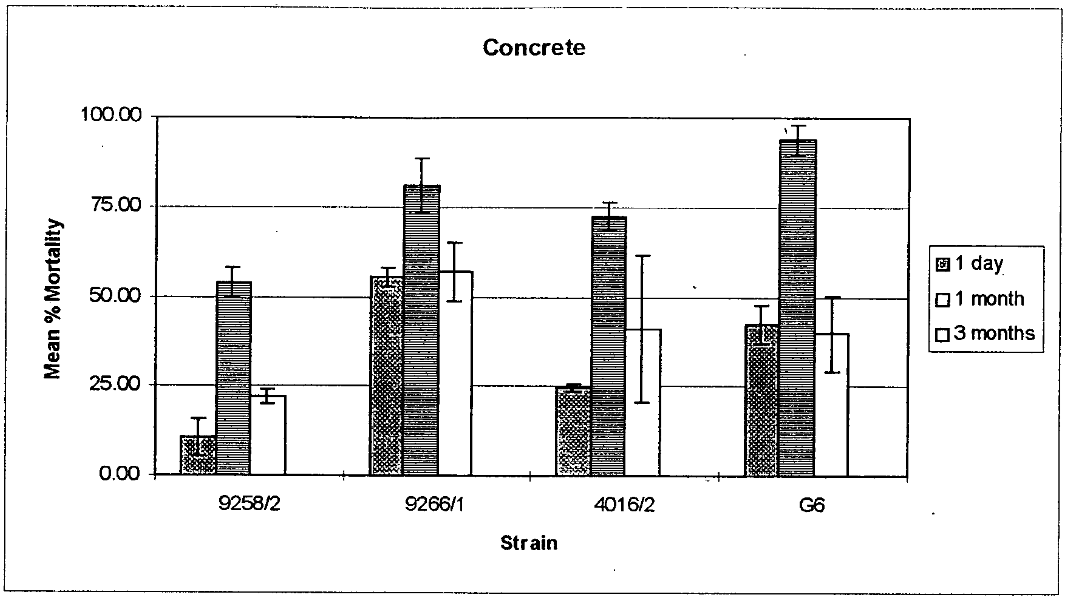



Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months

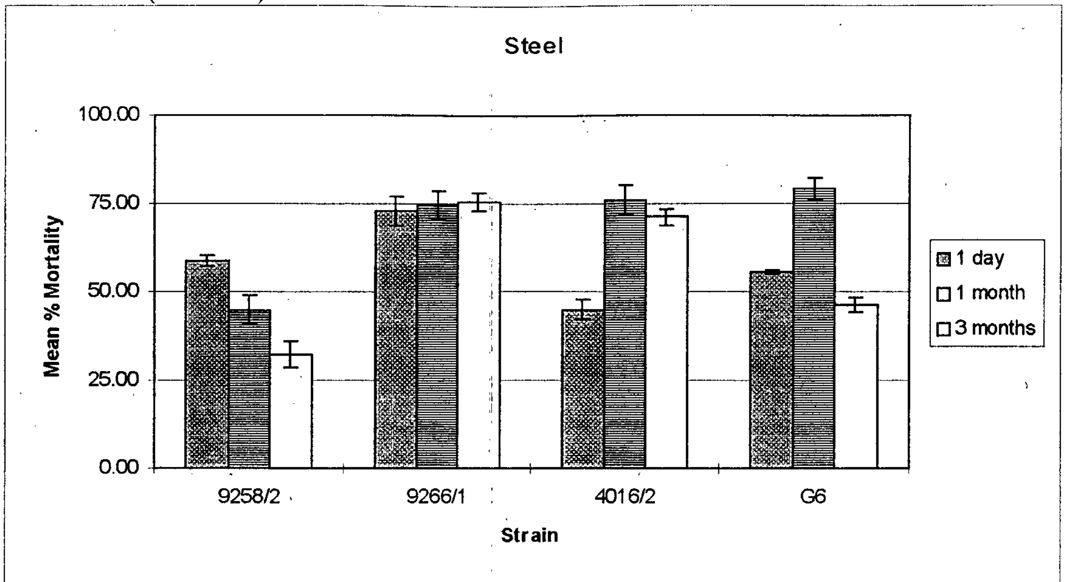
Pesticide 8 (Crackdown Rapide)

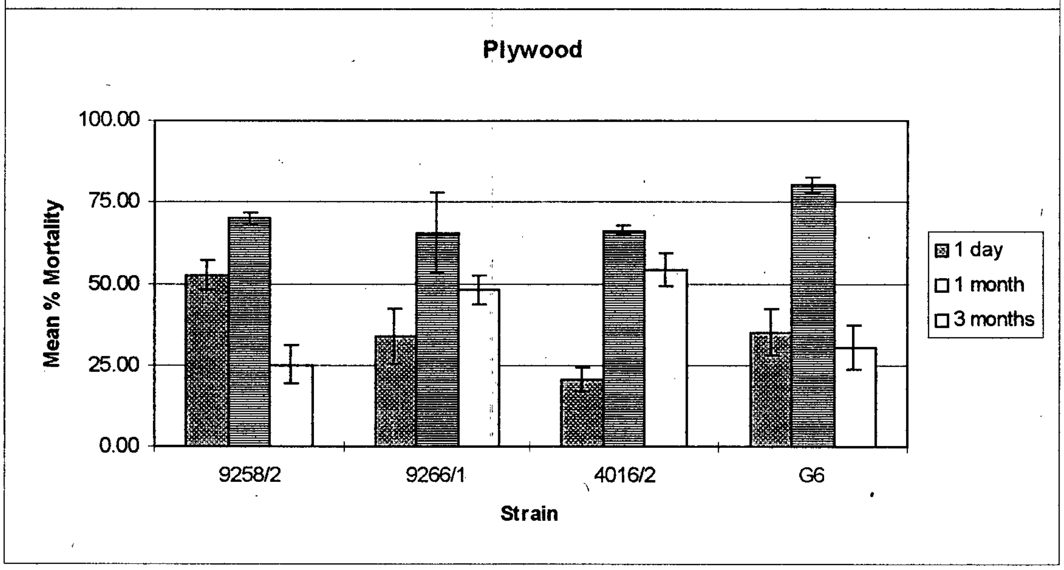


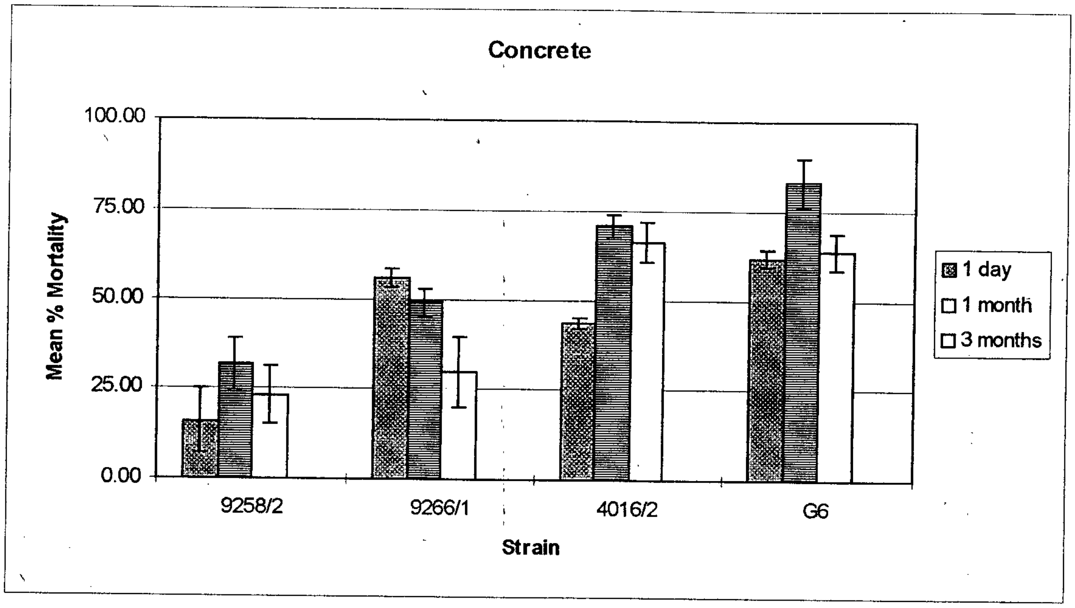



Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months

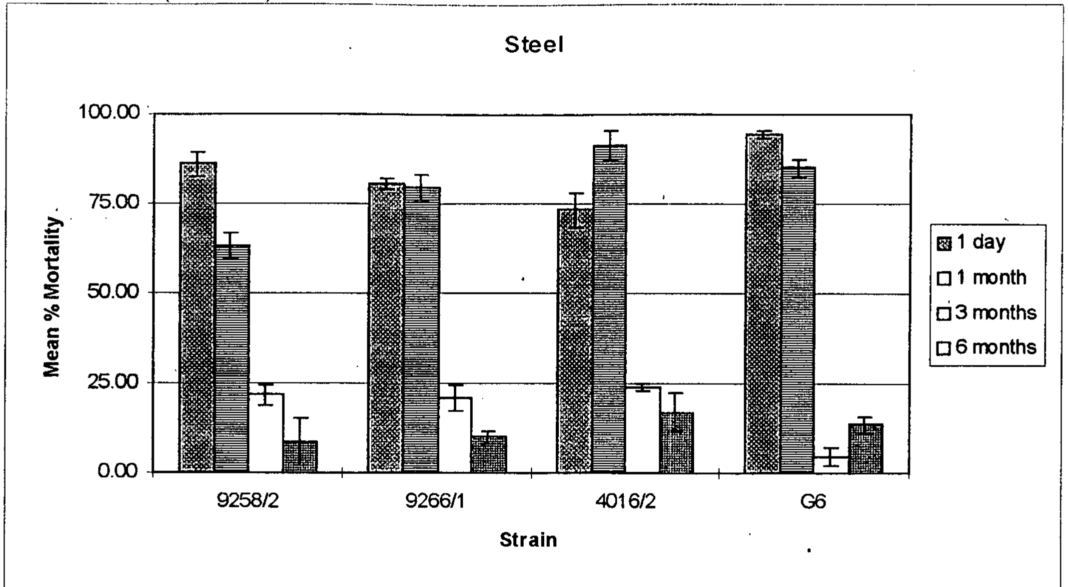
Pesticide 9 (Fendona)

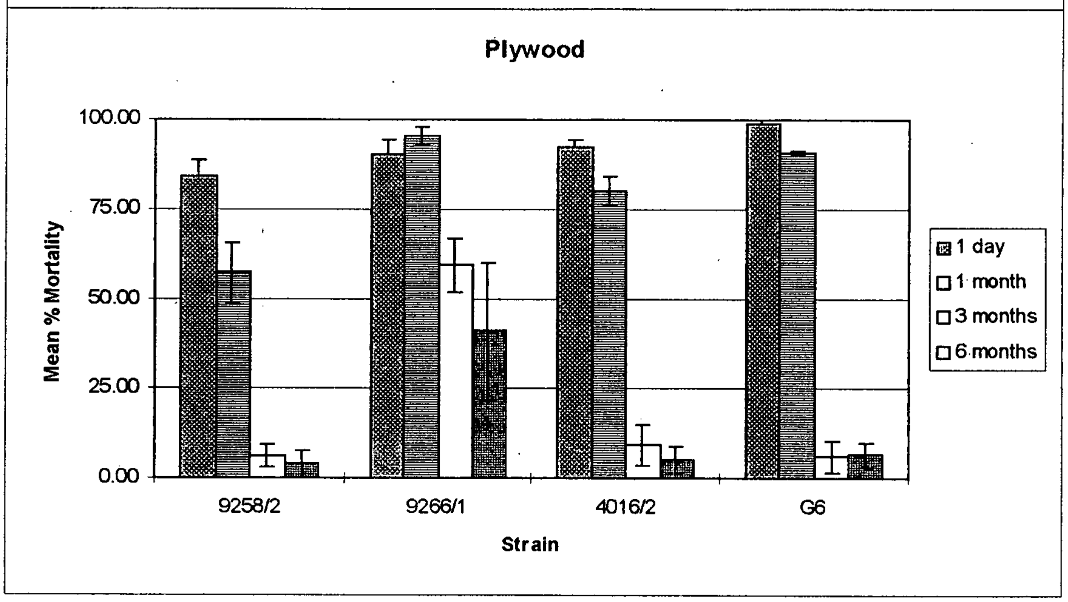


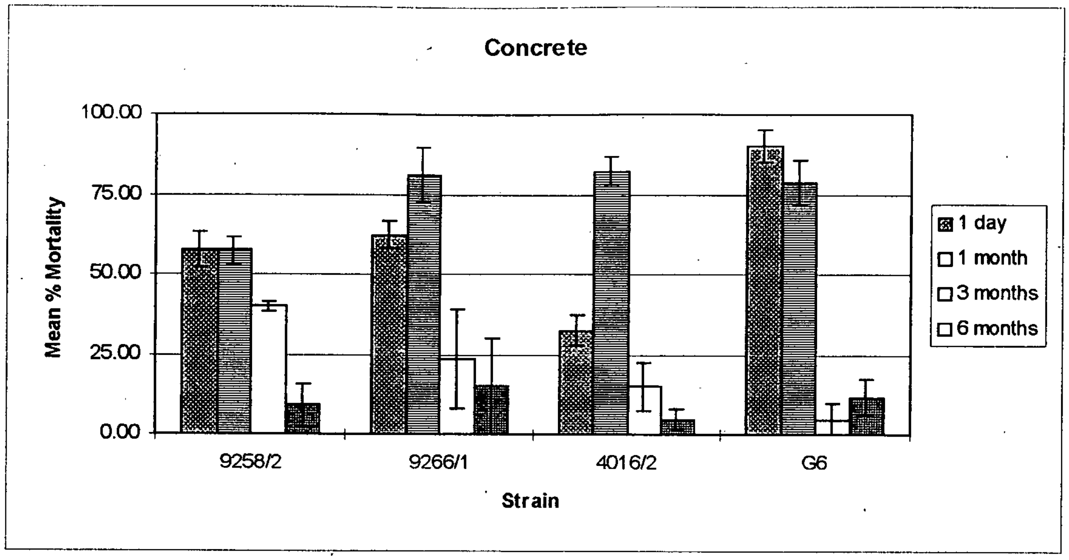



Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months

Pesticide 10 (Turbair)






Concrete
100.00
75.00
50.00
25.00
0.00
Mean % Mortality
9258/2
9266/1
4016/2
G6
Strain
1 day
1 month
3 months
6 months