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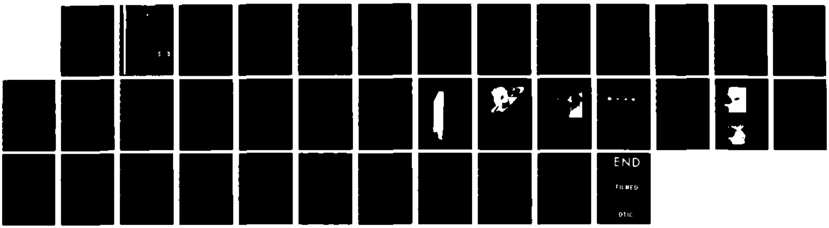

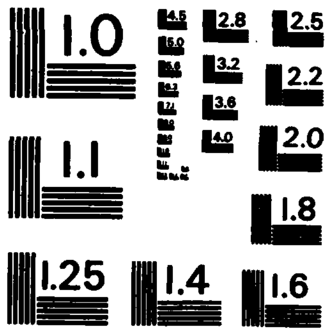

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DEPARTMENT OF DEFENCE

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MELBOURNE, VICTORIA

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Aircraft Materials Technical Memorandum 390

CHARACTERISTICS OF RAPID CURE MAGNETIC RUBBER INSPECTION FORMULATIONS

by

B.C. Bishop

Approved For Public Release.

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CHARACTERISTICS OF RAPID CURE MAGNETIC RUBBER INSPECTION FORMULATIONS

by

B.C. BISHOP

SUMMARY

The introduction of rapid-cure magnetic rubber inspection formulations has raised questions as to whether there may be some impairment of the sensitivity and reliability of the inspection technique relative to its performance with the well-established, slower curing formulation. This memorandum attempts to answer these questions.

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P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

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CONTENTS (CONT'D)

1. INTRODUCTION

1.1 Magnetic Rubber Inspection

Magnetic rubber inspection (MRI) is a form of magnetic particle inspection. In this particular form the magnetic particles are suspended in a liquid rubber curing at room temperature. The rubber, after the addition of a catalyst and a stablisizer, is poured into, or around, the area to be inspected, where it may be contained, if necessary, by a specially constructed reservoir. A magnetic field, complying with the principles of magnetic particle inspection, is then applied to the part for a period of approximately 2 to 4 minutes, after which the rubber solution continues to cure to the solid state. The flexible solid rubber cast is then removed from the part and the surface of the cast is examined in detail, in the relevant areas, using a low-power binocular microscope. Evidence of surface and near-surface defects in the material with which the rubber was in contact during the curing/magnetization period appears at the surface of the cast as corresponding concentrations of magnetic particles.

Over the last 10 years the magnetic rubber inspection method has proved very useful for the detection of very small (0.2mm surface length) fatigue cracks and other surface discontinuities (e.g. non-metallic inclusions) in magnetic materials. In many instances, it has been the only method whereby such defects could be detected non-destructively.

1.2 Recent Developments

A recent development in magnetic rubber inspection has been the introduction of a rubber solution of new formulation which cures much more quickly than the originally marketed material. The sole advantage in the use of the more rapid curing solution, apparently, is that the time to carry out an inspection may be much reduced. The new material is designated Type 502K KWIK CURE by the manufacturers. (The original, slower curing formulation, which is still available and still preferred for many applications, is designated simply Type 502). A further alternative new form, designated Type 502Y, has nominally the same characteristics as Type 502K, but has a base material which is bright yellow instead of the grey of the other formulations. For some applications it is thought that the greater contrast between the yellow base and the black magnetic particles provides a more positive indication of defects.

1.3 Purpose of Reported Investigation

This memorandum records and discusses observations made during test inspections whose aim was to obtain some assessment of the relative sensitivities and reliabilities of the MRI method using the above rubber formulations for the detection of fatigue cracks of very short surface length (e.g. 0.2mm).

2. PRACTICAL VARIABLES AND CHARACTERISTICS OF MAGNETIC RUBBER

2.1 Temperature, Curing Time and Pot Life

It has previously been reported (see reference) that temperature has a marked effect on the cure time of the original magnetic rubber formulation (Type 502) mixed with the standard, manufacturer-recommended, quantities of catalyst and stabilizer.

Temperature, through its effect on the curing process, may significantly influence the time available for migration of magnetic particles suspended within the solution. For effective inspection, the particles are required to move through the solution under the influence of the applied magnetic field to not less than some minimum degree (distance and concentration), before the solution starts to "gell" and movement becomes virtually impossible.

The time for which the rubber solution remains in a condition in which effective migration can occur is sometimes referred to as its "pot life". (The pot life is to be distinguished from the "shelf life", which is the period the rubber solution can be kept in storage, prior to catalyst/curing agent addition, before its curing performance becomes unacceptably variable).

If the pot life of a solution is short, the available migration time remaining after the liquid rubber solution, with catalyst added, is introduced into an inspection area and the magnetic field applied (and especially if some delay accidentally occurs) may be less than required for adequate migration to take place. As a result there will be, at best, a reduced clarity of the defect indication, and, at worst, a complete absence of any evidence of any defect.

2.2 Uncertainties with Respect to KWIK CURE

The KWIK CURE magnetic rubber solution is said by the manufacturer to have a specific cure time of 20 minutes and an associated pot life of 4-5 minutes, when mixed to the formula*

10 ml	rubber base solution
2 drops	catalyst
2 drops	stabilizer

(The foregoing times are to be compared with a cure time of 60 minutes and a pot life of 20 minutes quoted by the manufacturer for the original, Type 502 formulation, with comparable additions of catalyst and stabilizer, viz 10, 5, 2).

No information has been given by the manufacturer as to the temperature to which the above KWIK CURE times correspond. Therefore, as part of the present investigation, tests similar to those of the reference study have been conducted to ascertain the effect of temperature on the performance of the recently developed, rapidly curing magnetic rubber solutions.

3. EXPERIMENTAL PROCEDURES

3.1 Test Specimen and Inspection Arrangements

A test specimen typical of a component on which MRI would be carried out to detect fatigue cracks was prepared. The specimen, and the location of a laboratory-produced fatigue crack, are shown in Figure 1. The specimen, together with a field-inducing magnet, magnet pole pieces and a 'plasticine' dam arranged in the configuration used to produce each test cast in the investigation, is shown in Figure 2. For each cast a 20 ml quantity of rubber solution mixture was prepared, which provided sufficient material to fill the dam shown in Figure 2 and to leave in the mixing beaker a small amount of the solution to be used in determining the pot life and cure time of the specific mix.

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* This formula will be referred to throughout this memorandum as "10, 2, 2". Variations of the mixture will be expressed in the same abreviated form, e.g. "10, 1, 1".

3.2 Basic Comparison Standard (Cast)

For the first cast to produced from the test specimen, the original, well-tried Type 502 formulation was used, mixed in the standard proportions 10, 5, 2 and poured and cured at 20°C. The resulting cast and crack indication is shown in Fugure 3. This indication was used throughout the study as the reference standard for the comparative assessment of all casts made with the new magnetic rubber formulations.

3.3 Standard Routine for Preparation of Magnetic Rubber Mixtures

Each of the various 20 ml batches of new-formulation rubber used in the tests was prepared in accordance with a consistently repeated routine, precisely timed with a stop watch. In each instance the watch was started, the catalyst and stabilizer added (in that order), the mixture stirred for 30 seconds and then the liquid mixture poured into the previously prepared dam. The complete sequence, from the starting of the watch to completion of the pour took 60 to 70 seconds for each cast.

(In each instance the magnet and pole pieces had been placed in position prior to the mixing and pouring of the rubber solution. Positioning of the magnets prior to pouring the rubber is not usually recommended. If the liquid rubber mix accidently contacts the magnetic poles during pouring, a condition known as "drag-out" may occur, with a heavy concentration of particles occurring at the magnets poles and an associated depletion of the particle content in the inspection area, which seriously reduces the efficiency of the inspection. However, for the purposes of this study, it was considered that the extra time required to position the magnets after pouring the rubber would be a greater potential source of misleading variations in the experimental results than the rather unlikely events of unnoticed liquid rubber spillage and particle "drag-out")

3.4 Pot Life (Migration Time) Assessment

The pot life, or time available for effective migration, and the time required for such migration are difficult to determine accurately. Measurement of pot life was attempted firstly by placing drops of the curing liquid rubber mixture on a glass microscope slide held in a constant and uniform strong magnetic field (1000 gauss). The sample drops were taken from the solution at 30-second intervals until useful viscosity started to be lost, as indicated by the "stringing" of the solution (see below) as the sample drops were removed. After the drops on the slide had cured they were examined microscopically (Figure 4) to compare the distribution and orientation of the magnetic particles in each sample and, in this way, to estimate the time at which their migration was significantly affected by the increasing viscosity of the curing solution.

As may be seen from Figure 4, for the particular solution represented there, effective migration appears to have ceased, as indicated by the subsequent uniform particle distribution and orientation, at about 180 seconds.

It was thought that a more direct indication of the effect of the curing process on the viscosity of the solution, and hence on particle migration over this period of time, may have been obtained by observing, at the 30-second sampling intervals, the changing viscosity of the solution at the end of a wooden sampling rod used to remove the sampling drops from the bulk solution. The occurrence of the "stringing" effect in this operation after a certain period of time would appear to be related to the changing viscosity of the solution and thus might be expected to give a usefully accurate indication of pot life.

3.5 Cure Time Determination

The curing process was taken to be complete as soon as the remnant of the rubber solution in the beaker could be removed as a solid plug. The cure time determined in this way would be shorter than that allowed in field inspections, since the surface of the plug was still quite sticky when the plug could just be removed from the beaker without damage. This process provided a readily observed reference condition for the comparing of cure times.

3.6 Stabilization of Temperature of Test Specimen and Associated Equipment and Materials

The test specimen, together with all of the test equipment and the rubber solution and addatives, was allowed to stand in a temperature-controlled room at each of the chosen test temperatures (see Section 3.7 below) for at least 4 hours before the commencement of each test cast.

In this way accuracy of determination of variation in performance of the inspection technique with temperature, for each formulation and mixture, was assured. (This proecedure was considered to be particularly important following preliminary tests which showed that the practice of ARL (and others) of storing the magnetic rubber ingredients under refrigeration (at approximately 4°C) and then mixing them, for use, at various times after removal from cold storage resulted in a significant variation in cure time for the KWIK CURE formulation. Presumably the pot life/migration time would be similarly affected).

3.7 Range of Magnetic Rubber Formulations, Mixtures and Test Temperatures Used

The procedures outlined in the preceding paragraphs were used to produce at least three casts from each of the magnetic rubber formulations and mixtures, at each of the ambient temperatures, listed below -

Magnetic Rubber Formulation (Type)	Solution Mixture (Refer Section 2.2)	Ambient Temperature
502 K	10, 2, 2	15, 20, 28°C
502 Y	10, 2, 2	15, 20, 28°C
502 K	10, 1, 1	15, 20, 28°C
502 Y	10, 1, 1	15, 20, 28°C

Each of the cured casts was subsequently examined microscopically and the quality of each of the crack indications compared with that of the original, Type 502, control cast (refer Section 3.2) and with each of the other test casts.

4. EXPERIMENTAL RESULTS

4.1 Variation in Pot Life and Cure Time

The results of the tests for pot life and cure time are summarized in Figure 5. Each type of rubber formulation, each solution mixture and each test temperature is represented in the figure by a vertical column. The lower, wider section of the column represents the pot life and the narrower upper section represents the additional time required for the completion of the curing process after the expiration of the pot life. The hatched section of the columns represent the range of times observed for pot life and cure time over a number (3 to 6) of tests.

4.2 Particle Migration Time

The microscope examination of magnetic rubber mixtures curing at various temperatures indicated that, in all instances, particle migration ceased 30-60 seconds before the viscosity of the solution had decreased to the level at which "stringing" began when the samples were being taken. Intervals within this time-range comprise a significant proportion of the quoted standard pot life of 4-5 minutes for the KWIK CURE formulation. Evidently particle migration begins to decrease very significantly well before there are readily obvious signs of a significant increase in solution viscosity.

Supplementary experiments following on from the above observations, showed that a 10-second delay in the application of the magnetic field, after the pouring of the standard 10, 2, 2 KWIK CURE solution, had a marked effect on the crack detection performance of the technique. Even with this seemingly relatively short delay, the crack indication was only just discernible (Figure 6).

4.3 Clarity of Crack Indications Under Normal Conditions

All of the casts produced in the tests, where there was no delay in the application of the magnetic field (nor in pouring), resulted in satisfactory indications of the crack in the standard test specimen.

Opinions varied among competent laboratory staff as to which of the three rubber formulations (502, 502K, 502Y) produced the clearest indication of the test crack. The yellow-base material (502Y) provided a more contrasting background for the observation of the black magnetic particles aggregated in the cast at the position of the crack, which obviously emphasised the crack indication. However, in the same way, the general distribution of fine black particles over the remainder of the surface of the cast was more intrusive in appearance and, it was found in some instances, apt to introduce some unwarranted concern that there may have been some other incipient cracking in the specimen. But, in general, the degree of "seeability" of the crack indications was similar for both the grey and yellow formulations.

5. DISCUSSION

5.1 Comparison of Performance of Grey (502 K) and Yellow (502 Y) KWIK CURE Formulations

The pot life and cure time decreased with increase in ambient temperature for both rapid-cure formulations (Figures 5 and 7). However, although formulation 502K was nominally identical to 502Y , the grey 502K material did show, in the present experiments, a generally shorter pot life than the yellow 502Y.

Both containers of rubber solution used were marked with the same manufacturing lot number. It may be concluded therefore, at this stage, that notwithstanding the manufacturer's claim that the performances of the 502K and Y formulations is the same, the yellow colouring agent in the 502Y KWIK CURE formulation may have had an inhibiting effect on the curing agent or process.

5.2 Comparison of Observed and Quoted Values of Pot Life and Cure Time

The pot life of 4 minutes quoted by the manufacturer for the KWIK CURE formulations was achieved or exceeded only when the ambient temperature was 20°C or less, and then principally by the 502Y formulation in the 10, 1, 1 mixture (Figures 5 and 7). The pot life was only 2 minutes for some of the test conditions, which corresponded to what might be encountered in practice. Indeed the cure time, also, in some instances was barely equal to or not very much more than 4 minutes. It was always well below the quoted 20 minutes when the standard (10, 2, 2), recommended proportion of catalyst and stabilizer were used.

On the basis of the present observations, it is to be advised that the effective pot life of the new, quicker curing formulations be determined by a prospective user, using a standard cracked reference specimen, for the exact temperature conditions in which the material is to be applied. This must be done if it is to be ensured, by adjustment of the conditions and/or the mixing proportions, that adequate time will be available for particle migration after pouring of the solution and application of the magnetic field.

5.3 Apparent Importance of Accuracy of Measurement of Quantities of Additives

The cross-hatched sections of the columns in Figure 5 indicate the variability in pot life and cure time over the range of test temperatures for the two mixing formulas. The variability is markedly greater for the 10, 1, 1 mixture, especially with the Y formulation.

It is considered most likely that the variation for a given mixture at a given temperature may be, in significant part, attributable to variations (inaccuracies) in the measuring out of the catalyst and stabilizer quantities. The 10, 1, 1 mixture, with the reduced proportion of catalyst (and the relative increase in the proportion of stabilizer), would be the more sensitive of the two mixtures tested to such inaccuracies and it would be expected to display, as it did, the greater variability in pot life and cure time.

(The dispensing performance of the catalyst and stabilizer droppers supplied by the manufacturer with the new magnetic rubber formulations was judged, early in the tests, to be less satisfactory than that of the seemingly more precisely controllable eye-dropper type of dispensers originally provided by the manufacturer, when magnetic rubber was first introduced. In supplementary tests using the eye-dropper dispenser there was much less variation in cure time).

5.4 Maximum Achievable Pot Life and Cure Time at Practical Temperatures

Notwithstanding the variability of the observed pot life and cure time discussed in the previous section, a number of pertinent and valid conclusions may be drawn from the mean values of the lives and times measured in the described experiments.

Figures 8 and 9 show the effect of a change in the nominal proportion of catalyst on the nominal (mean) pot life and cure time respectively, for the 502K and 502Y formulations at constant temperature. At the lower test temperature (15°C), changes in the proportion of catalyst in both formulations had no effect on the mean value of pot life. Likewise, at the higher test temperature of 28°C, changes in the catalyst addition had little or no effect. At the middle test temperature (20°C), however, there was a significant increase in pot life (mean value) with decrease in catalyst content for both formulations. (See Figure 8).

For the cure time, there was a marked and consistent increase in the mean value with decrease in the proportion of catalyst at each of the test temperatures for the 502Y formulation (see Figure 9).

However, for the 502K formulation the change in cure time was inconsistent. It is also readily to be seen from Figure 9 that the decrease in the mean value of cure time with each increase in temperature is substantially restored for the Y formulation by the decrease in the quantity of catalyst, but this did not consistently happen with the K formulation.

The maximum for the mean value of pot life for the 502Y formulation was about 6 minutes, at 15°C, for both the 10, 2, 2 and 10, 1, 1 mixtures. For the 502K formulation the maximum was marginally less than 4 minutes, at 15°C for the 10, 2, 2 mixture and at 15° and 20°C for the 10, 1, 1 mixture.

The maximum cure time, for both formulations, was of the order of 11-13 minutes at 15 and 20°C for 502Y and at 15°C for 502K, for the 10, 2, 2 mixture. The mean value increased to about 20 minutes for the 502Y formulation, at 15°C, for the 10, 1, 1 mixture. The mean cure time for the 502K formulation, at 15°C, for the 10, 1, 1 mixture was only 9 minutes.

The results of the present tests indicate that, at temperatures most likely to be prevailing at places (localities) where the MRI technique may be applied, for example 20° - 25°C, the pot life for 502K may not be very much more than 2 minutes, as noted earlier, even with reduced catalyst content. For 502Y it may be as low as about 3 minutes. In summary, reduction of catalyst content only marginally improves the pot life of 502Y. There can be even less confidence, on the basis of present tests, that reducing the amount of catalyst added to the 502K formulation will produce even a marginal increase in pot life at likely practical temperatures.

It is also to be kept in mind that, for not fully identified reasons, there may be significant variation in pot life and cure time below the recorded mean values. When such variation occurs, there will be a further limitation of opportunity for particle migration and, thus, reduced "marking" of a defect with the new quick curing formulation.

5.5 Problem of Accurate Determination of Particle Migration Time

Pot life, as determined by the "stringing" test, does not appear to correspond exactly to the effective particle migration time, as was originally assumed (Section 2). Determination of the time when, precisely, effective migration of particles has ceased, is difficult.

The apparent cessation of particle migration 30-60 seconds before the expiration of pot life indicates that the time available for pouring the magnetic rubber mixture into place and applying the magnetic field may be very short indeed, if the ambient temperature is above 20°C. The effect of a delay (say 10 seconds) in the combined operation of doing these things may be critical. In these circumstances the probability of an indistinct crack indication, and even no crack indication at all, of an existing small crack may be unacceptably high.

5.6 Material Batch Differences as Possible Source of Variation in Performance

It is important to note that the results of the present study were derived from only one production batch of the two forms of quick curing rubber. From previous experience with the original magnetic rubber formulation and variability of performance (cure time especially) it is expected that there could be appreciable variations in the performance characteristics of other batches of the KWIK CURE material. On this account, also, relevant precautions, viz frequent use of a standard reference specimen, with a known crack, at a specified temperature and with a specified solution mix, should be observed.

6. CONCLUSIONS

The observations and considerations made in the present investigation of the performance of the new quick curing magnetic rubber formulations Type 502K and 502Y lead to the following conclusions regarding there capabilities and effective use -

(1) Their crack detection sensitivity is similar to that of the original (standard, Type 502) magnetic rubber formulation.

(2) The achievement and maintenance of this sensitivity, particularly with respect to the presence of very small cracks, depends upon appropriate and adequate control of the conditions of application of the new formulations.

(3) The need for appropriate and adequate control of the conditions of application of the new quick-curing formulations becomes more critical as the ambient temperature increases.

(4) Establishment of a uniform, and known, temperature for all the apparatus and materials used in the inspection, including of course the component(s) to be inspected, is an essential requirement.

(5) Accurate measurement of the quantity of additives, and their thorough mixing through the rubber solution, is essential if variation in pot life and curing time, and thus in overall performance, is to be minimized.

(6) Significant variation in performance is thought to be a possibility even when the dispensing of the additives is accurate and the mixing thorough. This variation may be expected as a result of batch variation in the supplied magnetic rubber solution (and possibly the catalyst and stabilizer). Therefore control tests should be undertaken (sample casts made) using a standard cracked reference specimen to check on the quality of the inspection procedure, in all instances. Such casts should be made at the beginning of an inspection activity and at appropriately frequent intervals thereafter, and at the exact temperature at which the rubber is to be (or is being) applied in the primary inspection process. (Indirectly, such casts check on the accuracy of the additive dispensing, the thoroughness of the mixing, the adequacy of the pot life and migration time and on the curing time).

For very critical inspections, sample casts may need to be made for every batch of rubber solution mixed. (Because of the difficulty of making multiple casts, given the short pot life of the quick-curing formulations, separate, but nominally identical, mixtures may have to be prepared for every cast made in the inspection process proper. The making and examination of control casts of course adds to the total inspection time and tends to negate the basic advantage of the quicker curing).

(7) Precise timing of the mixing, pouring and magnetization of the magnetic rubber solution should be carried out in every application.

(8) Timing should start with the addition of the first drops of catalyst to the rubber solution. Although mixing must be sufficiently long to ensure complete blending of the additives, it must not be so long as to excessively reduce the time available for the pouring and magnetization of the solution and the subsequent required particle migration.

(9) The field-inducing magnets should be positioned before the mixing and pouring of the rubber solution, if possible, i.e. where the presence of the magnets does not prevent access for pouring or make access so difficult that there is a high likelihood of spillage of some of the solution during pouring with consequent particle "drag-out". With

further reference to the possibility of solution spillage and resulting particle "drag-out" - an event which in general is most undesirable - some compromise may have to be made in the use of the quicker curing formulations. Where such an event occurs its effect can be assessed upon examination of the solidified cast and, if necessary, another cast made. Although, of course, this would negate the advantage of the quicker curing rubber, considerations regarding the quickness of the inspection must be secondary to those relating to the achievement of a valid inspection result with respect to the certain determination of whether or not a crack is present.

7. CONCLUDING REMARKS

Magnetic rubber, since its introduction as a practical inspection technique, has proved to be a particularly sensitive means for detecting small cracks and giving an accurate measure of their surface length, in circumstances which have made the application of other methods of inspection very difficult and unreliable.

The new, quicker curing ("KWIK CURE") types of rubber offer obvious advantages where a large number of inspections must be made, or where "down time" of a component (or system) must be kept to a minimum.

Magnetic rubber inspection, whether using KWIK CURE or regular rubber formulations may sometimes appear to be a simple technique which can be sensitively and reliably applied by operators with relatively little special training. The present investigation has shown, however, that a number of factors may influence the inspection performance and that successful inspection is likely to be achieved only where there is close and perceptive control of the effective variables. There is, therefore, a need for informed preparation of a detailed specification of the technique for each application, with full reference to materials and equipment to be used and the procedure to be followed. There is need also for careful training and instruction of inspectors who are to apply the technique. There must be developed in the mind of the inspectors an awareness and basic understanding, of the effects

(i) of variations in temperature,

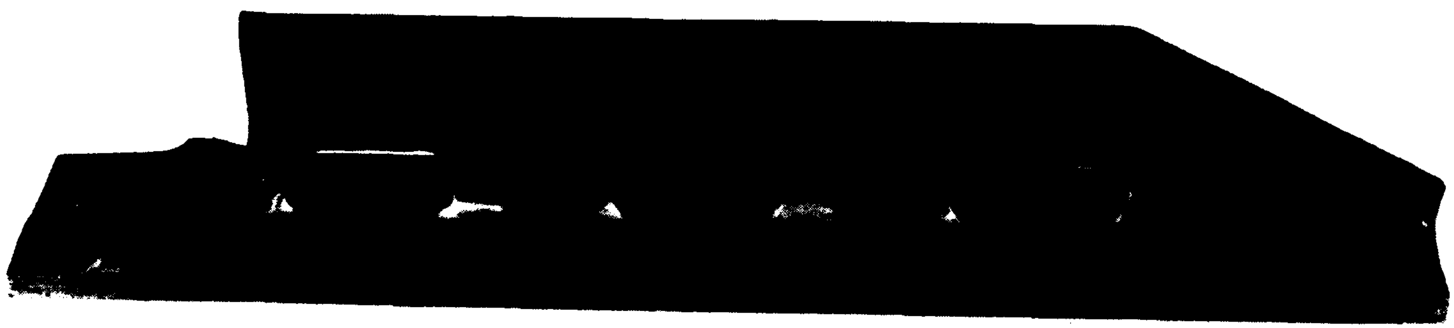
(ii) of small inaccuracies in the quantities of additives used, and

(iii) of delays in pouring the solution and in applying the magnetic field.

Such training, and understanding, and an all-pervading concern for quality of performance, are essential if the inspectors are to achieve the high levels of defect detection and measurement which the technique is capable of, and which are imperitive for the confident assessment of the integrity of critical structural and mechanical components. Otherwise, cracks may eventually be missed.

REFERENCE

1. Wilson, L. - The influence of Catalyst Concentration and Temperature on the Cure Time of Magnetic Rubber, ARL Materials, Note 117, July 1977



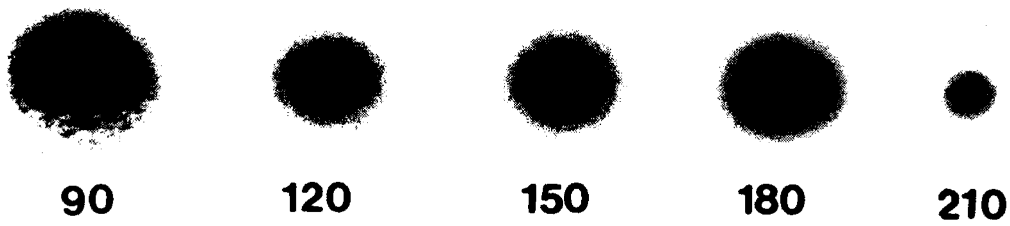
Scale: 5/8 (approx)

Fig.1 Test specimen representative of an actual component, showing location (arrowed) of laboratory - produced fatigue crack.

Fig. 2 Arrangement of magnet and pole pieces on test specimen, with rubber solution about to be poured into plasticene dam. (A similar dam is present on the other side of the specimen, between the pole pieces).

Magnification: 9

Fig. 3 Reference standard cast and crack indication, arrowed. (crack length is 1.7 mm)



Magnification: 5 (approx)

Fig. 4 Sample drops of given rubber taken from solution at 30 - second intervals (starting at 90 seconds after addition of catalyst) and allowed to cure on a glass microscope-slide in a constant and uniform magnetic field. Migration was from the bottom to top of drop, with greatest effect in first sample drop. Virtually no migration was evident after 180 seconds. Pot life in this instance was taken to be 210 seconds (3.5 minutes).

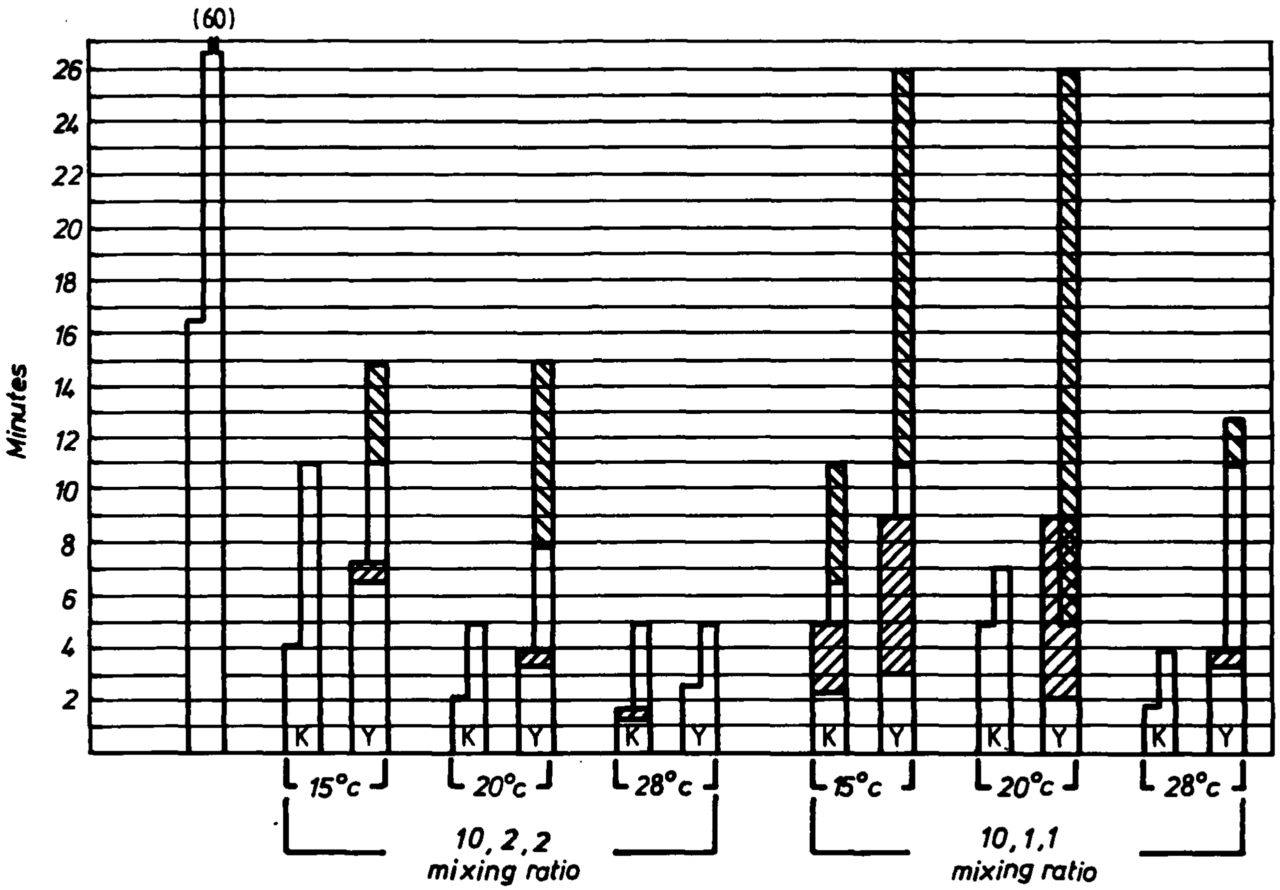
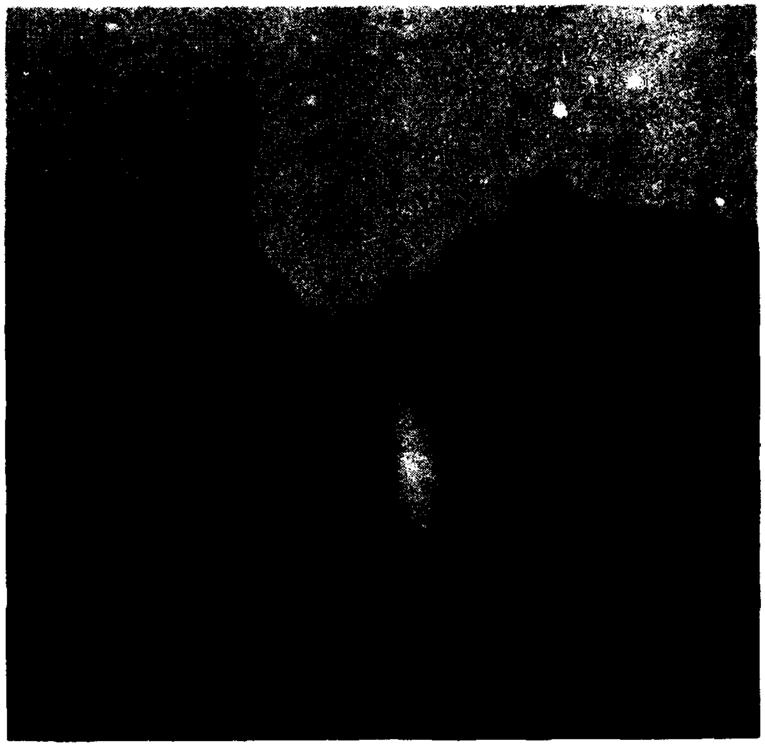


Fig. 5 Summary plot of test results.
(Broad columns represent pot life, narrow columns (extensions) represent cure time. K = grey (502K) formulation, Y = yellow (502Y) formulation. Further description of presentation is given in Section 4.1)

Barely discernable crack indication on rubber cast with 10-second delay in application of the magnetic field.

Magnification: 7



Clear indication of same crack on rubber cast when there was no delay in the application of the magnetic field after pouring of the rubber.

Magnification: 7

Fig. 6 Effect of delay in application of magnetic field, and corresponding reduction in time available for particle migration under the influence of the applied field. 10, 2, 2 mixed ratio used in each case.

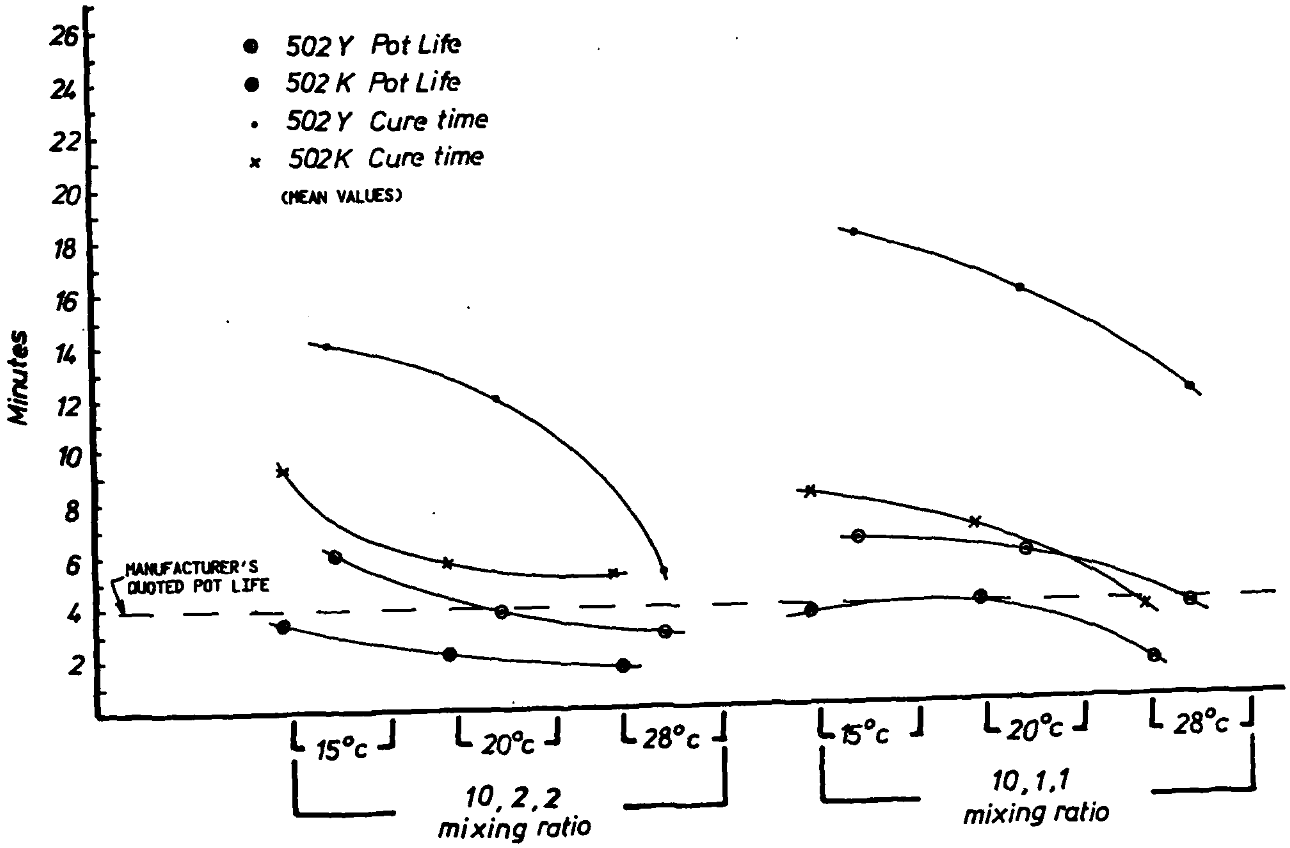


Fig. 7 Decrease in pot life and cure time for KWIK CURE formulations type 502K and 502Y with increase in ambient temperature, for two mixing ratios.

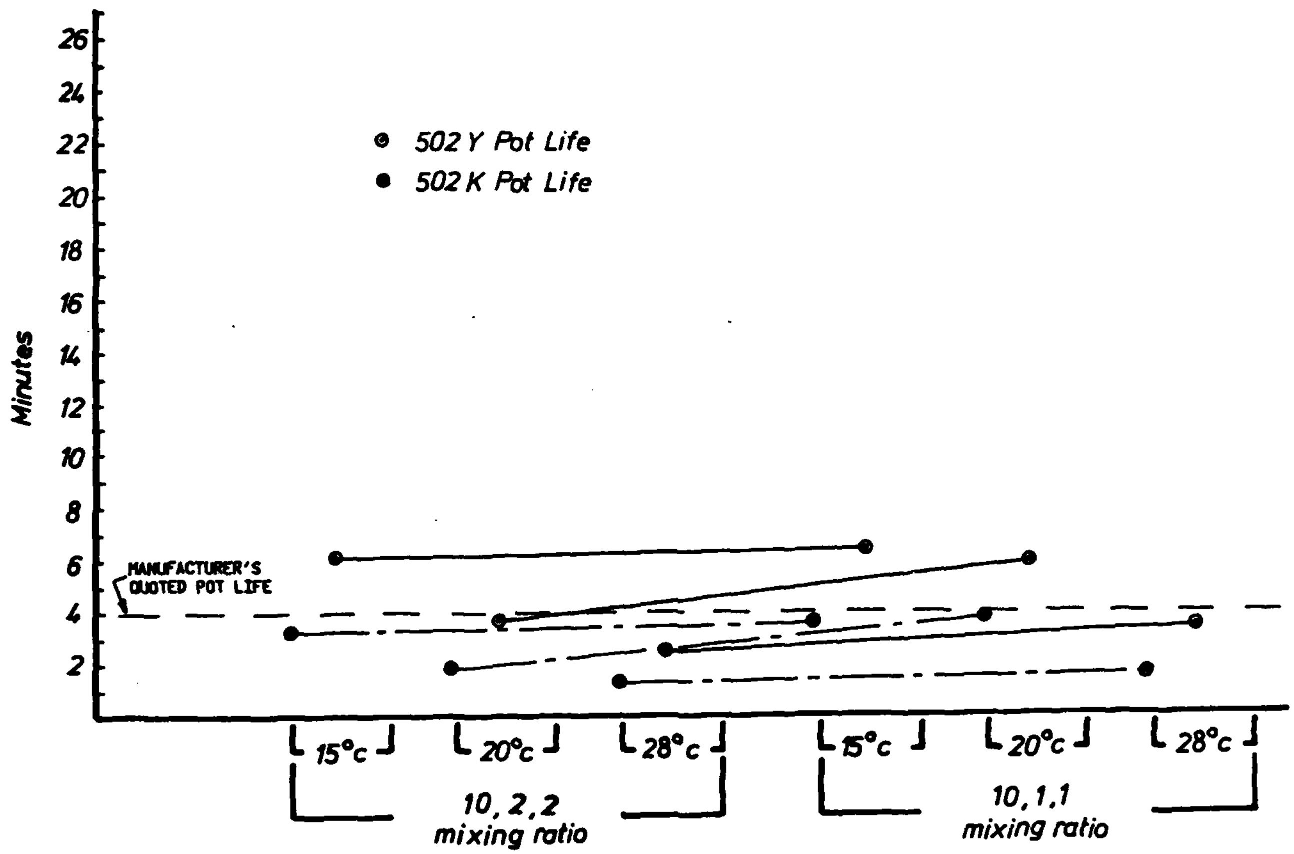


Fig. 8 Change in pot life for KWIK CURE formulations 502K and 502Y with change in mixing ratio, at constant temperature.

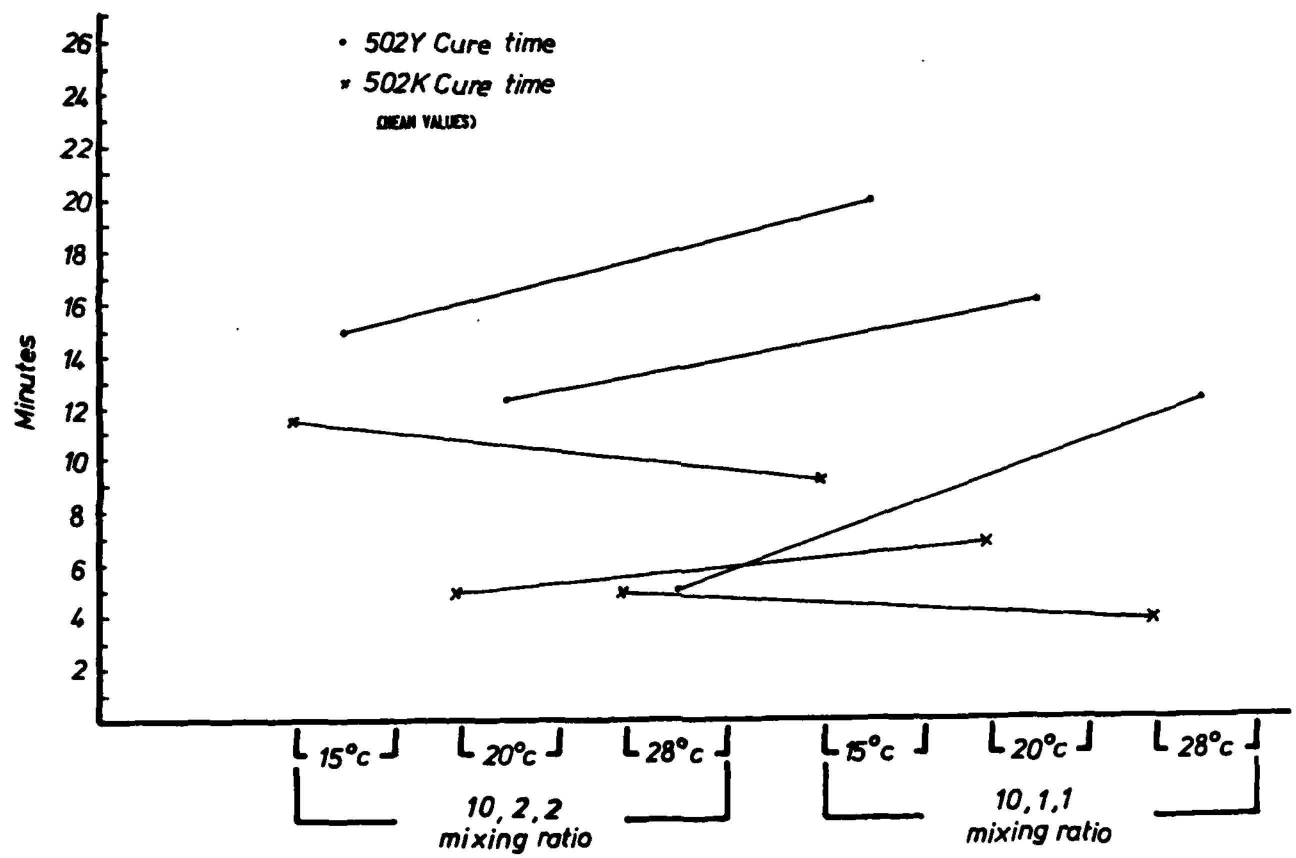


Fig. 9 Change in cure time for KWIK CURE formulations 502K and 502Y with change in mixing ratio, at constant temperature.

ADDENDUM

1. Since completion of this Technical Memorandum a paper titled "Development and Applications of Fast-Sensitive Magnetic Rubber Inspection Formulations" by H.J. Weltman, W.T. Kaarlela, J.D. Reynolds and J.E. Halkias has been published in the July 1984 issue of the Journal "Materials Evaluation". All of the Authors are staff members of the General Dynamics (GD) Corporation, the original developers of the Magnetic Rubber Inspection Technique.

2. The essential conclusion of the paper is that at "Room Temperature" the fast-curing grey magnetic rubber formulation (presumably 502K) has a pot life of between 4 and 9 minutes and corresponding cure times of between 10 and 20 minutes, depending on the quantity of catalyst added. Also it is implied in the report that by further adjustment of catalyst quantities and/or the temperature of application of the grey formulation, the cure time range may be extended to 5 minutes minimum to 30 minutes maximum. For the fast-curing yellow formulation (presumably 502Y) the limits of the cure range are reported to be 10 to 45 minutes.

3. The actual temperature taken as "Room Temperature' by the GD workers is not given in the paper.

4. The pot lives and cure times reported by the GD authors, together with those quoted by the manufacturers and those observed by ARL and reported in the present Technical Memorandum, are given in summary form in the attached table. Briefly, the ARL experience has been that although with catalyst additions corresponding to those used by the GD authors a pot life of 9 minutes could be achieved, this was the case only with the yellow (502Y) formulation and even then not consistently. For this formulation the pot life was frequently as low as 3 minutes, at 15°C (and 2 minutes at 20°C).

5. For the grey formulation, with the same catalyst additions, the observed pot life range at the same temperatures was 2.5 to 5.0 minutes (see table). A pot life of 9 minutes was never approached.

6. Similarly, under the conditions for which the GD authors recorded a cure time of 20 minutes for the grey formulation, cure times for the same formulation (502K) of 6.5 to 11.0 minutes were observed by ARL, at presumably similar temperatures.

7. In considering possible variations in pot lives and cure times it is of interest also to refer to the information given by the manufacturers with the commercially procured magnetic rubber supplies. According to this information a 20 minute cure time for the grey (502K) formulation is to be achieved with a different catalyst addition to that recorded in the GD authors' paper. And

.../ whereas with

whereas with a 20 minute cure time the GD authors recorded a 9 minute pot life the manufacturers report one of only 4 minutes. (For the same catalyst addition as that of the manufacturer ARL observed a pot life, for the grey formulation, as low as 2 minutes, at a comparable temperature of application).

8. The foregoing inconsistencies in observed/reported pot lives and cure times for the fast curing magnetic rubber formulations give support to the view that considerable care should be taken in their use. Action should be taken by the inspection technician to ensure that the formulation being used, together with the catalyst proportions chosen, provides adequate pot life, i.e. a life sufficiently long to allow detectable magnetic particle migration and aggregation to occur when a defect is present. For example, because of the possibilities of batch variation in formulation characteristics, pot life should be determined for each container of magnetic rubber used and upon each usage from the given container when there has been a significant storage time between usage.

Attachment: Table - Illustration of Variation in Pot Life and Cure Time

ILLUSTRATION OF VARIATION IN POT LIFE AND CURE TIME

Formulation	Mixture	Temperature of Application			Pot Life			Cure Time		
		Manuf.	G.D.	ARL	Manuf.	G.D.	ARL	Manuf.	G.D.	ARL
Original (502)	10, 5, 2 ("Fastest")		< RT						> 60	
		RT (?)	"Standard RT"	20°C	20	8	16.5	60	60	60
			> RT						< 60	
	10, 1, 1 (?)		RT (?)			> 8			> 60	
KWIK-CURE (502K)	(?)		RT (?)						5	
	10, 2, 2			15°C			4			11
		RT (?)	RT	20°C	4	4	2	20	10	5
				28°C			1.5-2.0			5
	10, 1, 1			15°C			2.5-5.0			6.5-11.0
			RT	20°C		9	5		20	7
				28°C			2			4
	(?)		RT (?)						30	
KWIK-CURE (502Y)	(?)		RT (?)						10	
	10, 2, 2			15°C			6.5-7.5			11.0-15.0
				20°C			3.5-4.0			8.0-15.0
				28°C			2.5			5
	10, 1, 1			15°C			3.0-9.0			11.0-26.0
				20°C			2.0-9.0			5.0-26.0
				28°C			3.5-4.0			11.0-13.0
	(?)		RT (?)						45	

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16. Abstract

The introduction of rapid cure magnetic rubber inspection formulations has raised questions as to whether there may be some impairment of the sensitivity and reliability of the inspection technique relative to its performance with the well-established, slower curing formulation. This memorandum attempts to answer these questions.

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