CANADIAN MORTGAGE & HOUSING CORPORATION (CMHC) RESEARCH REPORT

Exterior Insulation Finish System
Laboratory Evaluation of Materials and Joints
Subjected to Artificial Conditioning

January 26, 1995

NOTE: **DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:**

SYSTÈMES DE FINITION ET D'ISOLATION EXTÉRIEURS ÉVALUATION EN LABORATOIRE DE MATÉRIAUX ET DE JOINTS EXPOSÉS À DES CONDITIONS CONTRÔLÉES

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Jan 9, 1995

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CMHC Statement

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related field, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

Disclaimer

This study was conducted by Inchcape Testing Services, Warnock Hersey Professional Services Ltd. for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretation and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

Executive Summary

During the past decade Exterior Insulation Finish Systems (EIFS) have become a popular alternative to traditional cladding systems, however over the last few years some concern has been raised on the durability of the systems to resist weathering. This research study attempts to quantify the performance of various elements of these systems using controlled laboratory conditions and is not intended to provide specific best practice recommendations.

The report outlines testing conducted on EIFS joints to evaluate bond strength and water resistance of a number of different joint designs when exposed to accelerated aging conditions and simulate joint movement. Tests were also conducted on the EIFS lamina to evaluate its water vapour permeance, thermal coefficient of expansion and dry shrinkage. Materials for testing were submitted by number of major suppliers who were felt to be representative of good quality materials. Test samples were then laid up by qualified trades people in accordance with the EIFS manufacturers instructions. After curing sealants were applied using qualified trades as per the sealant manufactures instructions. All samples were cured for a minimum of 28 days before testing or accelerated again. Accelerated again was a combination of drying cycles with exposure to ultra violet light and wetting using simulated rain.

Specific tests conducted and results were:

Bond strength of various low modulus sealants to EIFS basecoats, finished coats and primed basecoats before and after accelerated aging. Elongation, ultimate strength and failure mode were recorded, using 150 mm long simulated joint cross sections. On completion of the tests the bond strength and elongation of each combination was rated. It was found that the multi-component urethane low modulus sealant had the greatest bond strength to a primed basecoat while the silicone sealant exhibited the greatest elongation when bonded to a primed basecoat.

Durability tests were conducted on various joint designs using the better performing bond combinations found in the first set of tests and a number of other joint technologies such as expanded acrylic impregnated foam, flashings and elastomeric membranes. The durability test consisted of four 305 mm x 305 mm panels laid up in a square with a 25 mm sealant joint between each panel. The panels were then connected to a test jig that allowed 2 of the panels to be moved, which cycled 3 of the joints through there design movement once per day. The resultant stresses in the joint created both pure tensile and combine shear and tensile forces. In combination with this daily movement joints were also subjected to accelerated weathering. On completion of 30 days of conditioning the joints were examined to determine the amount of bond delamination and then tested for air and water leakage. This test appeared to duplicate field condition well, and produced numerous cohesive failures at the basecoat/sealant interface of the type we have commonly seen in the field. It was found that the joint designs using some sort of secondary seal provided better resistance to water infiltration than did the traditional face seal systems presently used. With respect to the multicomponent urethane's and the silicone sealant no conclusive difference in performance was noted.

Three different types of moisture permeability tests were run on samples of the lamina with and without basecoat. These were vapour permeance in accordance with ASTM E96, a constant water head test in accordance with CCMC 07240 and water infiltration under a differential pressure as per ASTM E331. For each test lamina samples were tested unaged, after exposure to 1000 hours of accelerated aging and after being subject to a rapid drying cycle to induce surface cracking. Moisture permeability was found to be highly effected by the lamina thickness, thin lamina was found to contain more imperfections that allowed moisture penetration no significant differences were noted due to the conditioning. In all cases the finish coat was found to decrease moisture permeability.

Dry shrinkage rate of the lamina during curing, were measured in both directions, using different weights of reinforcing mesh over EPS foam for 48 hours immediately after the basecoat was applied. These rates were found to be relatively small in the 1 mm/m range.

Thermal coefficient of expansion was measured from +40 C to -20 C, on samples of un-restrained lamina, using varying weights of reinforcing mesh, over EPS foam board. The thermal coefficient of expansion was found to be in the order of 0.011 mm/m.

Reinforcing mesh tensile strength was measured in accordance with ASTM D1682 as received and when encased in the basecoat before and after aging. Results indicated that the tensile strength of the encased mesh increased over that of the mesh along and that this strength was affected by weathering decreasing by as much as 25% after 1000 hours of accelerated aging. Some direction properties were also noted in some of the meshes.

As with most research studies this program was not all encompassing. It is felt future work is still needed to determine the mechanism of failure between the lamina and sealants, develope alternative mechanical or rain screen principle joints, evaluate joint performance under varying temperatures and to develope methods to performance rate joints.

Résumé

Durant la dernière décennie, les systèmes de finition et d'isolation extérieurs sont devenus une solution de rechange populaire aux parements traditionnels. Or, au cours des dernières années, on s'est aperçu que la résistance aux intempéries de ces systèmes pouvait laisser à désirer. La présente étude a pour but de quantifier la performance des divers composants de ces systèmes au moyen d'essais en laboratoire menés dans des conditions contrôlées. Elle ne vise toutefois pas à formuler des recommandations précises quant à la meilleure façon de mettre en oeuvre ces systèmes.

Le rapport fait état d'essais menés sur les joints des systèmes de finition et d'isolation extérieurs en vue de déterminer la résistance d'adhésion et la résistance à l'eau de certains types de joints lorsqu'ils sont soumis à un vieillissement accéléré et à un mouvement simulé. Les essais ont également porté sur la lame de ces systèmes afin d'en évaluer la perméance à la vapeur d'eau, le coefficient de dilatation thermique et le retrait au séchage. Les matériaux mis à l'essai ont été offerts par des fournisseurs réputés pour leurs produits de qualité. Les échantillons d'essai ont été réalisés par des ouvriers qualifiés conformément aux instructions des fabricants. Par la suite, des produits de scellement ont été appliqués par des ouvriers spécialisés selon les instructions des fabricants. Tous les échantillons ont été soumis à une période de maturation minimale de 28 jours avant d'amorcer l'essai de vieillissement accéléré. Le vieillissement accéléré consiste à faire alterner des périodes de séchage, avec exposition à une lumière ultraviolette, et de mouillage au moyen de simulations de pluie.

Suivent les essais menés ainsi que les résultats obtenus :

On a déterminé la résistance d'adhésion de divers produits de scellement à faible module appliqués aux couches de fond, aux couches de finition et aux couches d'apprêt des systèmes de finition et d'isolation extérieurs avant et après le vieillissement accéléré. L'allongement, la résistance à la traction et le mode de défaillance ont été mesurés au moyen de sections de joints simulées de 150 mm de long. Une fois les essais terminés, on a établi la résistance d'adhésion et l'allongement de chacune des combinaisons. On a découvert que le complexe de scellement à faible module, à base d'uréthane, offrait la plus grande résistance d'adhésion sur une couche de fond avec apprêt alors que le produit de scellement à base de silicone présentait le meilleur degré d'allongement lorsqu'il était appliqué sur une couche de fond avec apprêt.

Des essais de durabilité ont été menés sur divers types de joints au moyen des meilleures combinaisons de liants établies lors de la première série d'essais et avec un certain nombre d'autres techniques de jointoiement comme la mousse expansée imprégnée d'acrylique, le solin et les membranes en élastomère. L'essai de durabilité a porté sur quatre panneaux de 305 mm x 305 mm agencés en carré au moyen d'un joint de scellement de 25 mm entre chaque panneau. Ces panneaux ont ensuite été raccordés à un gabarit d'essai qui permettait de faire bouger deux des quatre panneaux et, ainsi, de soumettre trois joints à un cycle de mouvements de calcul par jour. Les contraintes résultantes ont produit des forces de traction pures ainsi qu'une combinaison de forces de traction et de cisaillement. Outre ces mouvements quotidiens, les joints ont subi un essai de vieillissement accéléré. Après 30 jours de conditionnement, les joints ont été examinés pour déterminer l'importance du décollement, puis mis à l'essai afin d'en évaluer la perméabilité à l'eau et à l'air. Ces essais ont semblé bien reproduire les conditions en service, puisqu'ils ont produit de

nombreuses ruptures cohésives au niveau du joint, entre la couche de fond et le produit de scellement, comme celles que l'on observe fréquemment sur le terrain. On a découvert que les joints qui bénéficiaient d'un dispositif de scellement secondaire offraient une meilleure résistance à l'infiltration d'eau que les joints de surface traditionnels dont l'usage est courant. En ce qui a trait à l'uréthane composite et au silicone, aucune différence concluante dans la performance n'a pu être notée.

Trois essais de perméabilité à l'humidité différents ont été effectués sur des échantillons de la lame, avec et sans couche de fond. Il s'agissait de l'essai de perméance à la vapeur conforme à la norme ASTM E96, d'un essai à la colonne d'eau constante conforme à la directive CCMC 07240 et d'un essai d'infiltration d'eau sous une pression différentielle fondée sur la norme ASTM E331. Pour chaque essai, les échantillons de lame ont été examinés à l'état non âgé, après un vieillissement accéléré de 1 000 heures et après un cycle de séchage rapide visant à provoquer des fissurations en surface. Il s'est avéré que l'épaisseur de la lame influait beaucoup sur la perméabilité à l'humidité. En effet, les lames minces présentaient davantage d'imperfections laissant passer l'humidité. Aucune différence significative n'a pu être notée par suite du conditionnement. Dans tous les cas, la couche de finition a entraîné une diminution de la perméabilité à l'humidité.

Durant le séchage, les taux de retrait au séchage de la lame ont été mesurés pendant 48 heures et dans les deux directions avec des treillis d'armature de masse surfacique différente sur mousse de polystyrène extrudé immédiatement après l'application de la couche de fond. Ces taux se sont révélés relativement faibles, soit de l'ordre de 1 mm/m.

Le coefficient de dilatation thermique a été mesuré entre -40 °C et -20 °C sur des échantillons de lame non confinée avec des treillis d'armature de masse surfacique différente placés sur panneau de mousse de polystyrène extrudé. Le coefficient de dilatation thermique obtenu était de l'ordre de 0,011 mm/m.

La résistance à la traction du treillis d'armature a été mesurée, d'après la norme ASTM D1682, dans son état initial puis une fois noyé dans la couche de fond, avant et après le vieillissement accéléré. Les résultats indiquent que la résistance à la traction du treillis noyé est supérieure par rapport au treillis seul, et que cette résistance est modifiée par les intempéries puisqu'elle a diminué d'au moins 25 % après 1 000 heures de vieillissement accéléré. Pour certains des treillis étudiés, la résistance diffère selon l'orientation de la pose.

Comme pour la plupart des programmes de recherche, cette étude n'est pas exhaustive. Nous croyons que de plus amples études seront nécessaires pour déterminer le mécanisme de défaillance de la lame et des produits de scellement, pour mettre au point des joints nouveaux, qu'ils soient mécaniques ou de type écran pare-pluie, pour évaluer la performance des joints dans diverses conditions de température et pour concevoir des méthodes d'évaluation de la performance des joints.

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APPENDICES

Introduction

The EIFS studied in this report were all comprised of nonload-bearing exterior wall cladding systems using a integrally reinforced polymer based coating over top of an adhesively attached insulation board, and optionally finished with a textured acrylic protective finish coat where noted. This type of cladding has seen increasing use in both highrise and lowrise construction as an alternate to traditional cladding. The materials have the advantage of being economical, light weight, relatively easily designed, and offers a wide variety of textures, finishes and architectural details. The main perceived problems of present systems seems to be their use of highly exposed face seal technology, the lack of backup protection if the primary seal fails and the low tolerance of some of the substrates to water penetration.

Background

This study was the result of two other CMHC projects:

"Exterior Insulation and Finish Systems: Problems, Causes and Solutions", which presented information on literature searches and a series of interviews that were intended to examine some of the alleged problems and possible solutions that may adversely affect the performance of this type of cladding system.

"Exterior Insulation Finish Systems: Field Performance", which outlines a number of case studies on the performance of EIFS claddings on several existing buildings, ranging in age from 1 to 10 years.

Based on a request for proposal to further investigate the EIFS issued in March 1993 by CMHC, Warnock Hersey prepared a preliminary proposal that was accepted by CMHC. Warnock Hersey then formed a small Ad Hoc Committee of interested industry parties. The committee had representation from EIFS manufacturers, sealant manufacturers, applicators, regulatory authorities, architects and engineering design and consultants. The committee helped to fine tune the program, most specifically, with respect to the type of joint designs that should be tested.

Based on these two reports and concerns of CMHC staff, industry and Warnock Hersey, the following areas were identified as noteworthy of further investigation:

1. Sealant Bond: Due to concerns of problems in the field of sealant bonds at joints, window openings etc., this program was developed to review the main types of Low Modulus Sealants (LMS) currently being used to seal joints and determine conditions and methods that might offer improved field performance.

2. Joint Design: This program was conducted for similar reasons as the Sealant Bond program. Specifically, it was designed to evaluate alternate joint designs that might provide higher performance or greater reliability over joints currently being used. Eight joint designs were evaluated, varying from industry standard face sealed joints using a LMS and backer rod to systems that incorporated double seals with rain screen principles.

3. Moisture Permeability: This program was conducted on the EIFS' lamina to determine to what extent the lamina might contribute to water infiltration into the system. Samples were conditioned in what were considered to be harsh conditions that would lead to cracking of the lamina as it originally setup. Various tests were then run to measure the actual amount of water or moisture permeability.

4. Thermal Expansion & Dry Shrinkage: Little empirical data seems to be available at this time to qualitatively determine what the linear expansion and contraction rates on EIFS lamina are, and at what interval joints would be spaced. This program was intended to give some information on the lamina drying shrinkage rate and coefficient of thermal expansion.

5. Mesh Tensile Strength: This program was set up to attempt to address concerns over whether the current EIFS meshes were effected by the alkali in the EIFS basecoats. Samples of lamina (basecoat and mesh) were conditioned for various lengths of time and then compared to the original strength of the lamina.

Materials Used

Based on the original CMHC proposal and input from our Ad Hoc Industry Committee, a number of basic constraints were placed on the investigation to try to maximize the return of information for the primary types of construction currently used. Since the predominate type of EIFS presently used is the thin coat polymer based (PB) system, all testing of base and finish coat was limited to this type. It should be noted however, that some of the information gathered can be used generically for other types of similar systems, specifically with respect to the joint design.

The EIFS material used came from two different brand name Canadian suppliers who were felt to be representative of most manufacturers for quality and durability. It is recognized that there are variations in products between manufacturers, however, it was felt that in most cases, parallels could be drawn across the industry.

Where primers were used, they were supplied by the EIFS manufacturer. Sealants were generally restricted to multi-component urethane (MCU) Low Modulus Sealant (LMS) which accounts for the majority of sealants used on EIFS, however, a number of sets of tests were conducted using Silicone Sealant (SS). Additionally, an expanded acrylic impregnated foam sealant (IFS) and elastomeric membrane were used on some joints as a secondary seal.

Mesh was collected from two major suppliers and general duty mesh was used. It was described as a glass fibre reinforcing mesh with densities of 150 gm/m^2, 168 gm/m^2 and 700 gm/m^2

The Expanded Polystyrene Insulating Foam used complied with the EIFS manufacturer's recommendation conforming to CGSB 51-GP-20M Type 1 and was of a 16 kg/m^3 density.

Accelerated Aging Description

In order to simulate real world conditions as closely as possible, a number of different accelerated weather methods were used. The methods were selected for their ability to simulate field conditions, their repeatability (ie. standard test procedures were used wherever possible), their exposure cycle and their size limitation for the samples. It should be noted that no direct correlation exists between time spent in accelerated weather chambers and real world exposures. Instead, weathering data must be treated as a comparative process where various properties are compared before and after aging. This data can then be evaluated to determine how much a material was effected or which material performed best after aging. The expectation is then that these relationships will also hold true under actual weather conditions. In all, four different conditions were used to age the samples as follows:

1. <u>Standard Conditions</u>

   Unless noted otherwise, all samples were cured for a minimum of 28 days prior to testing or additional weathering to allow the basecoat, finish coat and LMS to properly set. These conditions were approximately 20°C and 50% RH.

   Note: Where LMS were used the base coat or finish coat was allowed to cure 28 days prior to the application of the LMS. The total assembly was then allowed to cure an additional 28 days.

2. <u>ASTM G53</u>

   This outlines the standard operating cycle for Q-UV Weather-Ometers. This is one of the most widely used methods of weathering small samples for roofing and siding applications. Samples were exposed for 1000 hours.

3. <u>Rapid Dry</u>

   Instead of the "Standard Conditions" noted above, samples were subject to temperatures of 40°C for the first 24 hours of drying to induce shrinkage cracks which are commonly noted under rapid drying conditions.

4. <u>ASTM D2898 Method B</u>

   This procedure was used to condition joint design samples. It was selected since it provided exposure to simulated rain, Ultra Violet (UV) light drying, it could hold a number of the rather large joint design samples (635 mm x 635 mm) and it was readily available. This procedure is normally used for conditioning roof decks but was modified for this specific program by re-orientating the samples vertically and redirecting the water spray and UV lights to be more typical of what a wall cladding might expect to be subjected to.

Application Details

In all cases, unless otherwise noted, manufacturer recommended trained trade persons familiar with the specific products' manufacturer's application instructions, were used to set-up test samples. This was felt to be particularly important since so much of the problems associated with EIFS are commonly attributed to "poor workmanship". Samples were then allowed to age 7 days prior to the finish coat application and then an additional 21 days before any testing or accelerated aging was conducted.

TEST PROCEDURES

Appendix IV includes a short description of reference test used where they were not explained in the main body of the report. For additional information the reader should consult the actual test standard.

Test Program and Results

1. Sealant Bond

Over the past 10 years, it has been our experience that the majority of problems associated with EIFS have generally been attributed to apparent failure of the sealant bonds at expansion joints, window openings, etc. This program attempts to compare the effect of various parameters on the bond strength of Low Modulus Sealants (LMS) currently being used. By quantifying how bond strength is effected by various application methods and weathering, it was felt that this could lead designers, manufacturers and installers to methods of producing better joints.

For each joint variation a 1.2 mm long joint sample was laid up. On each side of the joint, a 76 mm x 152 mm block of EPS foam with a 2 x 4 backing was wrapped with basecoat and, where required, finished with primer or finish coat. Joint spacings were approximately 18, 25 and 31 mm wide, unless otherwise noted, and contained an appropriately sized closed cell polyurethane foam backer rod. Sealant was applied using trained trade persons familiar with the specific products. Figure 1 illustrates the joint cross section (page 7). The following joint variations were tested:

a) The bond strength of LMS to EIFS basecoat.

b) The bond strength of LMS to EIFS primed basecoat.

c) The bond strength of LMS to EIFS finish coat.

d) The bond strength of LMS with 9 mm and 31 mm joint spacing using the joint detail which obtained the best results of items (a), (b) and (c), with joint depths equal to 50% of width.

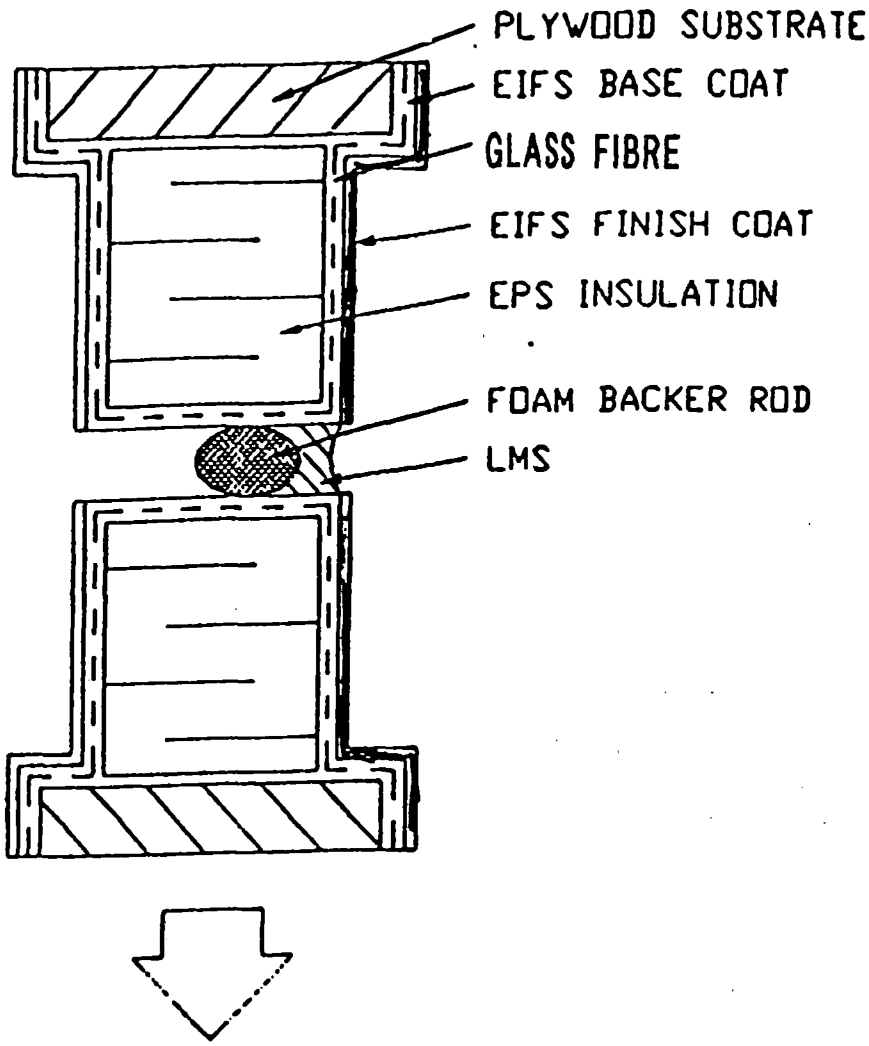
e) The bond strength of LMS to EIFS with a double caulk using the joint detail which obtained the best results of items (a), (b) and (c), with joint depths equal to 50% of width.

f) The bond strength of a silicon LMS joint caulked to basecoat with a secondary expandable acrylic impregnated foam joint.

Conditions (a) through (e) were carried out using multi-component urethane LMS. Condition (f) was carried out using a single component silicon LMS.

Samples where tested before and after accelerated aging to ASTM D2898 method B for 30 days. Six 150 mm long tensile test samples were cut from the laid up joints. Load vs elongation was recorded as well as the failure load and mode of failure. The first five out of six samples of each group were tested dry, the remaining sample was tested after a 24 hour exposure to water spray of 204 litres/hour per m^2.

Figure 1


PLYWOOD SUBSTRATE
EIFS BASE COAT
GLASS FIBRE
EIFS FINISH COAT
EPS INSULATION
FOAM BACKER ROD
LMS

RESULTS:

Figure 2

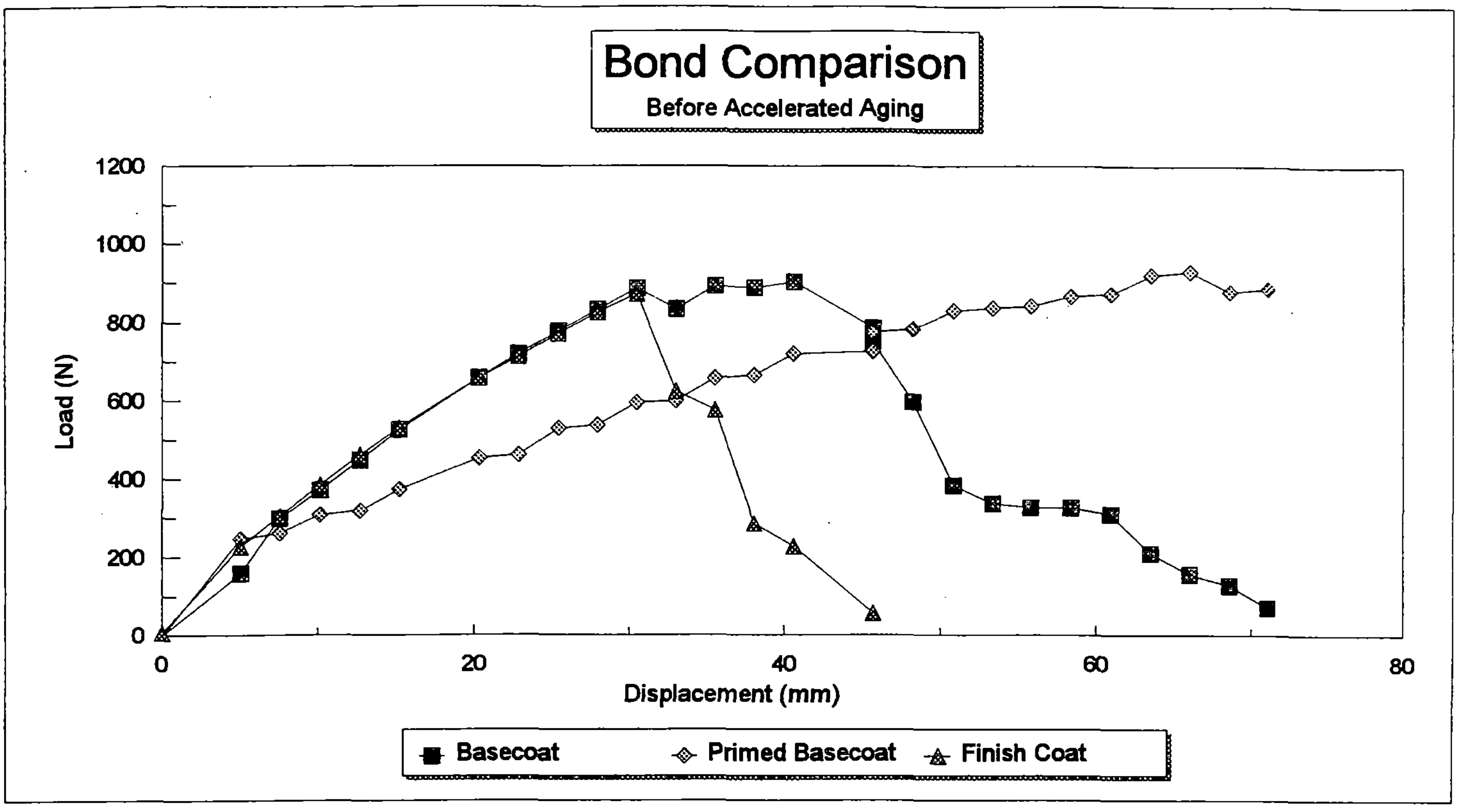


Figure 2 illustrates the comparison of joints before aging. This plot is based on average values of 3 to 5 tests and are not intended to represent any one joint but only indicate trends. The joints were initially tested to determine what effect the finish coat or primer had on the joint so that future tests could be conducted on the best of the unprimed or primed basecoat. Although all joint types tended to perform somewhat similarly with respect to ultimate load it was found that the primed basecoat held on better and allowed a greater displacement of the joint before failing. Hence additional tests on the basecoat were all conducted in the primed condition. Note, all samples broke at around 890 N which is approximately the maximum load that the lamina and foam will withstand.

Figure 3

Figure 3 outlines the average performance of the joints after aging. This is an average of a number of runs, and is only designed to represent trends rather than an actual joint performance since variations in ultimate failure loads are not taken into account. The data clearly shows many of the major trends that we found. The double dymeric joint had the highest load but allowed for little movement, much of the displacement shown was due to yielding of the foam and lamina. The finish coat performed almost as well as the primed basecoat for ultimate load but, as in the unconditioned samples, the primed basecoat allowed a greater joint displacement before final failure. The silicone, although it had the lowest ultimate tensile strength, had the greatest displacement and good consistency.

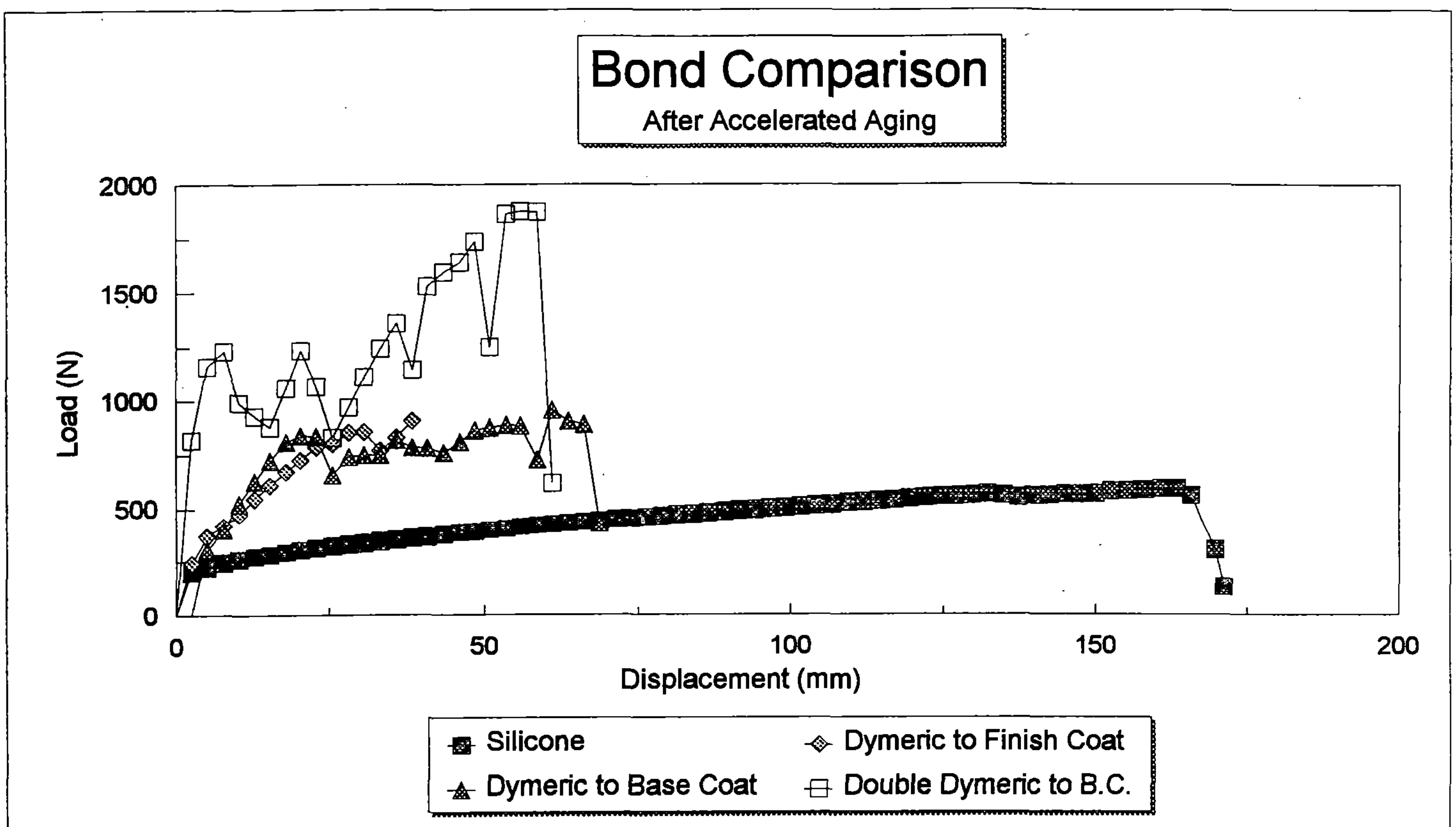


Table 1 outlines the results of our findings more specifically, and has been sorted by descending load at initial failure. Appendix 1 contains graphs of deflection vs load for each group of tests.

TABLE 1 - JOINTS SORTED BY FAILURE LOAD

Group	Initial Failure Load (N)	Displacement at Initial Failure Load (mm)	Joint Description	Failure Mode
12	1405	8.4	1" MCU 2 PACK to PRIMED BASECOAT #1	Foam broke/Basecoat delaminated at mesh
7	1045	21.1	1¼" MCU to PRIMED BASECOAT #2	Foam/mesh failure
A	987	36.6	1" MCU to BASECOAT U.C.	Basecoat Delaminated at mesh
9	983	22.9	1" MCU to FINISH COAT #1	Basecoat Delaminated at mesh
B	970	34.5	1¼" MCU to PRIMED BASECOAT U.C.	Basecoat Delaminated at mesh
C	934	35.3	1" MCU to FINISH COAT U.C.	Basecoat Delaminated at mesh
2	912	18.8	1¼" MCU to PRIMED BASECOAT #1	Basecoat Delaminated
8	907	29.5	1" MCU to FINISH COAT #1 & 2	Basecoat Delaminated at mesh
1	832	18.3	¾" MCU to PRIMED BASECOAT #1	Basecoat Delaminated at mesh
6	712	11.4	¾" MCU to PRIMED BASECOAT #2	Basecoat tore at mesh
3	569	9.1	1" MCU to PRIMED BASECOAT #2	Basecoat Delaminated at mesh
13	569	134.4	1" SILICONE to BASECOAT #2	Adhesive failure at Silicone/Basecoat
10	543	13.2	1" MCU to FINISH COAT #2	Basecoat Delaminated at mesh
5	498	61.5	¾" SILICONE with IFS TO BASECOAT #2	Adhesive failure at Silicone/Basecoat
4	480	100	1¼" SILICONE to BASECOAT #1	Adhesive failure at Silicone/Basecoat

* U.C. = UNCONDITIONED ALSO DENOTED BY A GROUP LETTER INSTEAD OF NUMBER, GROUP 11 NOT REPORTED DUE TO LACK OF DATA

As can be seen, the MCU LMS had the highest bond strength in the 890 N range, and although the finish coated sample appeared to perform well, it has been our experience that finish coats can re-emulsive when exposed to prolonged moisture with a consequential drop in strength (see Table 3). This appears to be supported by Table 3 which shows the LMS bonded to the finish coat ultimate tensile load dropped by 63.7%. In fact, it was found that many of the failures for the dymeric LMS were due to mesh or cohesive failures of the foam. See photographs 1 through 8. This may be why the double caulked joint (group 12) tensile strength was only about 40% better that a single caulked joint. It is also not surprising to see the 31 mm joints and 25 mm joints performing better than the 19 mm joints since they have proportionately more contact area with the lamina. Note of interest, 31 mm joints did not tend to show significant increase in joint displacement at failure.

In general the foam cohesive strength is around 69 kpa or around 667 N for the selected test sample size. Appendix I contains plots of each test by group and appendix 5 selected photographs. Most of the groups seem to behave fairly consistently over the initial loading, however in many of the tests, especially for the dymeric's, there was a substantial variance in both initial failure loads and final failure loads. Initial failure was defined as "the point at which the load dropped substantially for the first time", this was often due to cohesive failure of the foam, delamination of the lamina from the foam or lamina failure. In almost all cases where the dymerics were used, one of these events superseded the final failure of the LMS bond, hence the graphs show somewhat of a saw tooth effect as the foam fails and then the load is taken up by the lamina. Most final failures at high loads, in the 890 N range, were due to failure of the basecoat tearing away from the mesh and foam with the exception of a few cases where the LMS bond failed or the lamina failed the maximum load reached represented failure of the basecoat. For the purpose of Table 1, the initial failure load was chosen since it was felt it was of little value if the LMS held on but the joint had, in essence, failed due to some other mode.

As can be seen in Table 2, the silicone joints by far appeared to perform the best for elongation averaging around 75 mm or 300% elongation. The other very interesting point of the silicones is they also exhibited the most consistent failure loads within a few pounds of each other and displacements of similar magnitudes. Most of the other LMS exhibited much higher variation in results, one of the major reasons for this appears to be the silicones failed at relatively low loads between 479 N and 628 N. This load is low enough that it did not result in failures of the foam or lamina and the failures mode was an adhesive failure at the lamina silicone interface. With the dymerics, on the other hand, it was very common for either the foam or the lamina to fail, thereby distorting the results.

The dymerics bonded to the finish coat performed well with a 25 mm extension or 100%. The average for the other dymerics was around 15 mm or 60% which is not substantially higher than the traditional design allowable of 25%. The joint with the least elongation was the double caulked joint, with twice as much material to elongate, the resultant stresses on the lamina were that much higher and consequently failure occurred at 8 mm or 33% which is very close to the traditional design allowance.

Table 2 outlines the results sorted by descending Displacement at the initial failure load.

TABLE 2 - JOINTS SORTED BY DISPLACEMENT AT INITIAL FAILURE					
Group	**Initial Failure Load (N)**	**Displacement at Initial Failure Load (mm)**	**Pro-rated for Joint Size** (mm)**	**Joint Description**	**Failure Mode**
13	569	134	134	25" SILICONE to BASECOAT #2	Adhesive Failure at Silicone/Basecoat
5	498	61	82	19" SILICONE with IFS TO BASECOAT #2	Adhesive Failure at Basecoat
4	480	100	80	31" SILICONE TO BASECOAT #1	Adhesive Failure at Silicone/Basecoat
A	987	37	37	1" MCU to BASECOAT U.C.	Basecoat Delaminated at Mesh
C	934	35	35	1" MCU to FINISH COAT U.C.	Basecoat Delaminated at Mesh
8	907	29	29	1" MCU to FINISH COAT #1 & 2	Basecoat Delaminated at Mesh
B	969	35	28	1¼" MCU to PRIMED BASECOAT #1	Basecoat Delaminated at Mesh
1	831	18	24	¾" MCU to PRIMED BASECOAT #1	Basecoat Delaminated at Mesh
9	983	23	23	1" MCU to FINISH COAT #1	Basecoat Delaminated at Mesh
7	1058	21	17	1¼" MCU to PRIMED BASECOAT #2	Foam/Mesh Failure
6	711	11	15	¾" MCU to PRIMED BASECOAT #2	Basecoat Tore at Mesh
2	912	19	15	1¼" MCU to PRIMED BASECOAT #1	Basecoat Delaminated
10	543	13	13	1" MCU to FINISH COAT #2	Basecoat Delaminated at Mesh
3	569	9	9	1" MCU to PRIMED BASECOAT #2	Basecoat Delaminated at Mesh
12	1405	8	8	1" MCU 2 PACK to PRIMED BASECOAT #1	Foam Broke/Basecoat Delamination at Mesh

* U.C. = UNCONDITIONED
** (25 mm ÷ Actual Joint Size) x actual elongation

Table 3 outlines the results of tests run on the joints after exposure to simulated rain for 24 hours. Since this test was originally not in the program, only 1 test sample of each joint type was available so the data must be considered with this in mind. When average results for the bond strength to primed basecoat and finish coat are examined there appears to be a strong indication that finish coats/LMS bond strength deteriorates more than the basecoat/LMS bond 63.7% vs 93.4% respectively. This can be seen in the mode of failure of the wet tensile where two of the finish coats failed cohesive.

TABLE 3 - WET TENSILE TESTS

Group	Wet Failure (N)	Avg. Dry Failure (N)	Substrate	% of Dry Strength	Failure Mode
1	534	832	MCU to PRIMED BASECOAT	64	Mesh Tor at Block
2	1143	912	MCU to PRIMED BASECOAT	125	Basecoat Delaminated at Mesh
3	458	569	MCU to PRIMED BASECOAT	80	Adhesive Failure
6	716	712	MCU to PRIMED BASECOAT	101	Mesh Tor at Black
7	1005	1045	MCU to PRIMED BASECOAT	96	Basecoat Delaminated at Mesh
			Average:	**93**	
4	360	480	SILICONE to BASECOAT	75	Adhesive Failure
5	445	498	SILICONE to BASECOAT	89	Adhesive Failure
13	431	569	SILICONE to BASECOAT	76	Adhesive Failure
			Average:	**80**	
8	445	907	MCU to FINISH COAT	49	Cohesive Failure of Finish
9	632	983	MCU to FINISH COAT	64	Basecoat Delaminated at Mesh
10	370	543	MCU to FINISH COAT	68	Basecoat Delaminated at Mesh
11	230	391	MCU to FINISH COAT	58	Cohesive Failure at Finish
			Average:	**64**	

Conclusions:

The major findings of this program were that:

The MCU had the strongest adhesive properties of the LMS tested which actually exceeded the basecoat's and the foam's cohesive strength. In our results, the dymerics were stressing the EIFS foam to around 50% of its ultimate strength at a joint displacement of +25%. For 38 mm thick foam board this would be around 100% and for 50 mm foam around 75%. This is obviously a high value and does not represents a good design and may be one of the reasons the various joint sizes 19, 25 & 31 mm did not show significant differences in joint elongations. One method of improving this performance might be to change the joint cross section to make it thinner at the centre. The joints we tested had an approximate width to depth ration of 2:1 as recommended by the sealant manufacturer. Where width is the joint width and depth is the thickness of the caulking at its thinnest point. Some EIFS manufactures have now suggested the use of caulking applied using a ratio of 4:1. As long as the same bond area is maintained, this should have a positive effect on the joint by lowering the adhesive stress on the lamina for a given displacement and allow a higher joint displacement at failure. How practical this would be in the field is still questionable.

One point of disappointment in this series of tests was the lack of significant degradation of the joints after exposure. On one hand this is good since it shows the LMS/Bond/Lamina was not highly effected by our accelerated weathering, but on the other hand, we know these joints do fail in the field and for most of these failures we do not observe significant damage to the EIFS. This leads us to believe that we have not completely simulated real world conditions. There are two major possibilities regarding simulation that might well have effected the outcome, they are:

a) The LMS were installed under ideal lab conditions and were allowed to cure undisturbed.
b) Failure mode and ultimate loads could be different if the loading was extended over a much longer time period.

The silicones exhibited the highest joint elongations. Although the bond was not as strong as the dymerics, the silicone's bond appeared to be a better fit for the systems as tested since it obtained the maximum joint elongations before failure. (see photographs 5 & 6) In general, the stress on the EIFS foam was probably only around 35% of its ultimate at 25% joint elongation and did not exceed 60% of the foams ultimate tensile strength. This would actually make the silicone a very good candidate for a double caulked joint.

The double caulk joint had superior tensile strength but caused much higher stresses in the EIFS for a given displacement of the joint. (see photographs 7 & 8) Joints made this way with dymerics should only be used where minimum joint movement is expected, or, if some sort of double seal is to be used with the dymerics it should be of a very low modulus design like a membrane or IFS.

Bonding to finish coats should be avoided where possible since they appear to be highly affected by exposure to prolonged wetting.

2. Joint Design

The joint design section of the program was intended to life cycle a number of different joints and compare their performance. The Ad Hoc Industry Committee helped select and develop the specific test joints. The objective was to compare performance between joints and hopefully demonstrate that some alternative joint designs would provide more durable or higher performance joints.

In the last year the performance of EIFS joints has become an issue particularly in the Vancouver area where it has been the practice to use the same joint on a two story building as a 35 story highrise. A committee, formed by the City of Vancouver to study EIFS, reviewed many different joint designs and factors that affected joint failure of EIFS. One of the committee's major focuses was to try to quantify joint types and where they could be used. Unfortunately, at the time, there was very little, if any, quantitative data on the standard face sealed, rod and caulk, joints used on EIFS and even less data on alternative joints using expandable foam tapes or membranes behind the joint. The Ad Hoc Committee formed by Warnock Hersey used many of the same members as the Vancouver committee and, hence, many of the designs tested were similar. The joints selected were based on ease of field or panel construction, use of "rain screen" principles if possible, use of alternative sealing methods that reduced the reliance of the EIFS system on a single seal and protection of the joint from direct weathering.

Eight joints were tested as follows:

a) Expansion joint sealed using generic face seal method with multi-component urethan LMS applied to basecoat and backed with a closed cell polyurethane backer rod (see drawing 2 in Appendix II).

b) Expansion joint sealed using generic face seal method with multi-component urethan LMS applied to basecoat, backed with a closed cell polyurethane backer rod with an expanded acrylic impregnated foam secondary seal incorporating a vented cavity (rain screen) principle (see drawing 3 in Appendix II).

c) Expansion joint sealed using generic face seal method with multi-component urethane LMS applied to finish coat and backed with a closed cell polyurethane backer rod (see drawing 4 in Appendix II).

d) Expansion joint sealed using generic face seal method with multi-component urethane LMS applied to basecoat (incorporating an aluminum window frame) and backed with a closed cell polyurethane backer rod (see drawing 5 in Appendix II).

e) Expansion joint sealed using generic face seal method with single component silicone LMS applied to basecoat and backed with an expanded acrylic impregnated foam primary seal (see drawing 6 in Appendix II).

f) Expansion joint sealed using generic face seal method with multi-component urethan LMS applied to basecoat, backed with a closed cell polyurethane backer rod with a horizontal and vertical elastomeric membrane secondary seal incorporating a vented cavity (rain screen) principle (see drawing 7 in Appendix II).

g) Expansion joint sealed with a vented mechanical flashing with a horizontal and vertical elastomeric membrane primary seal (see drawing 8 in Appendix II).

h) Expansion joint sealed using multi-component urethan LMS recessed within the joint and applied to basecoat and backed with a closed cell polyurethane backer rod (car door principle) (see drawing 9 in Appendix II).

The test samples consisted of 635 mm x 635 mm panels composed of four 305 mm x 305 mm panels with 25 mm wide test joints (see figure 3). The two bottom panels were fixed and the top two panels were attached to movable plates. The upper left plate was cycled through a vertical travel of 13 mm (± 25% of the joint thickness) while the upper right plate was cycled through a diagonal travel of 13 mm. This arrangement allowed each of the four joints to be subjected to different simulated building movements. Joint 1 - 2 was pulled apart and down 9.7 mm (-23°) due to the relative motions of Panel 1 and Panel 2. Joint 3 - 4 experienced combine shearing and tensile stresses with a total displacement of 13 mm at 45°. Joint 5 - 6 remained stationary and was subjected to essentially no stress. Joint 7 - 8 was placed in pure tension with a displacement of 13 mm (Table 4 outlines the specific joint movements).

The actual test consisted of exposing each of the panels to a modified ASTM method B accelerated weather for 30 days with the joints cycled through their design movement (± 25% of joint thickness) once each day. Following the testing the amount of joint delamination was recorded and each panel was tested under a 75 kpa pressure differential in accordance with ASTM E289 & E331 respectively.

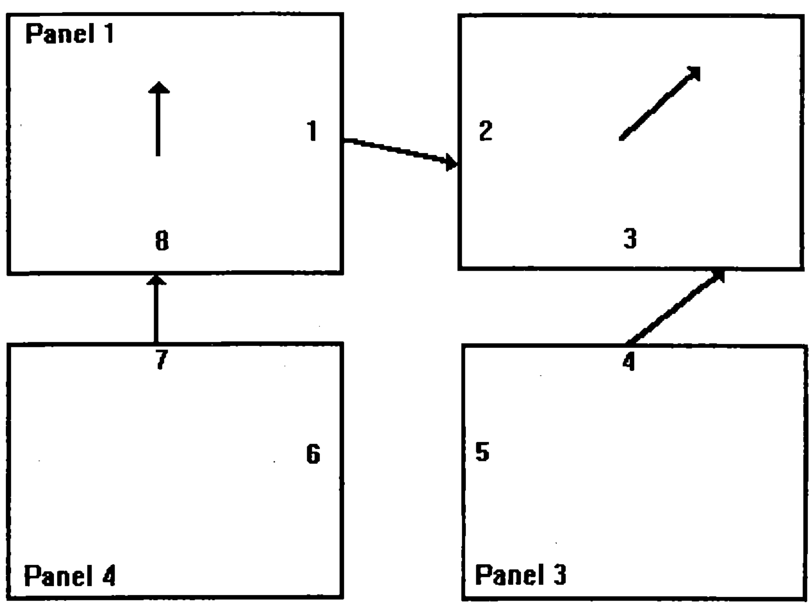


Figure 4 Joint Locations and Relative Displacements

Results:

The results of this test program were rather interesting when considering the results of the sealant bond tests. Firstly, we saw very few failures in the sealant bond tests at test loads that caused only a 25% displacement of the joint. Whereas in the Joint Design program, we saw numerous failure under essentially the same weathering conditions (see Table 5 for details of joint failures or Appendix III for locations of failures). Secondly, as noted in the conclusions of the sealant bond tests, the mode of failure we noted was not very consistent with the modes of failures we commonly find in the field. However, with the joint design program, the majority of the failures were of a cohesive nature (a failure within the body of the basecoat) where the exposed surface of the basecoat or finish coat separates with the sealant, which is the most common mode of failure we have seen in the field.

TABLE 4 - RELATIVE JOINT MOVEMENT IN MILIMETERS				
Joint	**Up**	**Left**	**Total**	**Angle**
1 - 2	-3.7	9.0	9.7	-23
3 - 4	9.0	9.0	13.07	45
5 - 6	0.0	0.00	0.00	0
7 - 8	13.0	0.00	13.0	90

With respect to the specific joints, Table 5 outlines the failures observed and the mode of failure for each joint. Although it may be inaccurate to generalize on so small a test sample, it would appear that the following may be true:

a) Since joint 3 - 4 showed the greater failure rates than joint 7 - 8, a combined shearing and tensile action is worse than tension alone.

b) Stressing the joint during weathering is a worst case and much more realistic scenario than conducting tests after weathering. We base this on the fact that the failure modes were much more representative of field failures and no failures occurred on the unstressed areas of joint 5 - 6.

c) Although the Silicones seemed to perform well during the sealant bond tests, there was no significant difference between them and the dymerics for percent of joint delaminating.

Table 6 shows the results of air and water infiltration tests on the samples after weathering. The most apparent observation is the fact that a secondary seal, IFS or a membrane, seems to dramatically reduce or stop water infiltration. Note, a point of concern here that may be misleading is the fact that for a traditional EIFS system, water must be stopped from getting to the gypsum sheathing. Since the membrane design used in this study was attached to the sheathing, it stopped water penetration at the joint but it probably would allow water into the sheathing causing other problems.

TABLE 5 - JOINT FAILURE BY LOCATION & PERCENT OF LENGTH DELAMINATED

	Joint Location (See Figure 3)									
Sample Number	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	Average %	Failure Mode
1	100	0	0	100	6	8	79	58	**44**	Cohesive Failure Base & Finish Coat
2	100	21	54	100	8	8	71	8	**46**	Cohesive Failure Finish Coat
3	54	100	71	83	6	0	100	46	**58**	Cohesive Failure Finish Coat
4	100	0	42	100	0	0	0	79	**40**	Cohesive & Adhesive at Frame
5	21	58	0	100	0	0	63	54	**37**	Adhesive Failure
6	0	0	13	100	0	0	42	0	**19**	Cohesive Failure Base & Finish Coat
7	0	0	0	0	0	0	0	0	**0**	N/A
8	58	58	100	67	0	0	6	100	**49**	Cohesive Failure
Average	**54**	**30**	**35**	**81**	**3**	**2**	**45**	**43**	**37**	

TABLE 6 - AIR & WATER INFILTRATION ON WEATHERED JOINTS AT NEUTRAL POSITION

Sample Number	Joint Description	Air Leakage m^3/min	Time to Water Infiltration (min.)	Number of Leaks	Blow Out Pressure kPa
1	Standard MCU Joint to Basecoat	.0028	1.5	2	1.3
2	MCU to Finish Coat with IFS	.0142	N/A	0	1.3
3	MCU to Finish Coat	.0142	1	1	1.4
4	MCU to Basecoat & Window Frame	.0057	?	3	1.4
5	Silicone to Basecoat with IFS Backing	.0142	12	1	1.5+
6	MCU to Basecoat with Membrane	.0142	N/A	0	1.5+
7	Flashing and Membrane	.0057	N/A	0	1.5+
8	Recessed MCU (car door design)	.0036	0.5	2	1.5+

Other points of interest were;

a) The Performance of the Recessed Joint Design

This joint was expected to be more resistant to weathering yet it appeared to be one of the worst performers. One possible reason for this may be that since the caulking bond was located close to the substrate it had to absorb all of the panel movement. Sealants located at the outer edge of the foam would be subject to slightly less stress due to the deformation of the foam (ie. the foam acts something like a cantilevered beam).

b) The Adhesive Failure of the Sealant to the Window Frame

The high failure rate of the sealant bond to aluminum window frame was surprising. It is possible the frame was contaminated in someway. Further investigation would be required to determine if this was more than a random occurrence.

c) Little Correlation Between Crack Length and Air Infiltration

This seemed to be due to the problem of returning the samples to their true neutral starting position. A small difference in this could cause a crack to open up and allow more air in. This did not seem to be nearly as much of a problem with water infiltration since we were not worried about volume, only if it leaked and how long it took to leak.

The blowout resistance of the joints were, in general, not found to be a problem. The first four samples failed at pressures of 1.3 kpa and 1.4 kpa and the last four we were unable to cause to fail at up to 1.5 kpa.

Joint Design Conclusions:

Table 7 summarizes our opinions of which joint designs performed best. We call this an opinion since it is based only on the tests conducted and may not be valid for all applications. The joints were rated on water leakage, the amount of air leakage and the amount of bond failure noted.

Note: Water infiltration test was run for 15 minutes at 75 Pa, where no leakage was observed, this is indicated with N/A.

TABLE 7 - JOINT PERFORMANCE RATING

Sample Number	Joint Description	Air Infiltration m^3/min	Time to Water Infiltration (min.)	Amount of Bond Failures
1	Flashing with Membrane	.0057	N/A	0%
2	MCU to Basecoat with Membrane	.0142	N/A	19%
3	MCU to Finish Coat with IFS	.0142	N/A	46%
4	Silicone to Basecoat with IFS Backing	.0142	12	37%
5	Standards MCU Joint to Basecoat	.0028	1.5	44%
6	MCU to Finish Coat	.0142	1	58%
7	MCU to Basecoat & Window Frame	.0057	?	40%
8	Recessed MCU (car door design)	.0036	0.5	49%

Our testing would indicate that a double seal performs better than a single seal and that a membrane offers probably the highest overall defence against water infiltration. The flashing joint appeared to perform very well and offers the good protection for horizontal joints, however one of its' major problems is that it tends to be architecturally unappealing. For vertical joints, where typically joint movement are much smaller, a LMS joint to a primed basecoat has a much higher likelihood of standing up. Behind both joints, the use of a membrane would provide a durable backup with the provision the joint is designed to allow drainage of water penetrating the primary seal and the substrate is of a water resistant construction.

As a lower performing option, an LMC primary joint with a secondary seal like IFS offers a reasonable alternative. Being an expandable material, IFS has the advantage that it does not additionally stress the EIFS lamina at the joint the way a double caulked joint would. It will also tend to stay in contact with both sides of the joint while substantially reducing any air and water infiltration. Our findings tended to indicate care was required with the IFS during installation especially at corners other wise it would allow some air and water infiltration and hence it did not appear to be suitable as a primary seal.

Although the silicone would appear to be a good design choice according to the sealant bond tests, results of the joint design tests did not appear to be as conclusive with both the Silicone and MCUs having similar amounts of bond failures.

Single LMS joints were only found to work well where joint movement was low; below the traditional ± 25%. Further study would be required to quantify the actual joint movement that LMS could reliably absorb without failure.

3. Moisture Permeability

The intent of this set of tests was to measure moisture penetration through the lamina. There have been numerous reported cases where water seems to be able to penetrate an EIFS envelope without obvious reason and the moisture permeability of the lamina has been suspected. These tests attempted to quantify the order of magnitude of moisture permeability and to evaluate some of the factors that may affect permeability such as rapid drying of the lamina. The following tests were conducted:

a) Vapour Permeance of EIFS basecoat and finish coat in accordance with ASTM E96.

b) Constant Water head on EIFS basecoat Constant Water head on EIFS basecoat with finish coat in accordance with CCMC 07240.

c) Water infiltration in accordance with ASTM E331.

Lamina samples of EIFS were laid up and tested under six conditions without any foam backing, these conditions were:

- Basecoat Unweathered
- Basecoat & Finish Coat Unweathered
- Basecoat dried rapidly to induce shrinkage cracks
- Basecoat Weathered to ASTM G53 for 1000 hours
- Basecoat & Finish Coat to ASTM G53 for 1000 hours.

Results

TABLE 8 - WATER VAPOUR TRANSMISSION IN ACCORDANCE WITH ASTM E96		
Sample Description	**Vapour Transmission $ng/m^2/s$**	**Thickness mm**
Non-weathered Basecoat	2644	2.11
Non-weathered Base & Finish Coat	744	3.35
Weathered Basecoat	742	2.64
Weathered Base & Finish Coat	541	3.91
Rapid Dry Basecoat	406	4.01
Rapid Dry Base & Finish Coat	328	4.52

* **This high reading seams to be due to a small pin sized hole in the lamina.**

Table 8 outlines the results of the Vapour Transmission tests. Surprisingly, the rapid dry samples appeared to have a lower vapour transmission rate than the other samples, even then those that did exhibit the hairline cracks that are commonly seen in the field. We attribute this discrepancy to the variation in lamina thickness. One problem we ran into on testing was that in order to get substantial surface cracking, we found the lamina had to be applied thicker than normal and this tended to skew the results. By applying the basecoat thicker, stresses due to differentials in the curing appear to cause the micro cracks noted.

The non-weathered basecoat definitely had the highest vapour transmission rate, but this is attributed to the fact the it contained a small pin sized hole and was also the thinnest. In general, the test data seems to be reversed in that it appears that weathered samples had a lower vapour transmission than non-weathered and the rapid dry had the lowest vapour transmission rate. It is our opinion that these results are due to the variability of a hand applied product, as can be seen in Table 8, the performance of the system appears to be more related to the lamina thickness then to the conditioning effects. Also since the base and finish coats have varying sized aggregates, they are subject to numerous small imperfections from large sand gains and uneven lamina thickness and air entrainment due to the manual application.

As expected, the finish coat tended to reduce vapour transmission but not by a significant amount, around 20% to 30%. It would certainly be expected that a finish coat would fill most small random imperfections, and, produce a much more consistent overall vapour barrier than the basecoat alone.

TABLE 9 - WATER PERMEABILITY IN ACCORDANCE WITH CCMC 07240			
Sample Description	**Time to First Moisture Penetration (min)**	**Time to Entire Area Damp (hrs)**	**Dry After 2 Hours**
Non-weathered Basecoat	3	2 to 2.5	No
Non-weathered Base & Finish Coat	30	N/A	No
Weathered Basecoat	3	N/A	No
Weathered Base & Finish Coat	N/A	N/A	Yes
Rapid Dry Basecoat	N/A	N/A	Yes
Rapid Dry Base & Finish Coat	N/A	N/A	Yes

Note: N/A means no water penetration was observed.

Table 9 outlines the water permeability tests. Like the vapour transmission results, the data is somewhat reversed and again we attribute much of this to the variability of the product.

TABLE 10 - ASTM WATER AND AIR INFILTRATION TEST RESULTS		
Sample Description	**Water Infiltration @ 75 Pa Time to Leakage**	**Air Leakage @ 75 Pa (m^3/min)**
Non-weathered Basecoat	No Leakage	0.0014
Weathered Basecoat	Drips @ 30 Sec.	0
Basecoat Rapid Dry	No Leakage	0
Finish Coat Non-weathered	No Leakage	0
Finish Coat Weathered	No Leakage	0
Finish Coat Rapid Dry	No Leakage	0.0014

Table 10 summarizes the results of the Air and Water tests conducted on the lamina. For the purposes of this test, the water permeability test samples outlined in Table 8 were used. Although larger samples would have given more accurate air infiltration results, it was thought that being able to compare results from both tests outweighed this. In as far as air infiltration went, the amount measured was very small below the detection levels of our equipment and, in the two cases where some air leakage was noted, it may well have been due air leaking around the perimeter of the sample.

With respect to water infiltration, the only sample found to leak was the weathered basecoat which showed a number of small drips.

TABLE 11 - WATER VAPOUR TRANSMISSION VALUES OF VARIOUS MATERIALS

Material	Vapour Transmission Value $ng/m^2/s$
EIFS Base and Finish Coat	300 to 2800
Building Paper	55,000
Vapour Barrier	14 to 61
Roofing Membrane	< 3

Moisture Permeability Conclusions:

For comparative purposes, we have included in Table 11 a number of vapour transmission values for various other materials. With the EIFS lamina having an average vapour transmission rate of somewhere between 300 and 2,800 $ng/m^2/s$, it is more permeable than asphalt impregnated building paper but less permeable than a vapour barrier or roofing membrane. With respect to the product's application, this is about where we would expect it. What the "best" value would be for this product probably depends on each specific application and is beyond the scope of this project.

At the rates noted in all of the tests, we would not expect small hairline cracks nor the small imperfections (pin sized holes, etc.) to substantially effect the systems performance in as far as water infiltration and certainly not be the major cause for large scale water infiltration. Again, caution should be used in interpreting these results. These conclusions are not applicable to larger stress induced cracks. Additionally it was our opinion that the Water Permeability in Accordance to CCMC 07240 was more sensitive to water penetrations and that likely, only failures within the first minute of that test would allow actual drops of water to penetrate. Compared to the water leakage noted in the joint design tests, a failed joint is much more likely to allow passages of "large" volumes of water.

4. Thermal Expansion & Dry Shrinkage

Dry shrinkage and thermal expansion/contraction were evaluated using a modified ASTM C531. Testing was conducted on the lamina with mesh over a 50 mm thick EPS board. Each sample was 480 mm x 480 mm as this was the optimum size for accurate results. Samples were laid up with reference points embedded in the lamina and the samples allowed to cure at standard conditions. Table 12 outlines the dimensions recorded. For thermal expansion and contraction the samples were conditioned at various temperatures between +40°C. and -20°C. until equilibrium and their dimensions recorded see Table 13.

Results

TABLE 12 - DRY SHRINKAGE and THERMAL EXPANSION RATES millimetre change per 10 meters of lamina			
Samples	**Mesh Wt. (gm/m^2)**	**Shrinkage (mm)**	**Thermal Expansion (mm/C)**
Lamina 1	151	9.7	0.11
Lamina 2	168	11.4	0.08
Lamina 3	670	11.7	0.15

Conclusions

The above data is for an unrestrained plainer lamina on 50 mm of EPS, it would be our opinion that the orders of magnitude noted would be similar for most other PB EIFS systems and that since the EPS has a fairly low compressive and tensile modulus these values should be relatively unaffected by the foam thickness. Based on this it would appear that the contraction of the lamina for a 10 m run would be approximately 10 mm during drying. This, however, is not a serious concern since caulking is not installed until the majority of this shrinkage has occurred. In our experience, the only time this plays a role is when the lamina has been installed to thick or it drys too quickly resulting in stress cracking.

Of more interest is the contraction due to thermal changes. For a drop of 30 °C, 10 m of unrestrained lamina would be expected to change 3.3 mm. In actual field conditions the mesh is restrained however, by the foam and hence actual in place lamina would be expected to contract/expand somewhat less than this. Since large expanses of EIFS have been used successfully without expansion joints it is unclear at this time whether stress due to thermal changes are significant. Regardless of this, it is the responsibility of the designer to understand this mechanism and at least consider its impact on the total design.

5. Mesh Tensile Strength

The purpose of this evaluation was to determine if there were any major difference between the meshes used in the industry and whether they appeared to be subject to any digitation due to weathering or alkali attack. Samples of mesh were tested in accordance with ASTM D1682 as received and as part of the lamina. Tests on the lamina were run after 28 days and after 1000 hours of accelerated aging in accordance with ASTM G53.

Results

TABLE 13 - ULTIMATE TENSILE STRENGTH OF MESH

Sample	Heavy Mesh Ultimate Load		Standard Weight #1 Ultimate Load		Standard Weight #2 Ultimate Load	
	Cross (N)	Machine (N)	Cross (N)	Machine (N)	Cross (N)	Machine (N)
1	--	5004	489	560	1103	391
2	2695	4848	569	560	863	436
3	3229	5115	552	534	916	532
4	3803	4986	547	525	1027	512
5	3848	5604	534	547	992	494
6	3932	4759	605	578	934	445
7	2980	4782	721	552	1019	716
8	3247	4942	543	574	1068	512
9	3705	4893	525	560	979	681
10	3803	4559	600	556	970	543
Average	**3124**	**4949**	**568**	**555**	**987**	**532**
Std Dev	1115	263	60	16	68	99
Min.	2695	4559	489	525	863	391
Max.	3932	5604	721	578	1103	716
Density gm/sqm		670	151		168	

TABLE 14 - ULTIMATE TENSILE STRENGTH OF MESH AND BASECOAT

Sample	Weathered Lamina Heavy Mesh		Non-weathered Lamina Standard Weight		Weathered Lamina Standard Weight	
	Cross (N)	Machine (N)	Cross (N)	Machine (N)	Cross (N)	Machine (N)
1	4404	4541	1290	1290	854	934
2	4208	3959	1214	1334	1081	1027
3	4626	4332	1099	1228	881	934
4	4795	4226	1050	1401	836	1045
5	4448	4150	1085	1672	881	979
Average	**4496**	**4242**	**1148**	**1385**	**907**	**984**
Std Dev	200	193	90	154	89	46
Min.	4208	3959	1050	1228	836	934
Max.	4795	4541	1290	1672	1081	1045
Thickness	5.06	5.06	2.53	2.53	2.53	2.53

Conclusion

The tests on the mesh indicated a substantial difference in strength between meshes of different types and also of the directional properties of some mesh. Sample #2 was 50% stronger in the cross direction than in the machine direction. Since mesh sample #2 was directionally sensitive, it would seem that applicators should be made aware of this so that they can utilize it in the correct orientation where additional strength is required, for example window corners.

A comparison of mesh strengths to that claimed by the manufacture indicated that our findings were similar to the claimed values. Some values varied by as much as 25% but this may well have been do to the use of different tests methods. The test method used by the mesh supplier was ASTM D638.

Tests on mesh embedded in basecoat (lamina) indicated that the overall strength of the lamina was greater than that of the mesh and that weathering did effect strength of the lamina decreasing it by approximately 25%. At this time we are not sure if this constitutes a significant degradation of the lamina but since we do not commonly see ripping or tearing as a major concern in the field, it is our opinion at this time that it is not a major concern.

Program Review and Conclusions

This study compared various aspects of Exterior Insulation Finish Systems to evaluate specific aspects of their performance when subjected to accelerated weathering. This work is for research purposes only and not intended to provide specific system recommendations, in order to insolate specific properties, tests were run on samples that in many cases were not representative of a full system but which were designed to minimize the influence of other factors. As a consequence, the data must be treated with care to ensure that conclusions drawn from the tests are indicative of the real world performance of the full system. With this in mind, we felt the following were the major findings of this study

Bond Strength

The most important criteria is the ability of the joint to keep air and water out. To reliably do this the joint must accommodate movement of respective EIFS panels to this end the elongation of the Low Modulus Sealant was felt to be the most important parameter. The tests indicated that in this respect, the silicone based sealants performed best allowing around a 300% joint movement. The silicone also had the added advantage that they did not overstress and damage the EIFS lamina.

The Dymerics withstood joint movements in excess of the traditional ± 25% and generally exhibited very good bonding to the EIFS lamina and certainly seem to able meet present expectations. It is possible that their performance could be improved by ensuring the thickness of the caulking was kept to the minimum recommended by the LMS manufacturer. Some EIFS manufacturers now recommend the joint width to caulking thickness be a ratio of 4:1, most LMS manufacturers generally recommend 2:1. Increasing this ratio would lower stresses on the joint and probably provide for better joint elongation, however the ability to control this minimum thickness in the field may be questionable. Along this same line we did not feel that a double caulked joint for Dymerics would be a good practice unless the joint was redesigned since it would tend to overstress the lamina for relatively small joint movements. Temperature effects not considered, low temperatures could effect results substantially between types of sealants.

Joint Design

The joint design section evaluated eight EIFS joints designs, using accelerated weathering and a simulated joint. This test appeared to work very well at stressing the joints and appeared to duplicate field failures quite accurately. The major findings of this particular program were that for the EIFS products tested the lamina does not provide a good base for LMS to bond to when exposed to continuous wetting and stressed to design limits. In all of our tests where the joint relied on an adhesive bond, some failure was evident regardless of whether the LMS was bonded to a primed basecoat, an unprimed basecoat or a finish coat. Of these three, the primed basecoat was found to perform the best and the finish coat the worst. The best options for joint designs appear to be the use of some sort of mechanical device. In its most simple form, this can be a flashing. However, since it was found that the LMS did maintain their bond under low stresses, it is felt that other mechanical joints incorporating slip joints or bellows type devices might be able to provide more functionality and be more ascetically appealing provided they required little force to expand and contract. It was also felt that all joints should be designed so that they do not have flat surfaces for water to pool.

The use of a secondary seal was found to improve overall joint reliability. A simple membrane functioned well in out-tests but some concern was raised about draining any water getting into the cavity between the primary and secondary seal. If this water was not allowed to drain effectively, the water would cause degradation of the lamina and could seriously damage some substrate commonly used with EIFS. Also depending on how and where the membrane was attached, mechanical fastening of the foam board could be necessary.

An optional secondary seal that also provided improved performance over a simple face sealed joint was expandable impregnated foam tape. This product did not appear to perform as well as the membrane and required special attention at joints to make a good water resistant seal. The tape did have the advantage that it was easy to use and could readily be added to most present joint designs with out modification.

Faced sealed systems were not found to be reliable were joints were subjected to the traditional design movements of ± 25%, however they were found to work extremely well where the joint movements were minimal. Unfortunately, the determination of the actual safe working range was not within the scope of this program nor were variations on the LMS width to thickness ratio, which may have shown improved results by lowing the working stresses.

Moisture Permeability

Our findings tended to indicate that one of the greatest factors affecting moisture permeability of an EIFS wall was the lamina thickness. Due to the fact that EIFS is a hand applied material, it is subject to imperfections from variations in the installation and inconsistency of the basecoat and finish coat (ie. large sand grains etc.). As such, increases in the lamina thickness tends to reduce the risk of small holes which can allow a relatively large volume of moisture thought the lamina. It was also found that increasing the lamina thickness tended to increase the chances of drying shrinkage cracks, although this condition appeared to be less sensitive to moisture permeability. Additionally, it was found that the addition of the finish coat improved overall moisture resistance around 25%, as it provided a secondary seal and covered up imperfections in the basecoat.

Our tests appeared to be relatively inconclusive in determining how the lamina moisture permeability was effected by accelerated aging or rapid drying. This was due mainly to variations in the lamina thickness which was felt to be the controlling factor. However, since the results did not show significant degradation of the moisture permeability and since it was generally of a low value, it is our opinion that permeability of the lamina is not likely a major concern.

For the purposes of evaluating the moisture permeability it was felt that the CCMC 07240 test provided the most discriminating values and was a better test for the lamina than the ASTM E331.

Thermal Expansion & Dry Shrinkage

Although two different sets of tests were conducted, drying shrinkage and thermal expansion, it was felt that only thermal contraction would play a role in determining joint spacing. Unrestrained lamina drying shrinkage was found to be in the order of magnitude 10 mm per 10 m of lamina, however, since the majority of this shrinkage occurs in the first 24 hours, well before the installation of the LMS, any movement caused by the drying shrinkage would not effect the joint.

Thermal expansion was found to be in the order of magnitude of 3 mm per 10 m per 30 °C of unrestrained lamina in the temperature ranges of +40 °C. to -20 °C. At this time it is unclear to us whether manufacturers currently plan for this movement in their systems or whether it creates any substantial stresses in the system. Our opinion is that because the lamina is relatively thin and applied over expanded polystyrene which has a low modulus of elasticity, that the stresses developed are not significant when compared to those from building movements.

Mesh Tensile

These tests appeared to confirm that the strengths of meshes tested were representative of the manufactures claimed values. The different grades of mesh had substantially different strength, as expected, and the combined strength of mesh and lamina appeared to be greater than that of the mesh alone.

Tests on aged lamina and unaged lamina showed some degradation of tensile strength, although the actual significance of the reduction could not be quantified as to whether it could cause a problem for the long term durability of the product. It also could not be quantified as to whether this degradation was due to alkali attack or some other mechanism.

General Comments

At this time it is our opinion that the weakest link of EIFS is the joints, specifically the ability of lamina under wet and stressed conditions to maintain its bond with the LMS. However, this does not mean these systems do not work. There are far too many good systems in the field for this to be true. The findings of this report have indicated that there are a number of methods to improve the joint performance from changing the LMS width to depth ration to the use of flashings or secondary seals incorporating rain screen principles. Although all aspects of EIFS systems must be constantly reviewed to ensure the product works as a complete system, it is certainly felt that better design and attention to joint details by manufacturers, installers and designers would probably result in the greatest pay back of increased performance and durability of the systems.

Future Work

Recommendations for future work are mainly related to the improving the performance of expansion joints. Specifically, it is felt that further studies should be conducted on:

a) Developing mechanical type joints that would induce minimal stress on the lamina. Potentially they would be designed such that they are always in compression.

b) Determining the mechanism that is causing the breakdown of the lamina bond to the LMS and potentially improving the basecoat or finish coat formulation so that they are more resistance to this mode of failure. One possibility at present would be to test joints coated with a polymer modified vapour barrier. These products are now being produced by a number of EIFS manufactures as trowel applicable vapour barrier for use with there systems. They generally have a much higher polymer content and appear to be more flexible and moisture resistant.

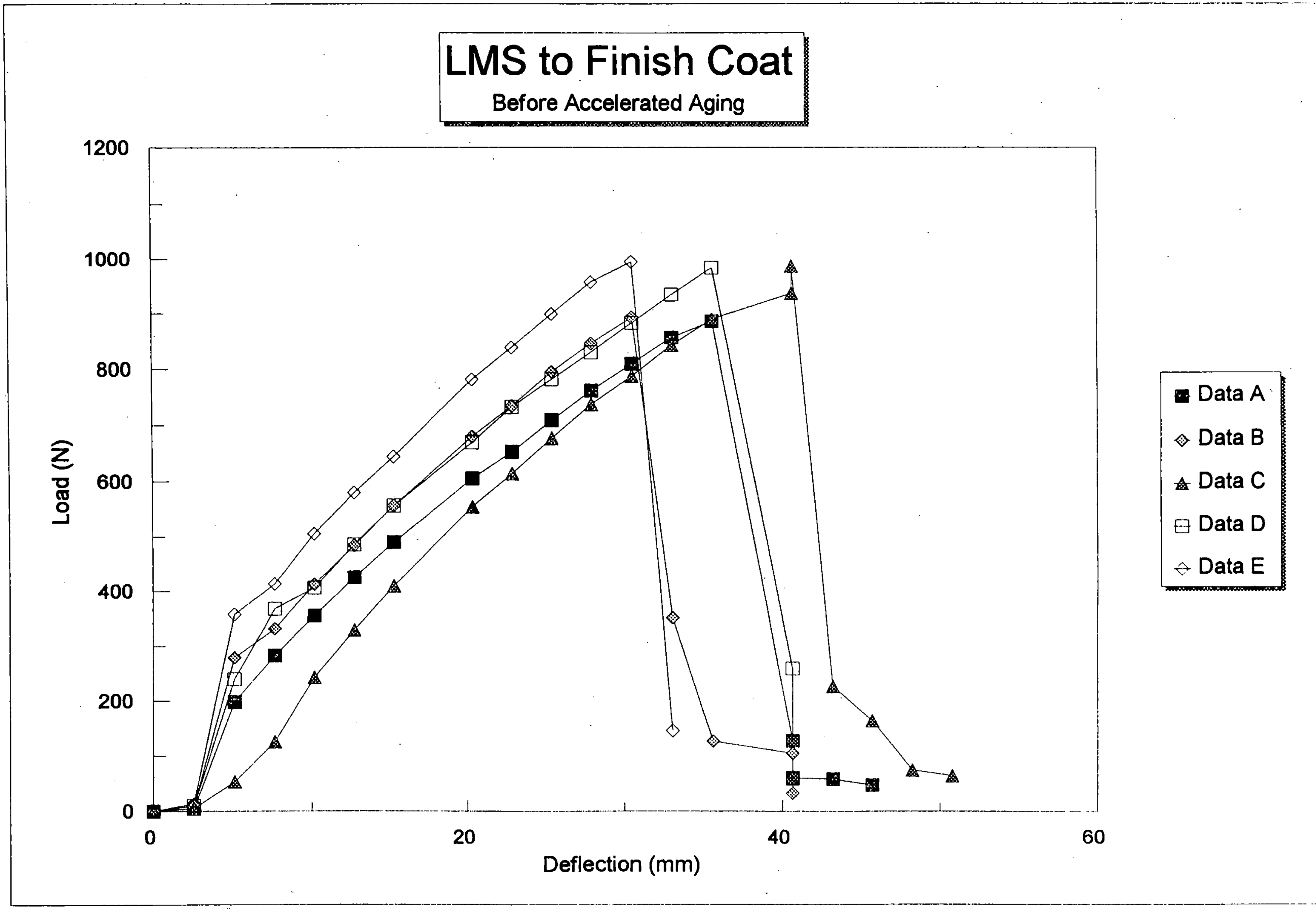
c) Evaluate the variation of rainscreen type joints to determine their water and air tightness performance as well as their efficiency of draining water and preventing water from pooling on horizontal areas (ie. in horizontal joints).

d) Develop a test or tests to rate joint performance for various applications much like the present CSA A440 standard does for windows. To this end, it is felt that the tests used in the joint design section of this investigation worked well at stressing the joints and simulating actual working conditions.

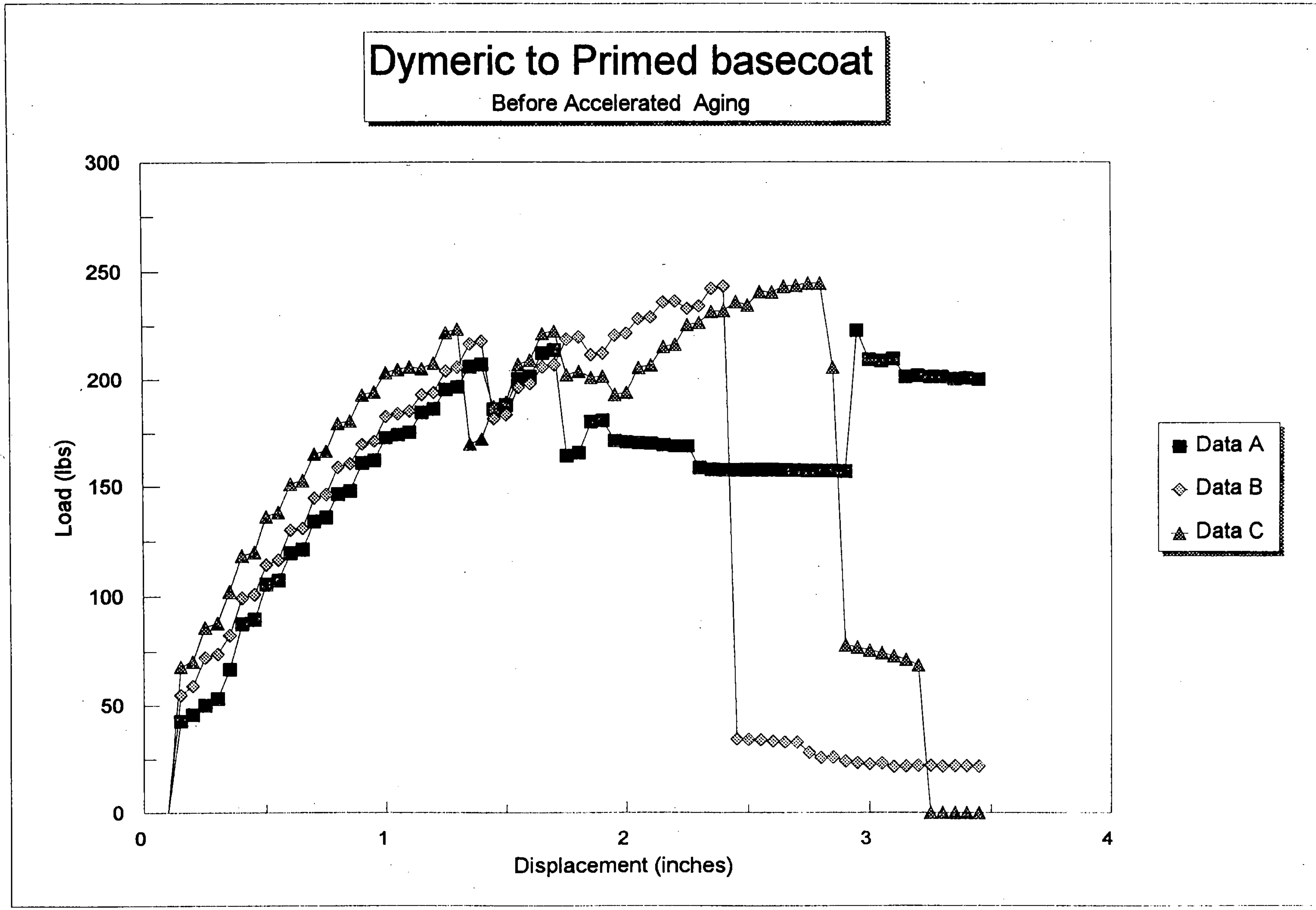
e) Evaluation of various ratio of depth to width of LMS to determine whether tensile stresses between the lamina and LMS could be reduced to provide better performing joints.

f) Evaluate effect of temperature on LMS bond and elongation performance.

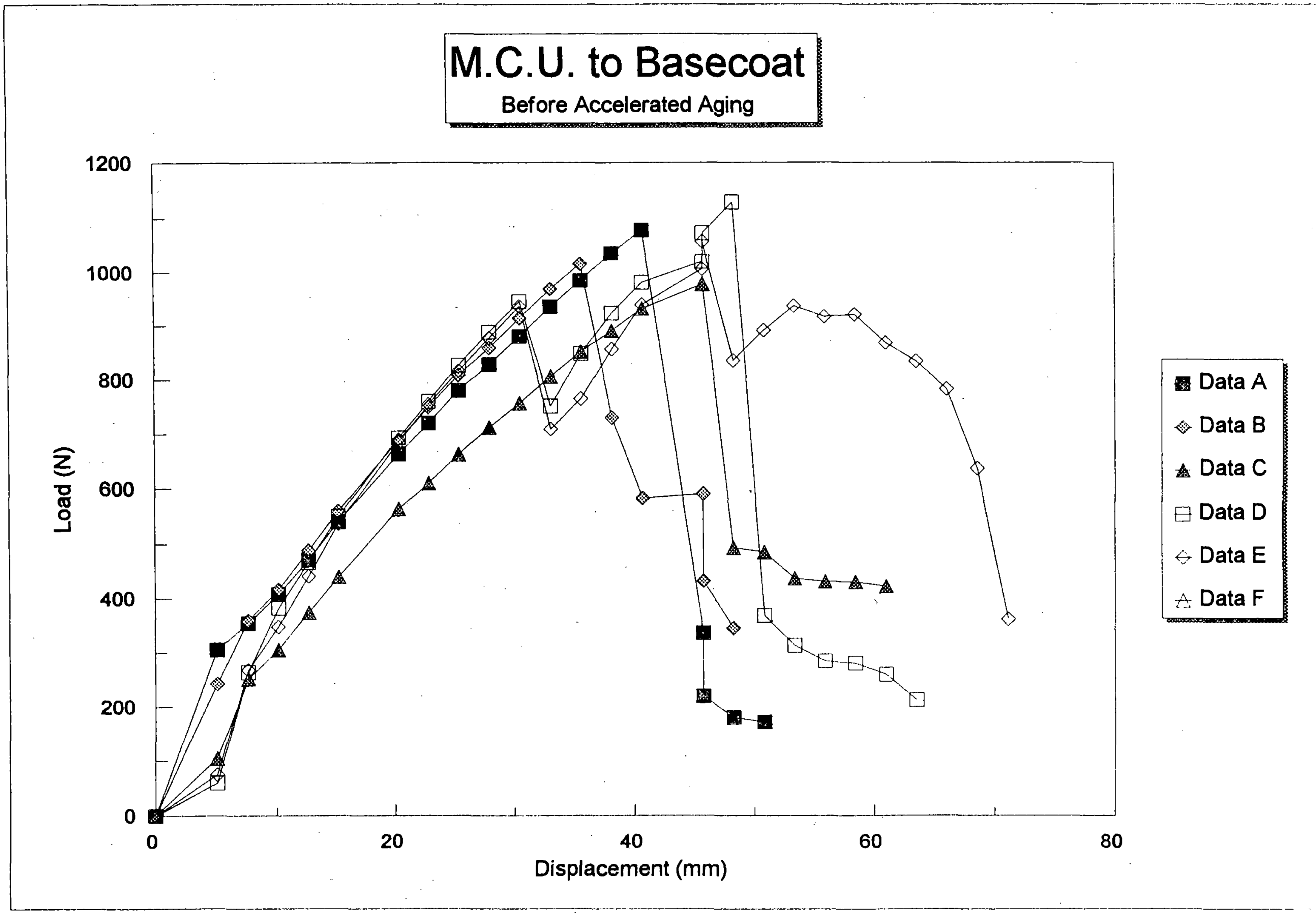
APPENDIX 1



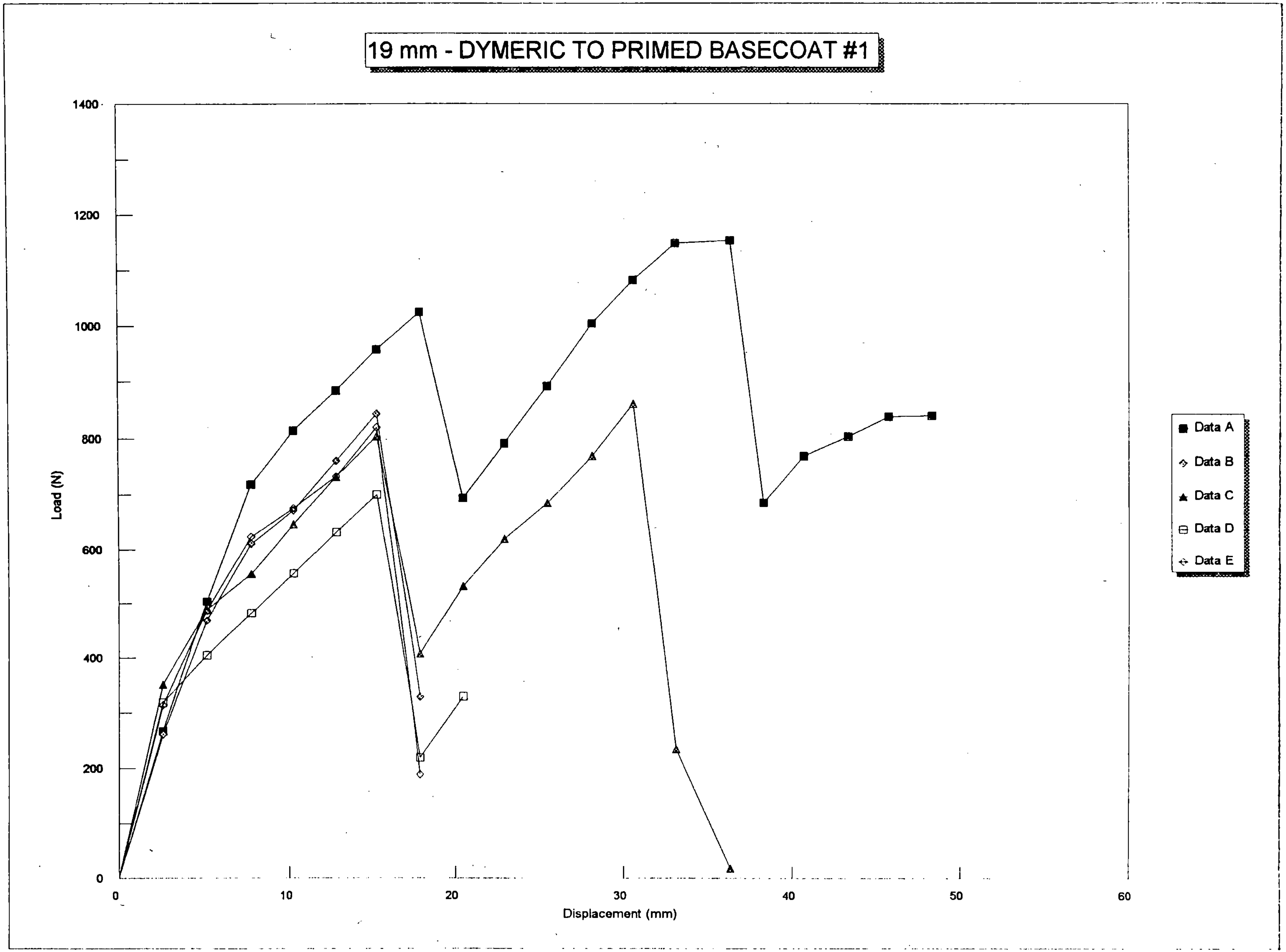
Unconditioned Joint Samples



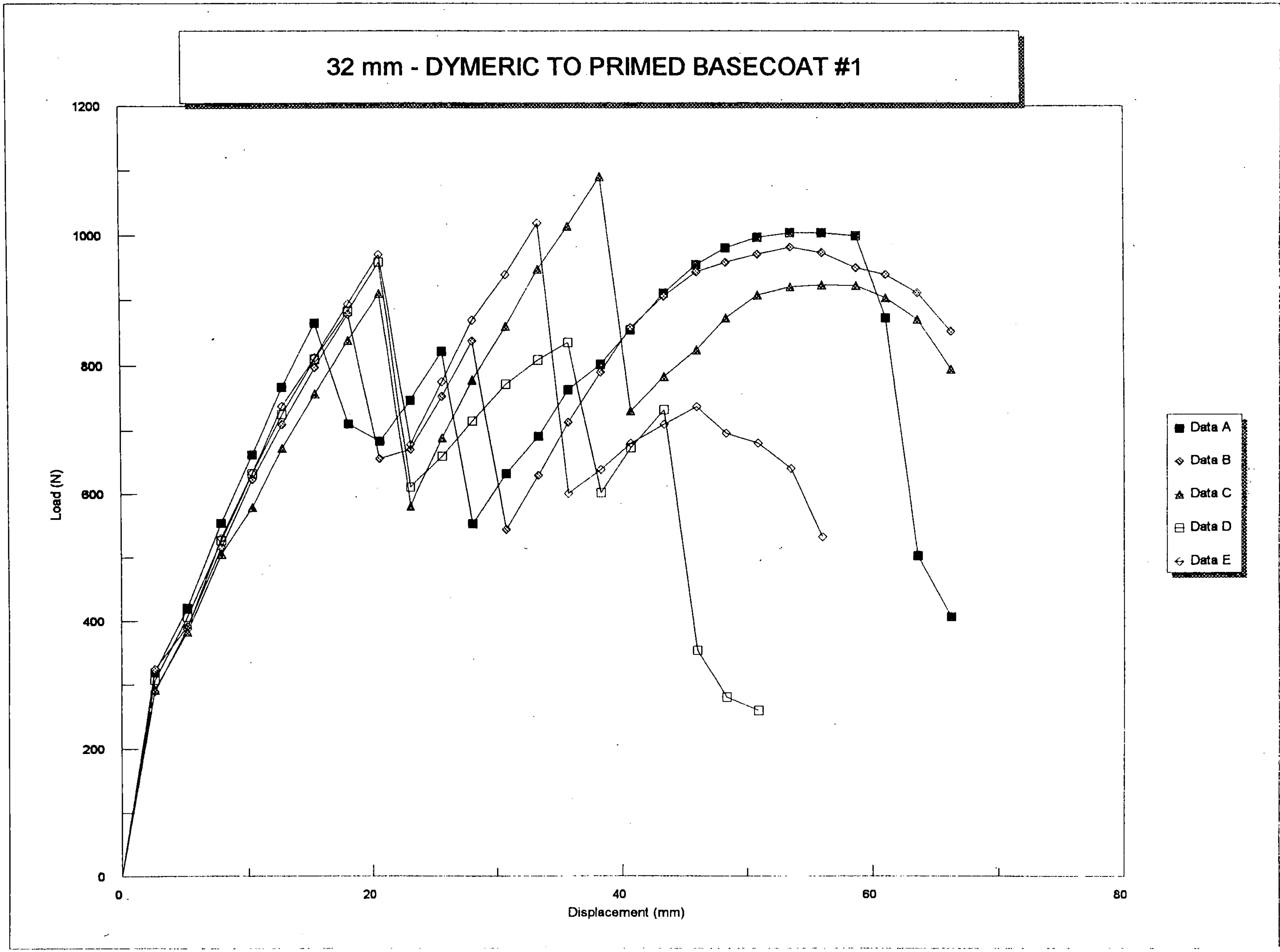
Unconditioned Joint Samples



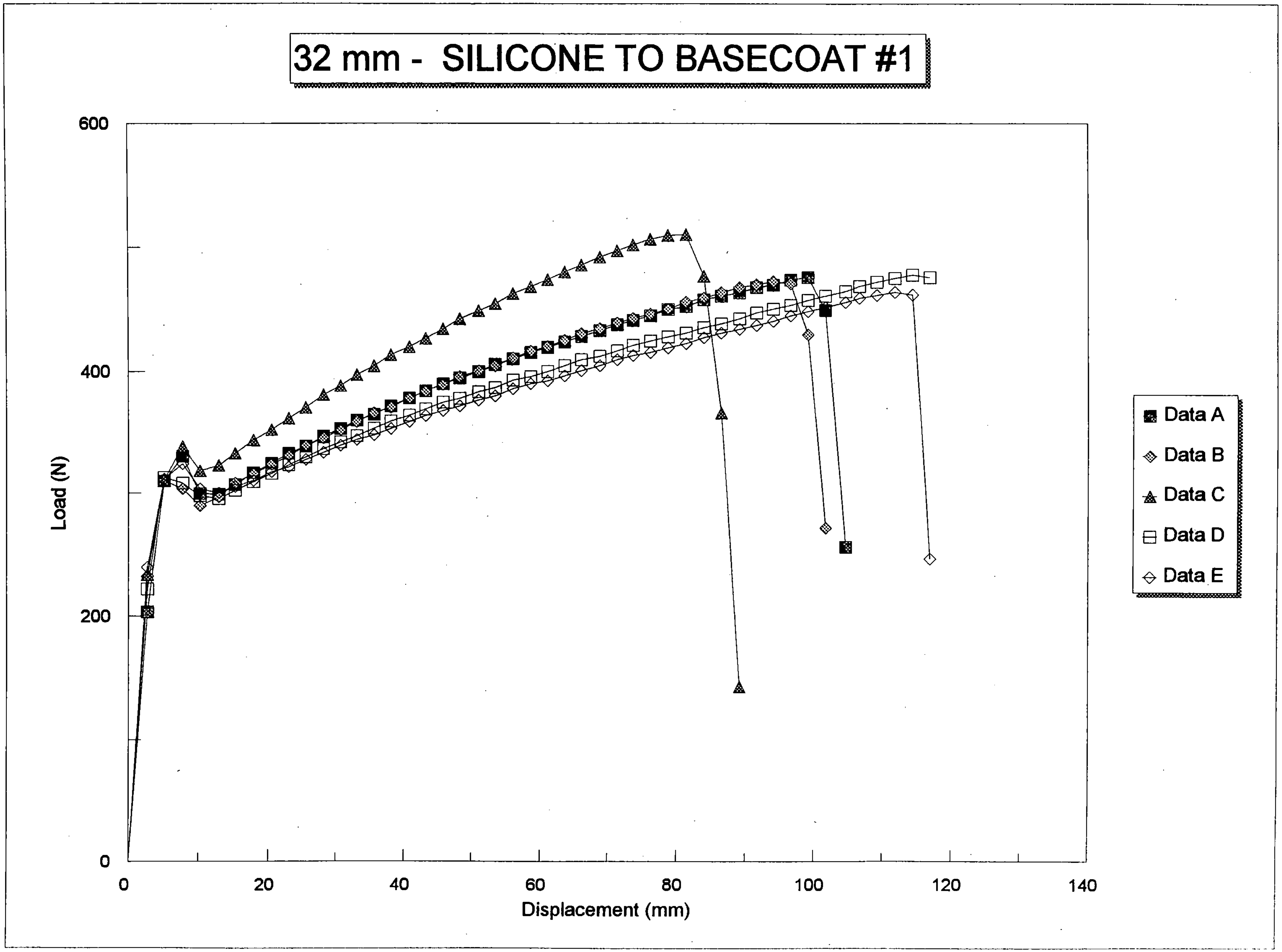
Unconditioned Joint Samples



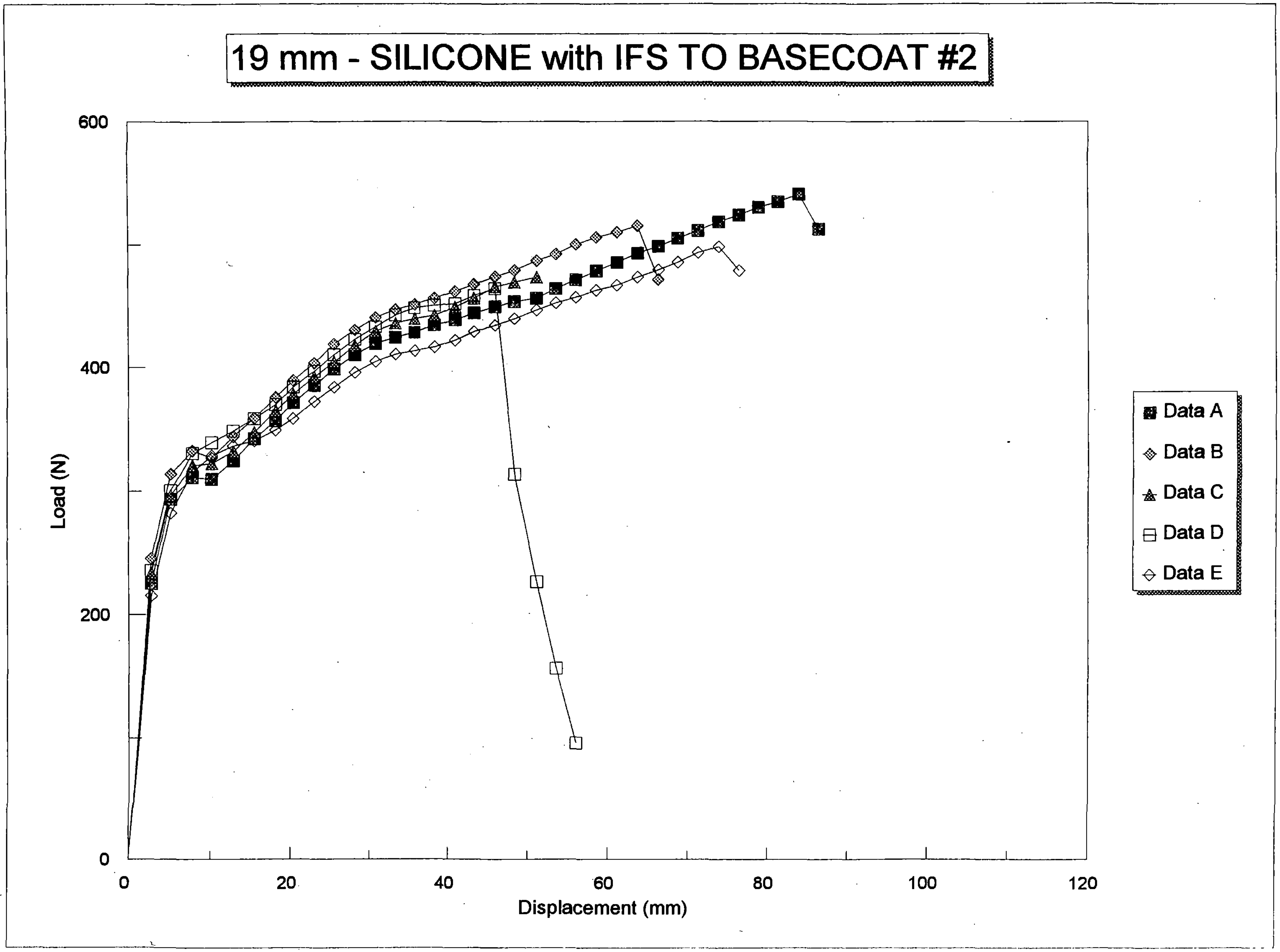
19 mm - DYMERIC TO PRIMED BASECOAT #1
Load (N)
0
200
400
600
800
1000
1200
1400
Displacement (mm)
0
10
20
30
40
50
60
Data A
Data B
Data C
Data D
Data E

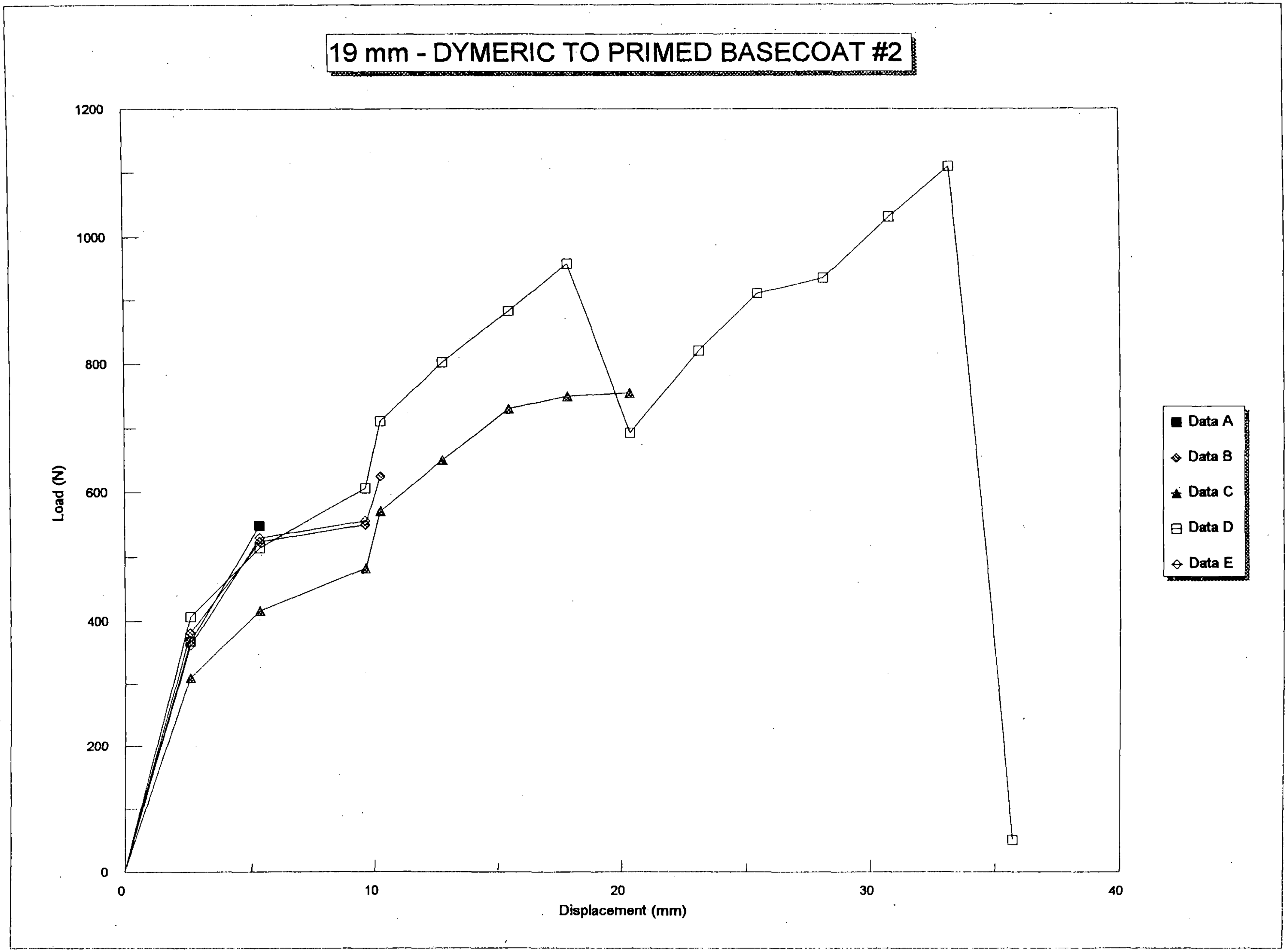


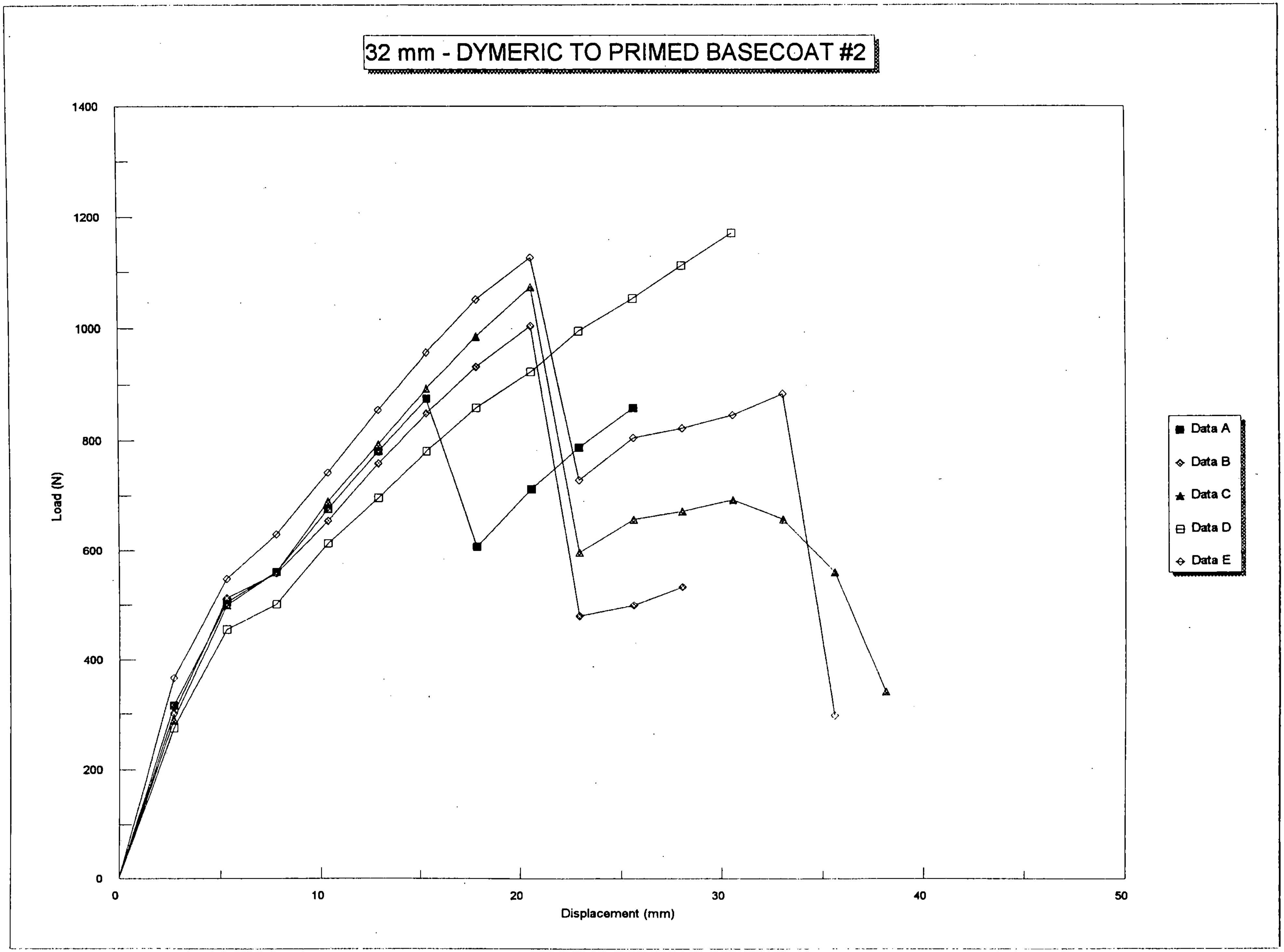
32 mm - DYMERIC TO PRIMED BASECOAT #1
Load (N)
Displacement (mm)
0
200
400
600
800
1000
1200
0
20
40
60
80
Data A
Data B
Data C
Data D
Data E



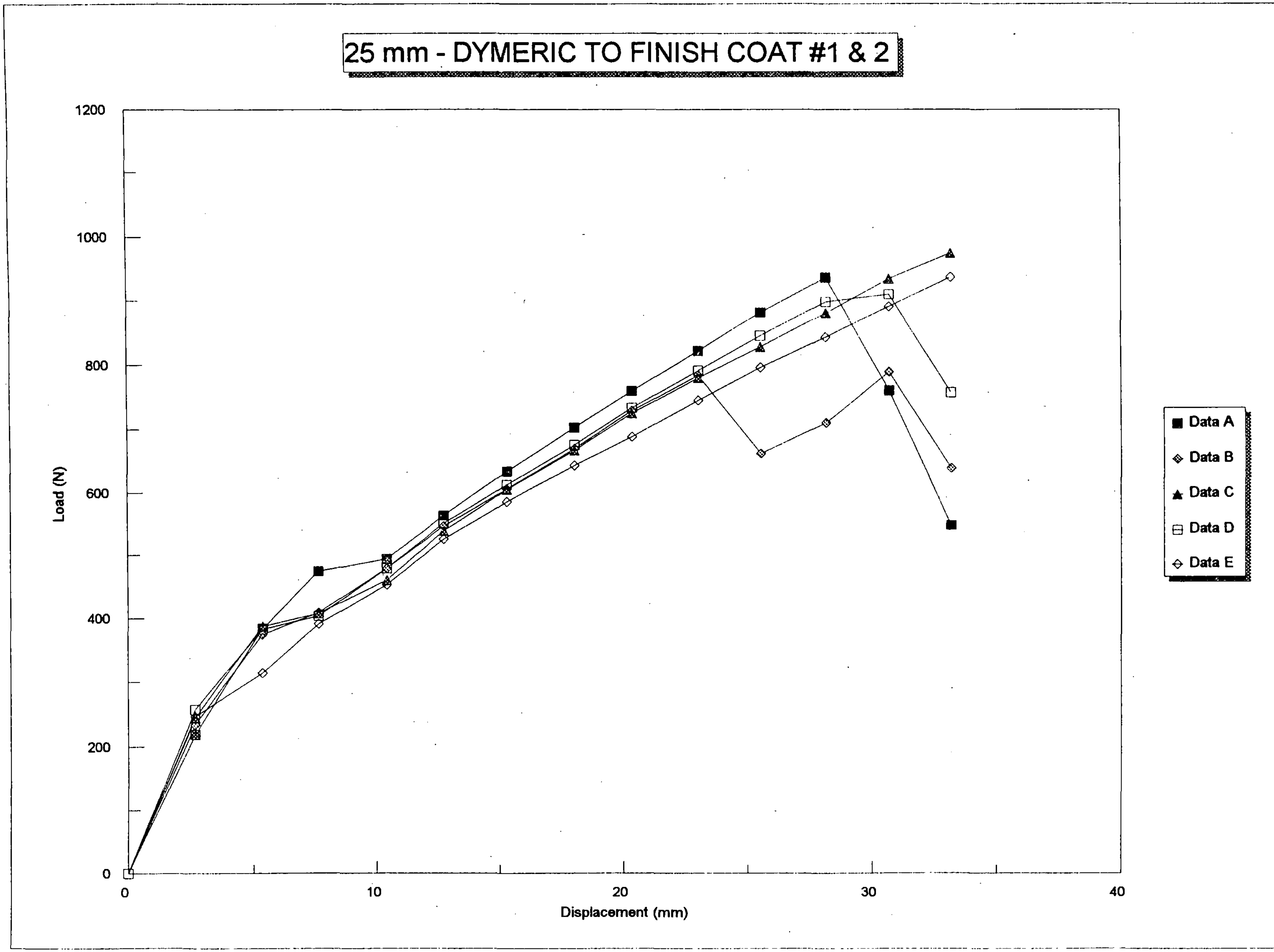
32 mm - SILICONE TO BASECOAT #1
600
400
200
0
Load (N)
0
20
40
60
80
100
120
140
Displacement (mm)
Data A
Data B
Data C
Data D
Data E

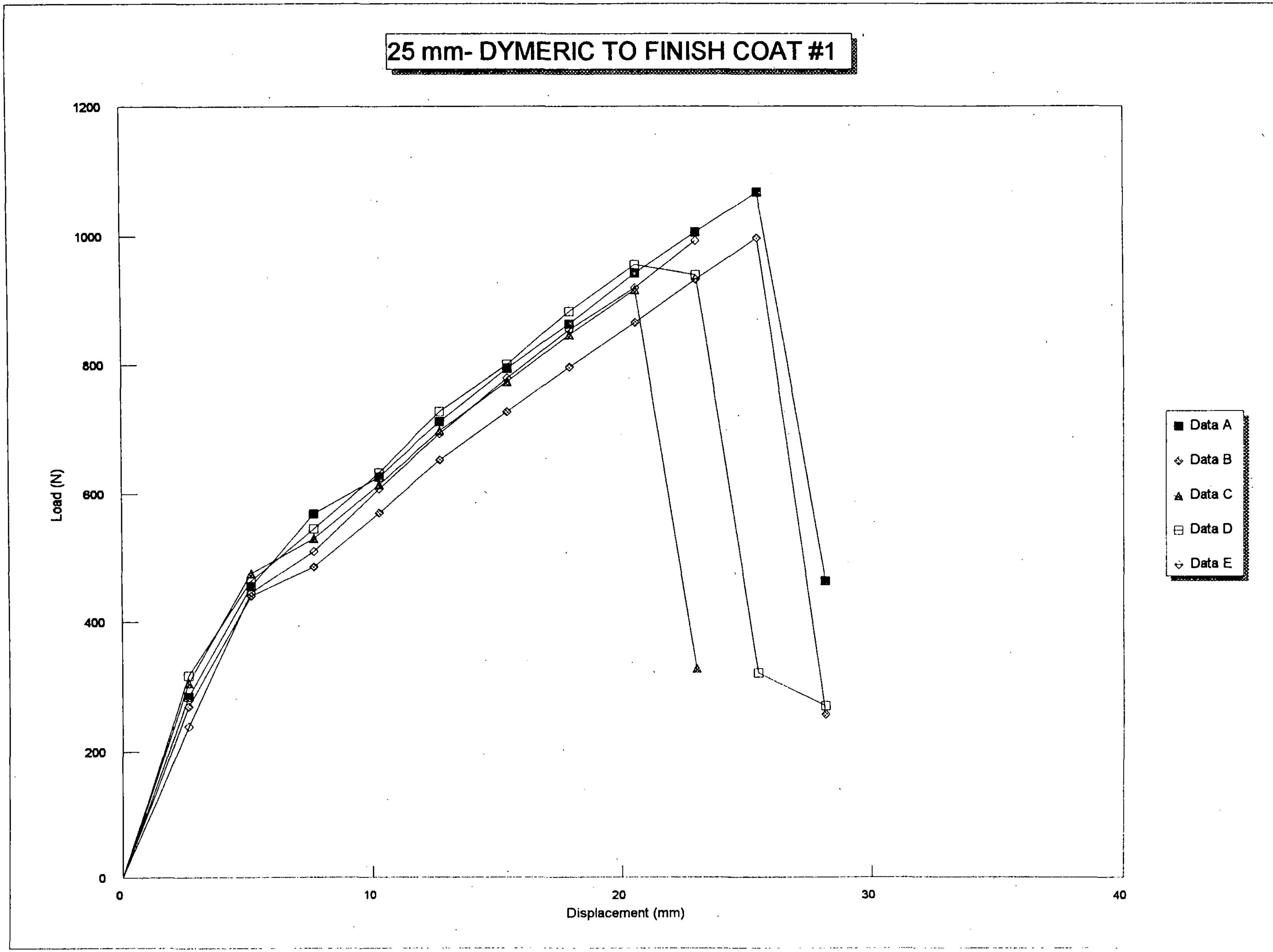

19 mm - SILICONE with IFS TO BASECOAT #2
Load (N)
600
400
200
0
0
20
40
60
80
100
120
Displacement (mm)
Data A
Data B
Data C
Data D
Data E


19 mm - DYMERIC TO PRIMED BASECOAT #2
1200
1000
800
600
400
200
0
Load (N)
0
10
20
30
40
Displacement (mm)
Data A
Data B
Data C
Data D
Data E

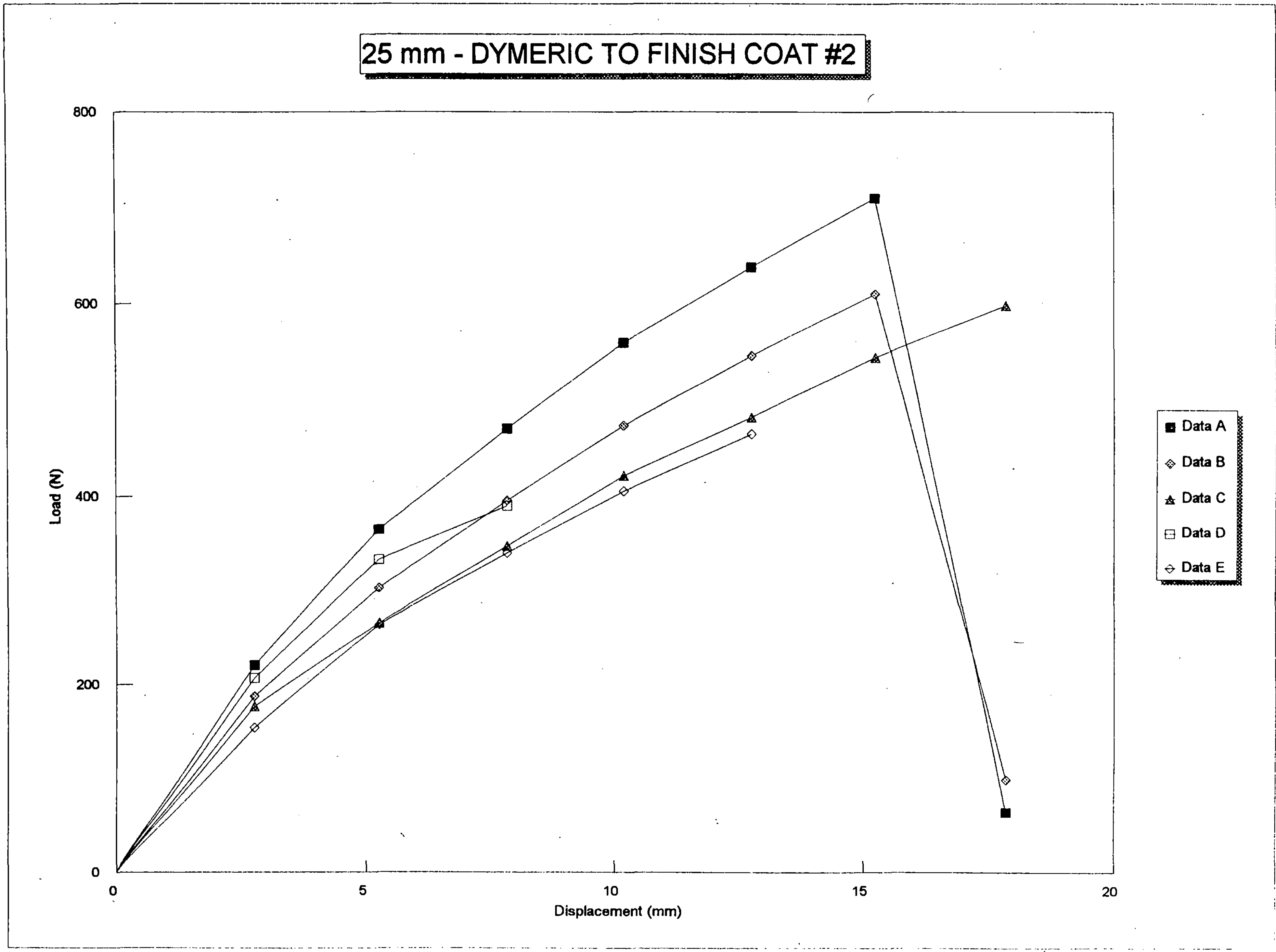


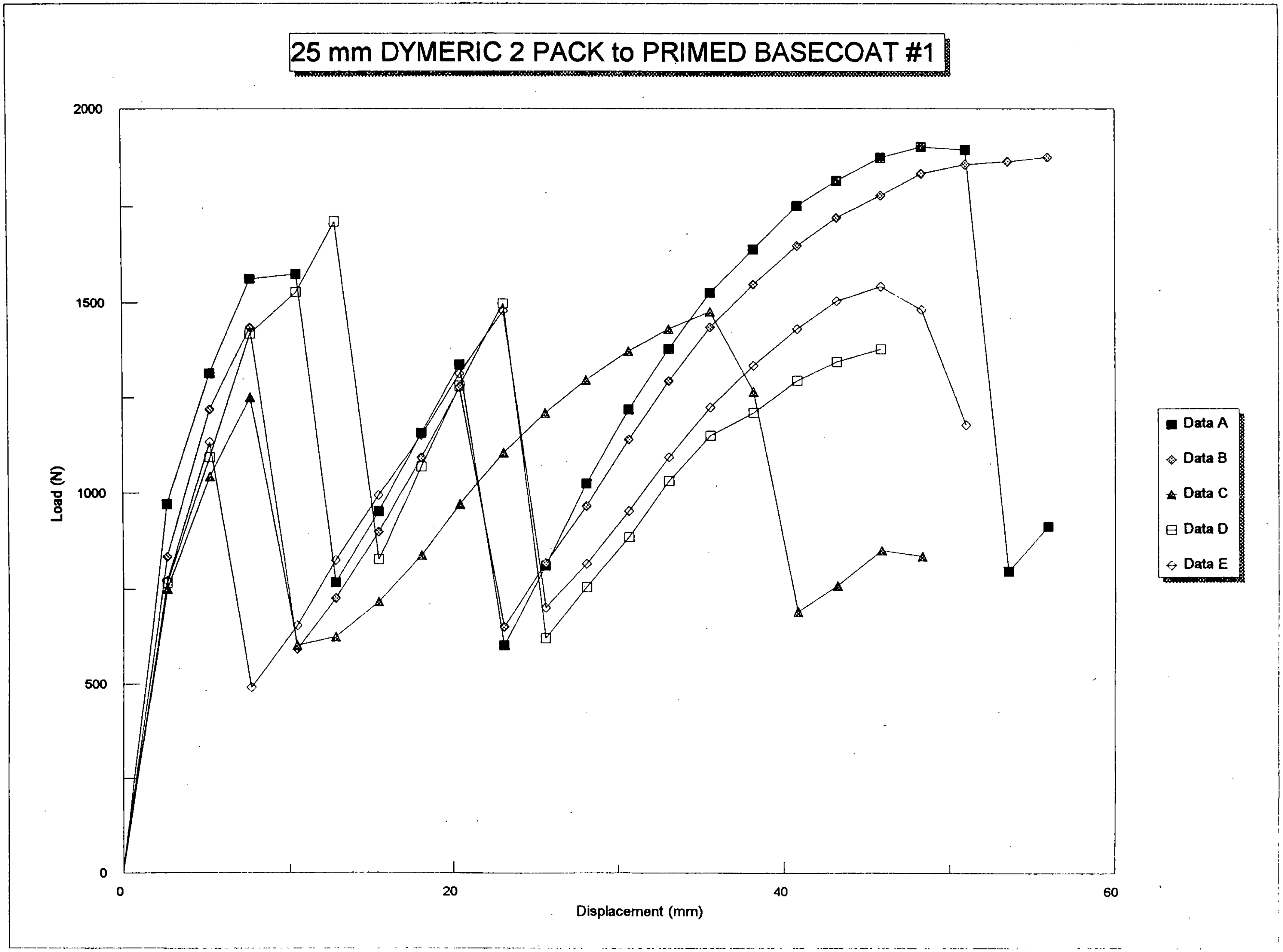
32 mm - DYMERIC TO PRIMED BASECOAT #2
1400
1200
1000
800
600
400
200
0
Load (N)
0
10
20
30
40
50
Displacement (mm)
Data A
Data B
Data C
Data D
Data E


25 mm - DYMERIC TO FINISH COAT #1 & 2
Load (N)
1200
1000
800
600
400
200
0
0
10
20
30
40
Displacement (mm)
Data A
Data B
Data C
Data D
Data E



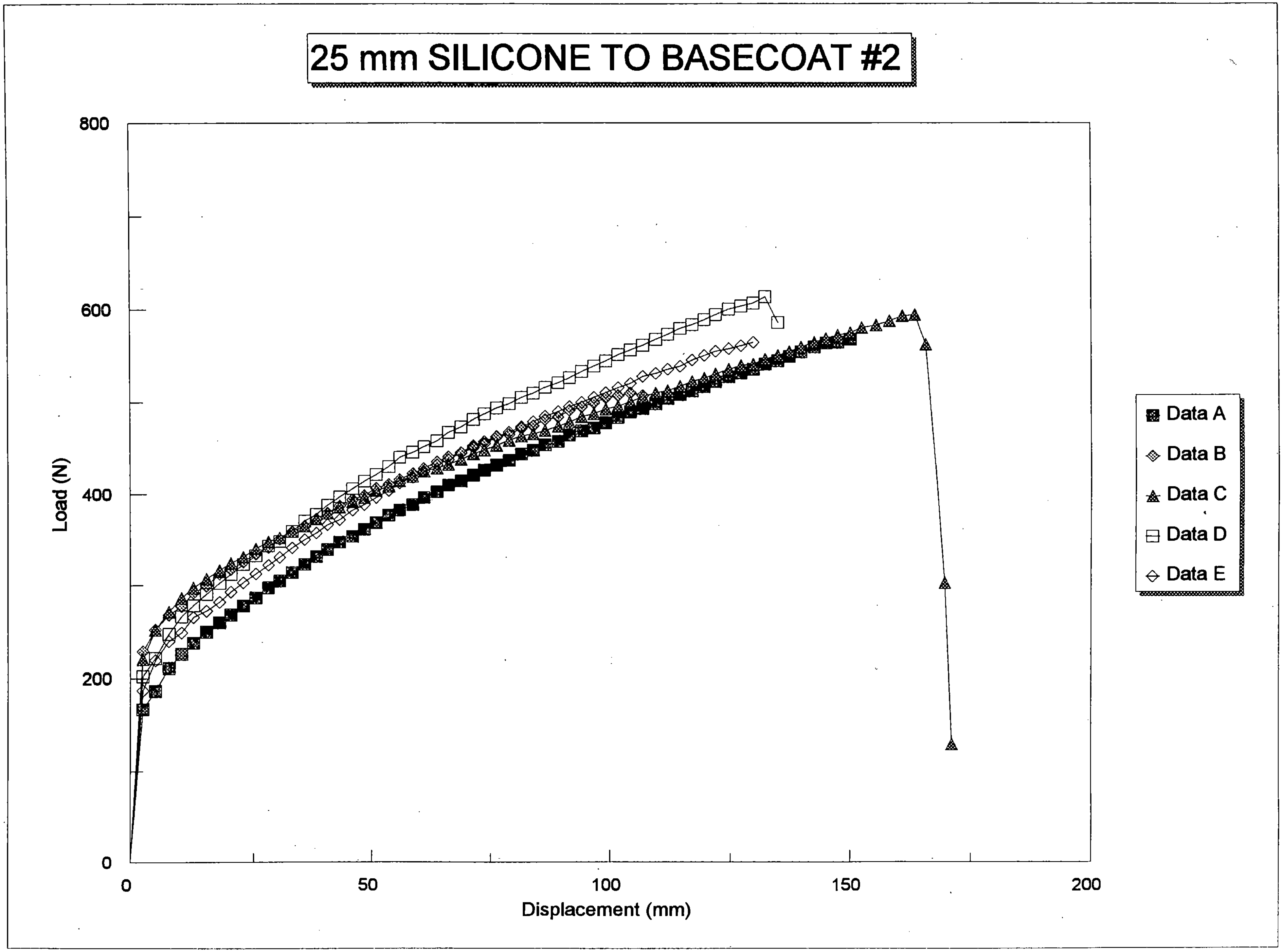
25 mm- DYMERIC TO FINISH COAT #1
1200
1000
800
600
400
200
0
Load (N)
0
10
20
30
40
Displacement (mm)
Data A
Data B
Data C
Data D
Data E


25 mm - DYMERIC TO FINISH COAT #2
Load (N)
800
600
400
200
0
0
5
10
15
20
Displacement (mm)
Data A
Data B
Data C
Data D
Data E

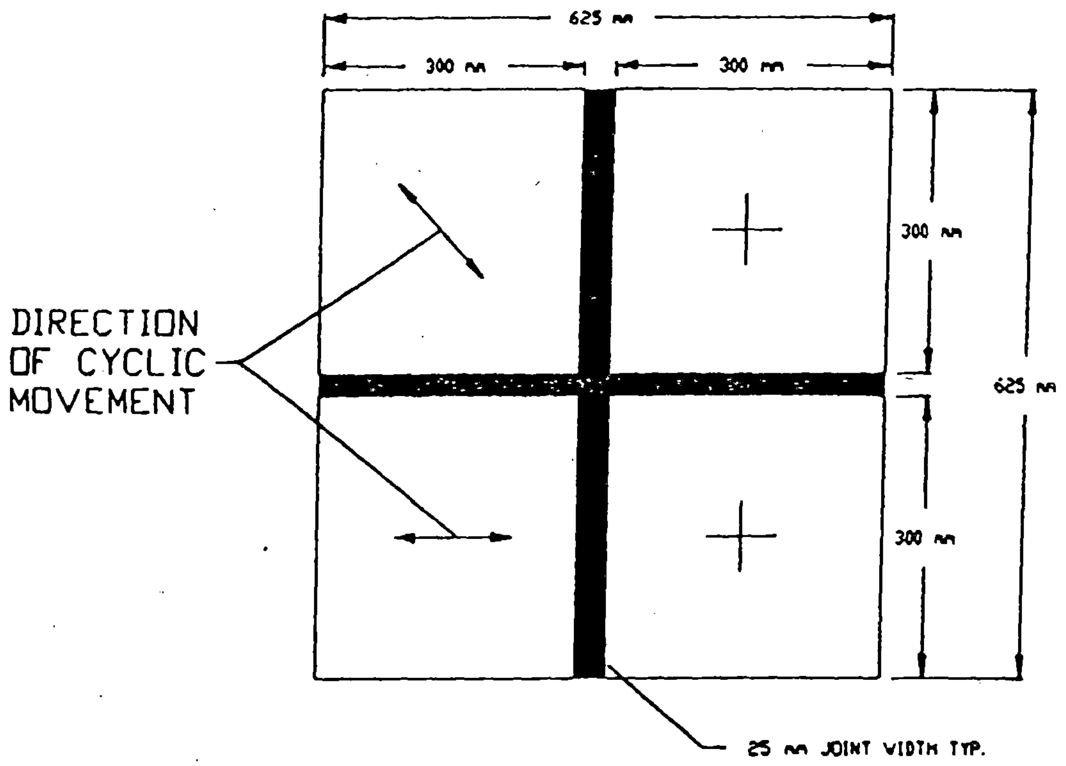


25 mm DYMERIC 2 PACK to PRIMED BASECOAT #1
2000
1500
1000
500
0
Load (N)
0
20
40
60
Displacement (mm)
Data A
Data B
Data C
Data D
Data E

APPENDIX 2

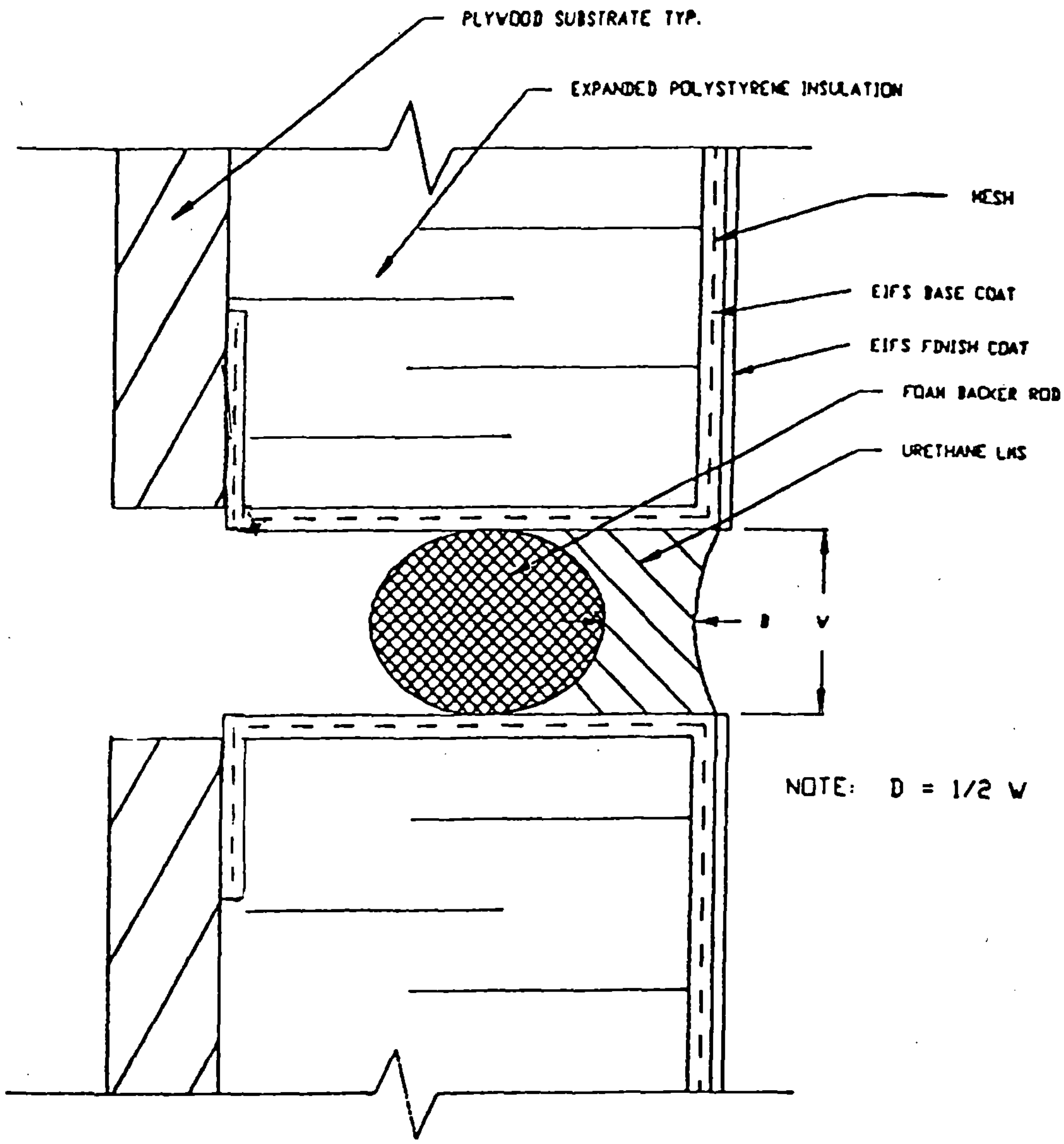


25 mm SILICONE TO BASECOAT #2
Load (N)
800
600
400
200
0
0
50
100
150
200
Displacement (mm)
Data A
Data B
Data C
Data D
Data E



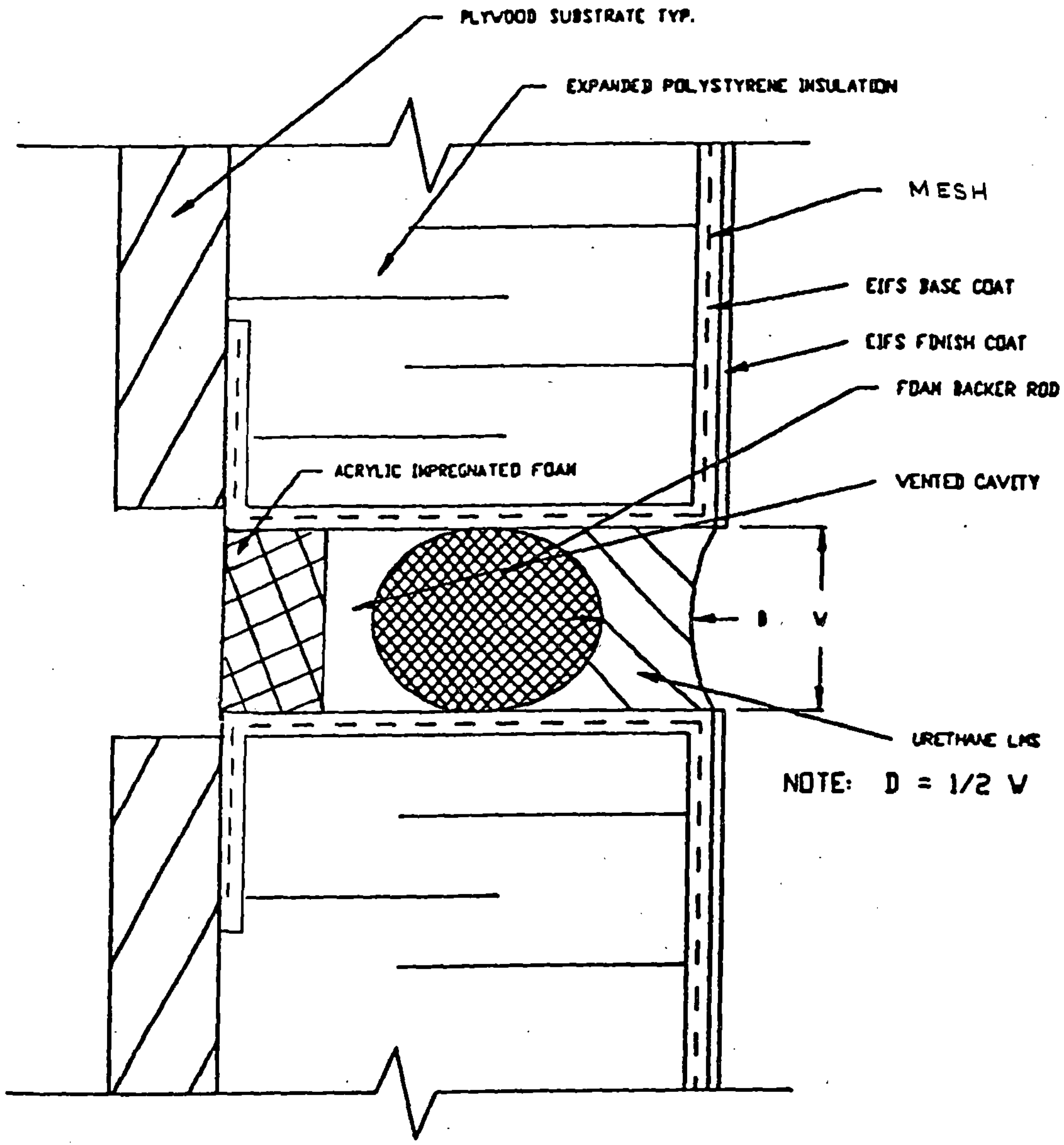
PLAN VIEW

CMHC EIFS RESEARCH PROGRAM		*DWG. 1 OF 9*
LIFE CYCLE TEST SAMPLES		
SCALE: N.T.S.	*DATE: 93-8-18*	*DWG. BY: P.A.*



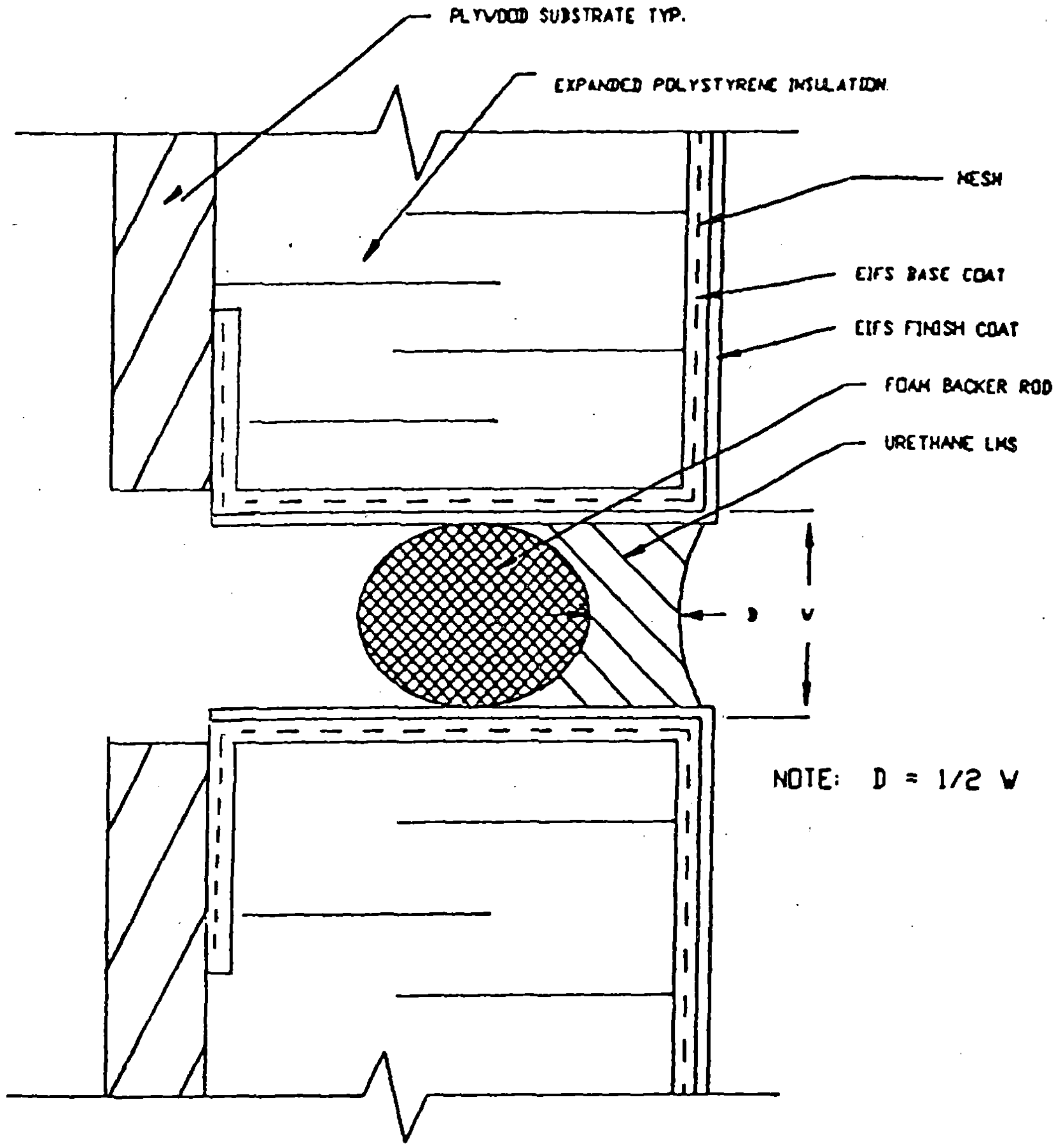
SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM	DWG. 2
LMS to EIFS BASE COAT	OF 9
SCALE: N.T.S. DATE: 93-8-18	DWG. BY: P.A.



SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM		*DWG. 3 OF 9*
VENTED LMS to EIFS BASE COAT		
SCALE: N.T.S.	*DATE: 93-8-18*	*DWG. BY: P.A.*



SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM	DWG. 4 OF 9
LMS TO EIFS FINISH COAT	
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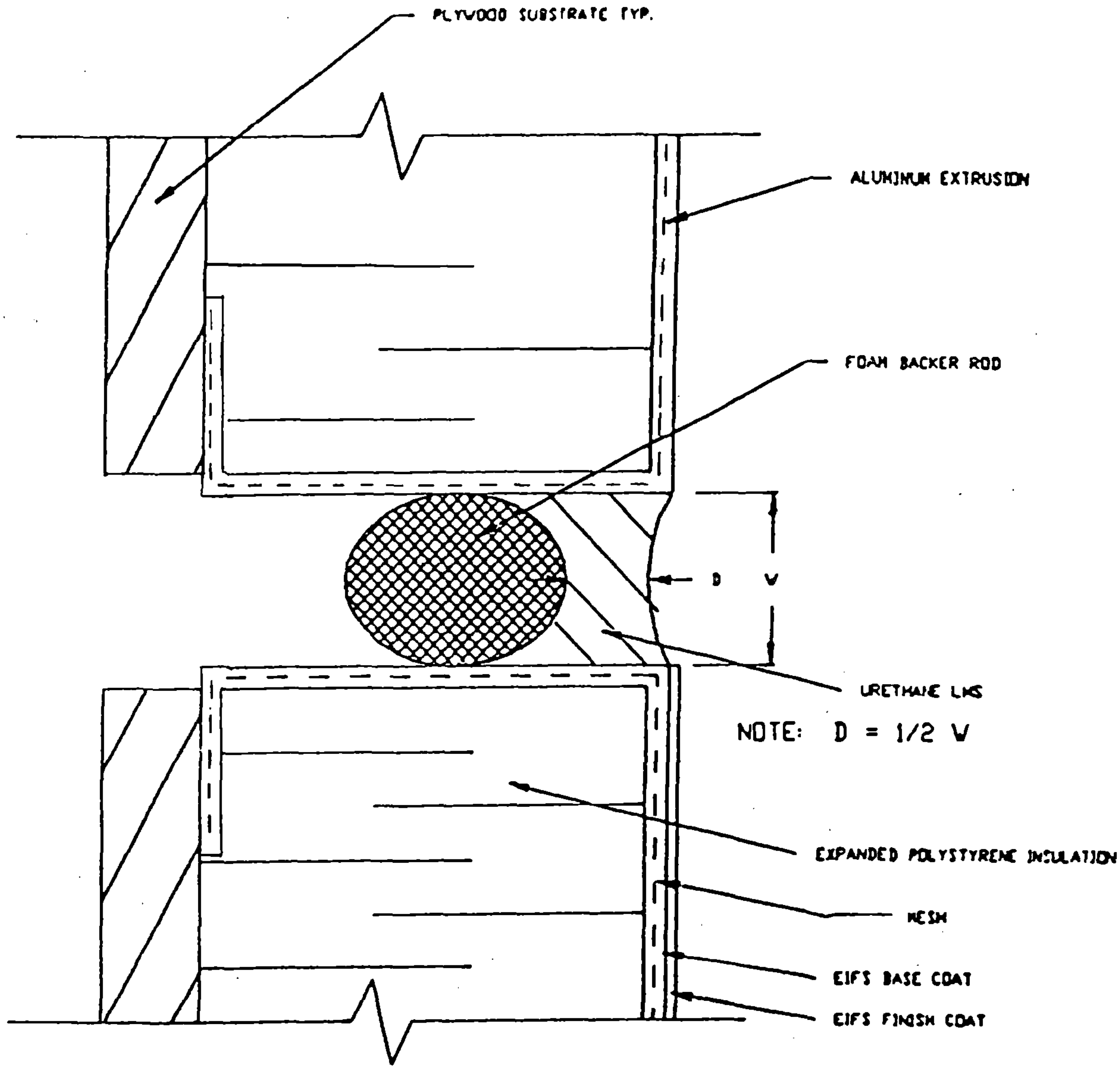

SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM		DWG. 5 OF 9
LMS PENETRATION JOINT		
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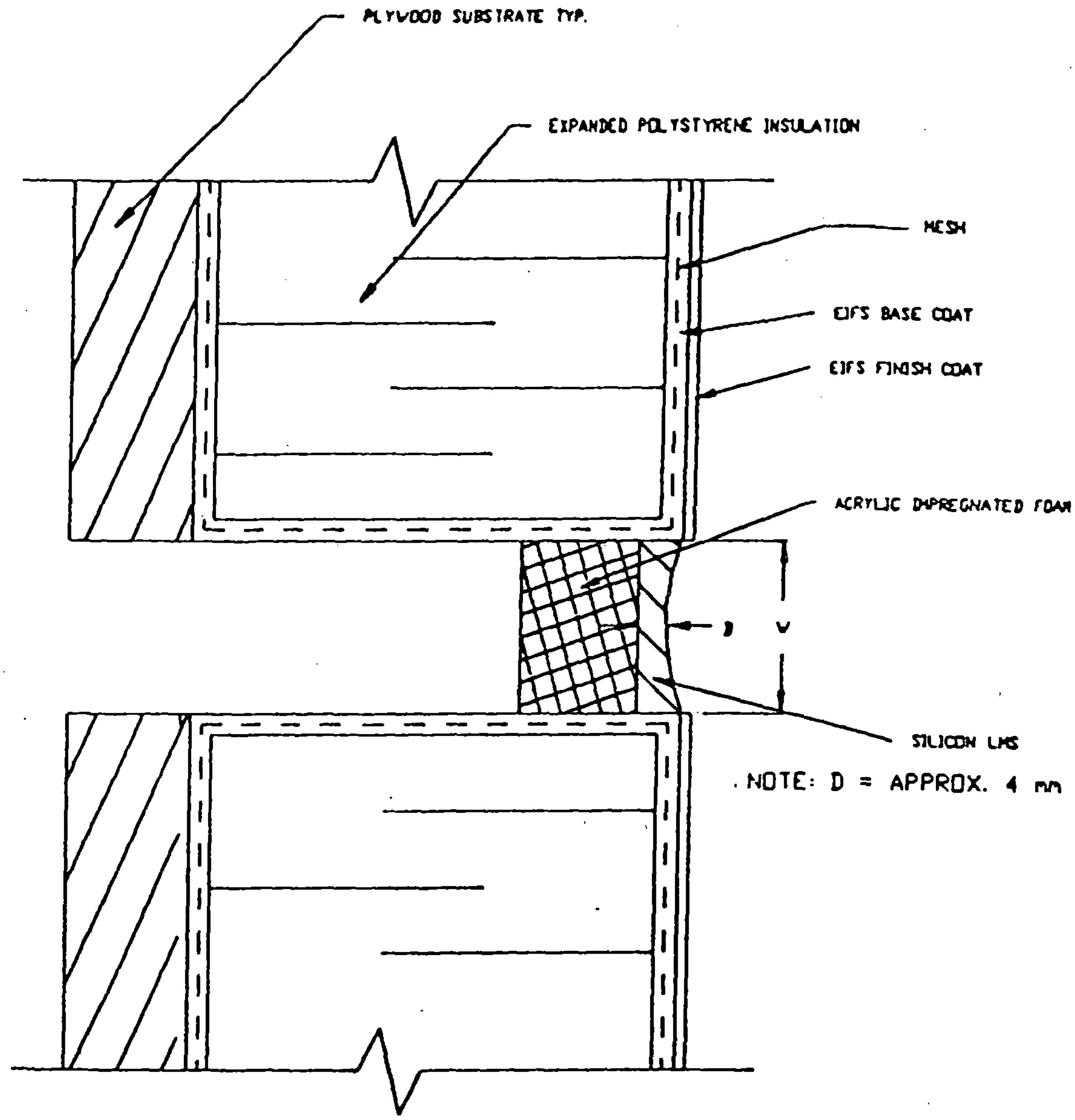

SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM	DWG. 6 OF 9
ASHPALT IMPREGNATED FOAM	
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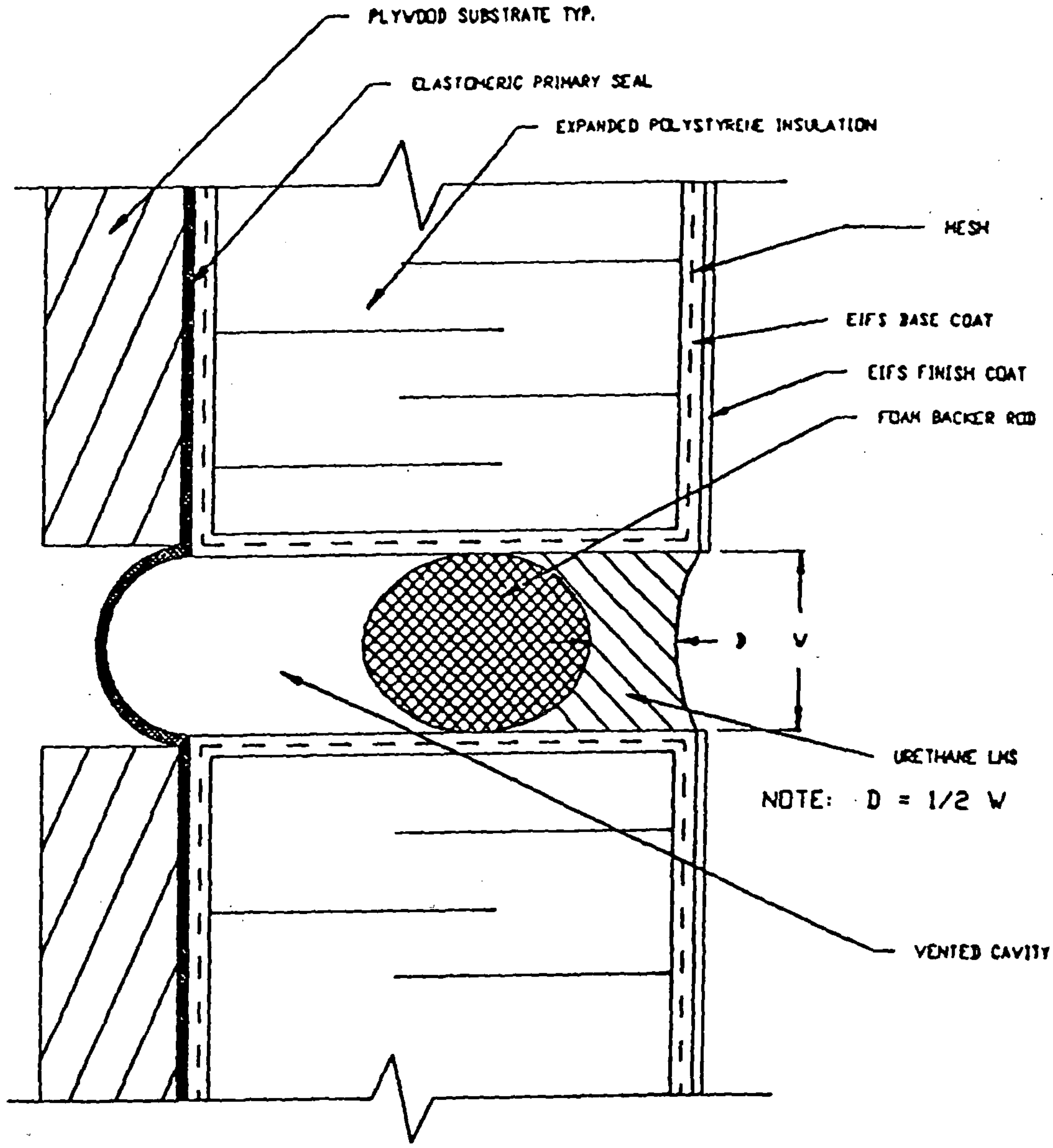

SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM		DWG. 7 OF 9
ELASTOMERIC/LMS VENTED JOINT		
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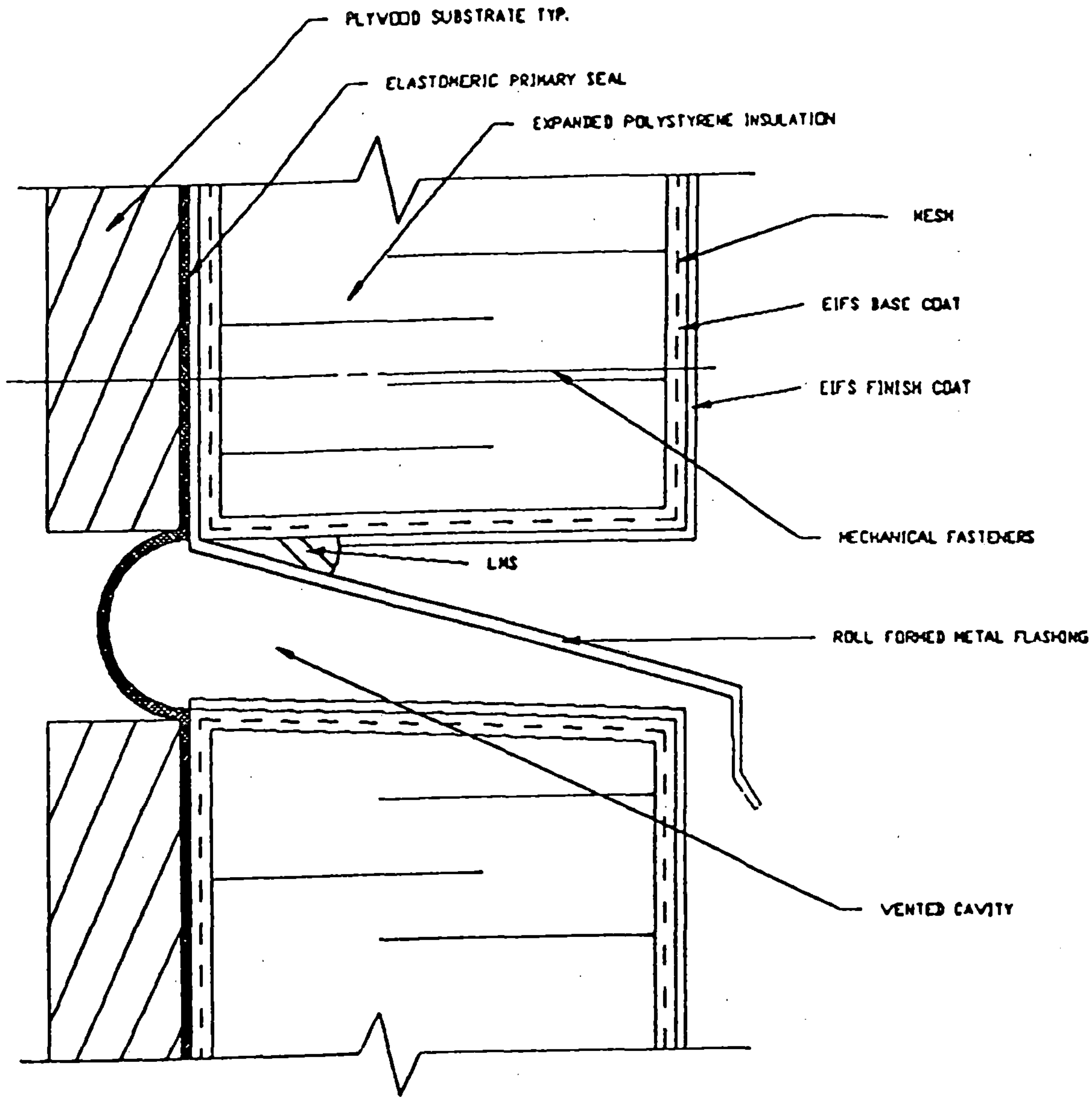

SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM	DWG. 8 OF 9
ELASTOMERIC/FLASHING JOINT	
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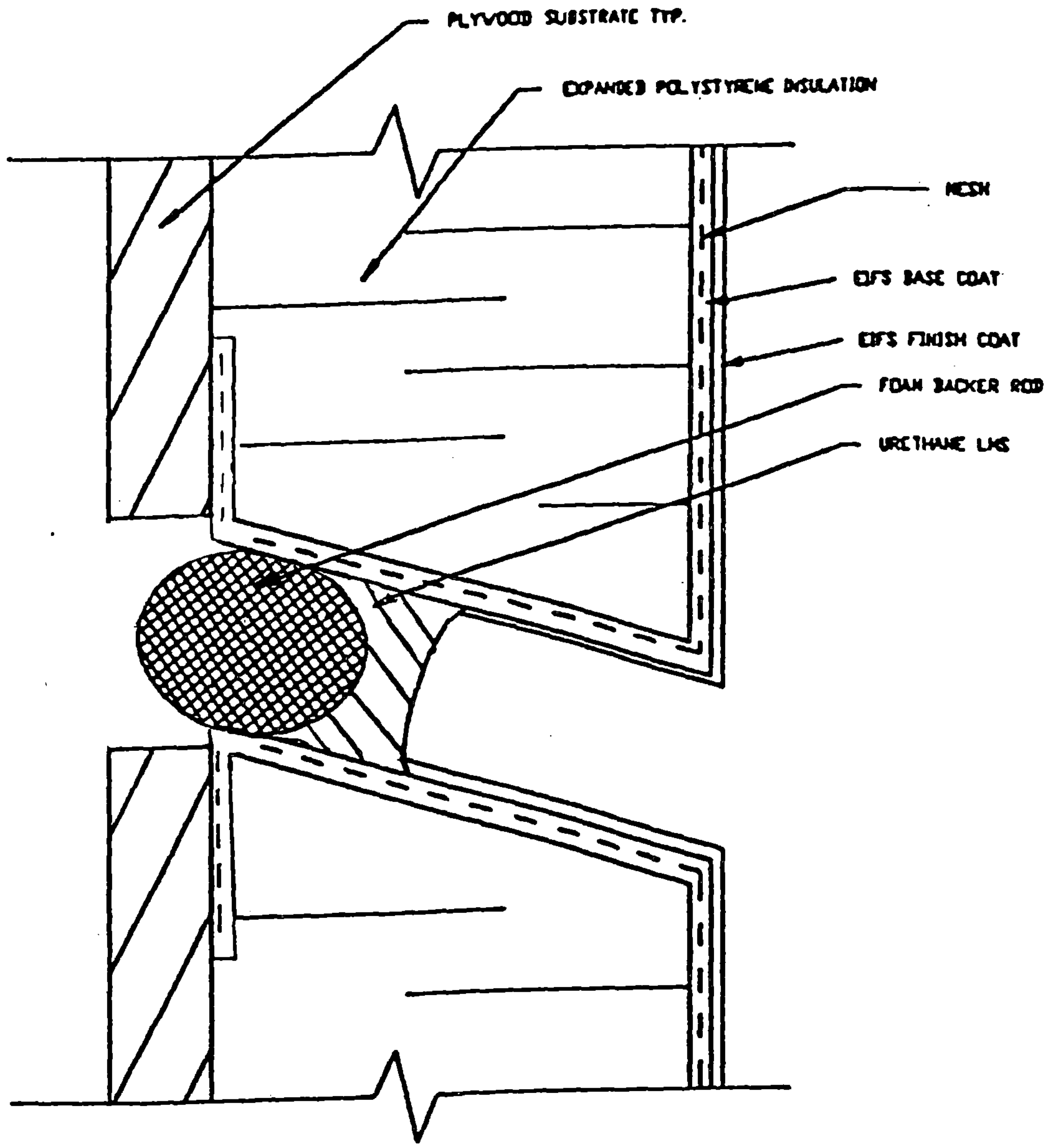

SECTION THROUGH JOINT

CMHC EIFS RESEARCH PROGRAM	DWG. 9 OF 9
RECESSED LMS SEAL (CAR DOOR)	
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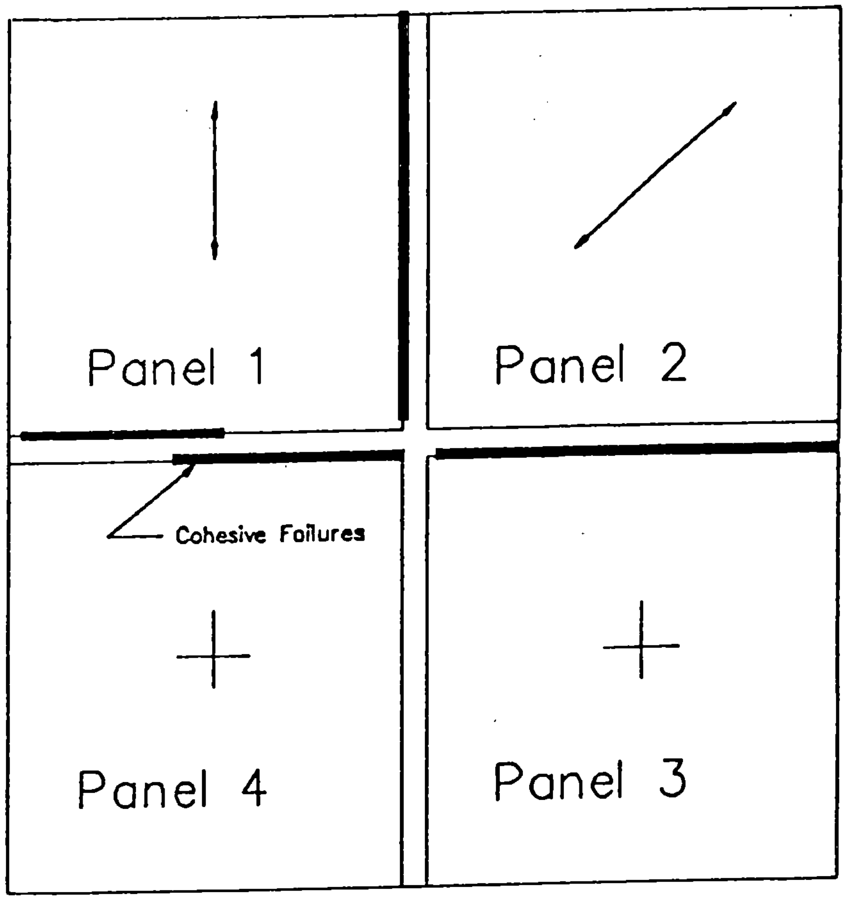
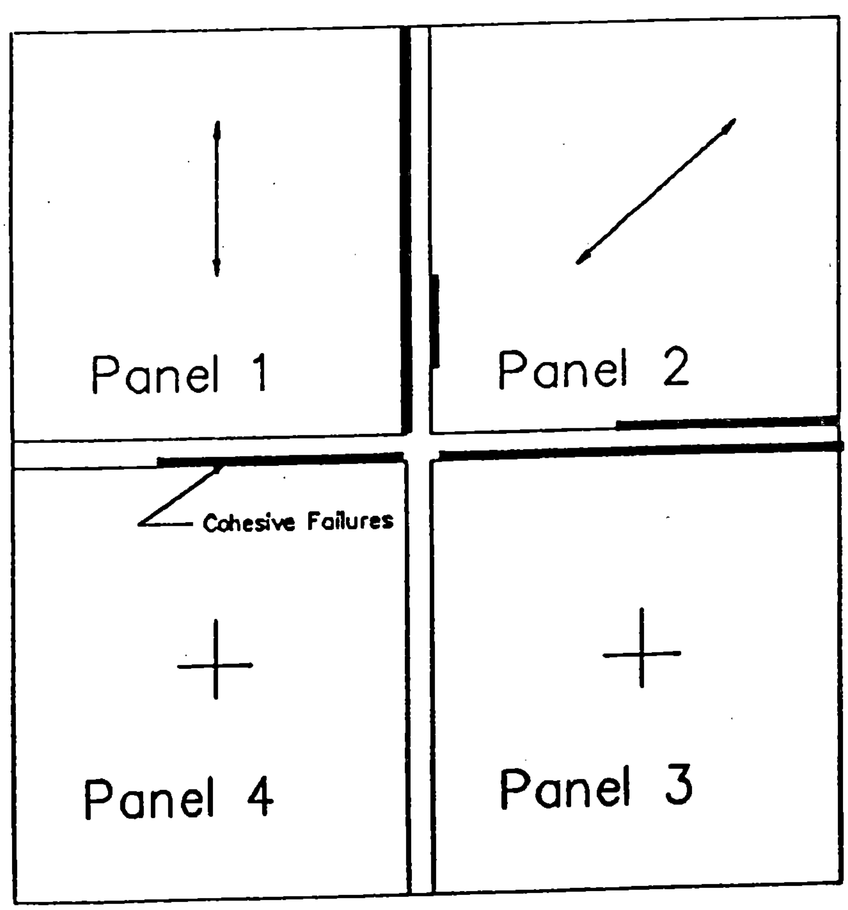
APPENDIX 3

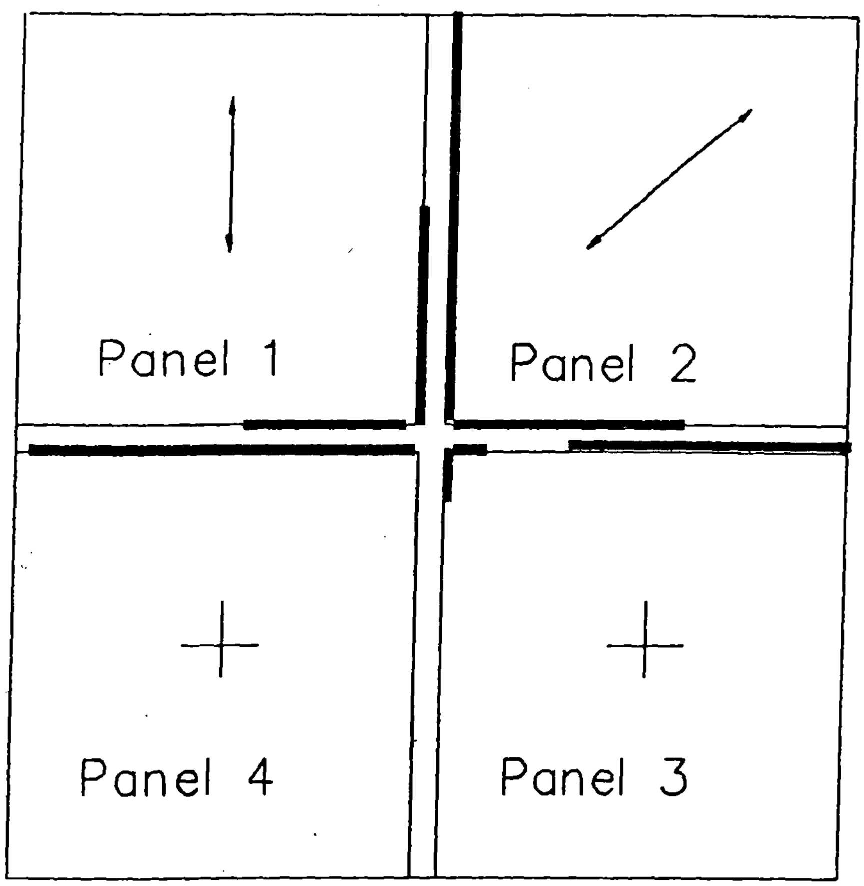
Joint #1: Generic Dymeric Face Sealed Joint



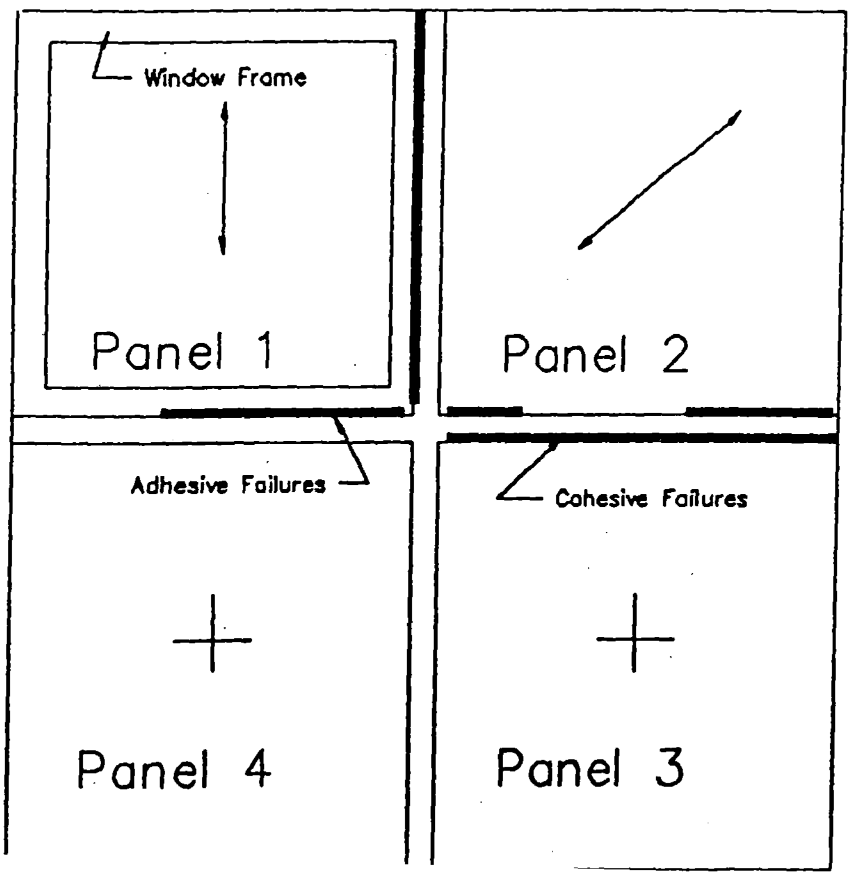
Joint #2: Dymeric to Finish, With Emseal



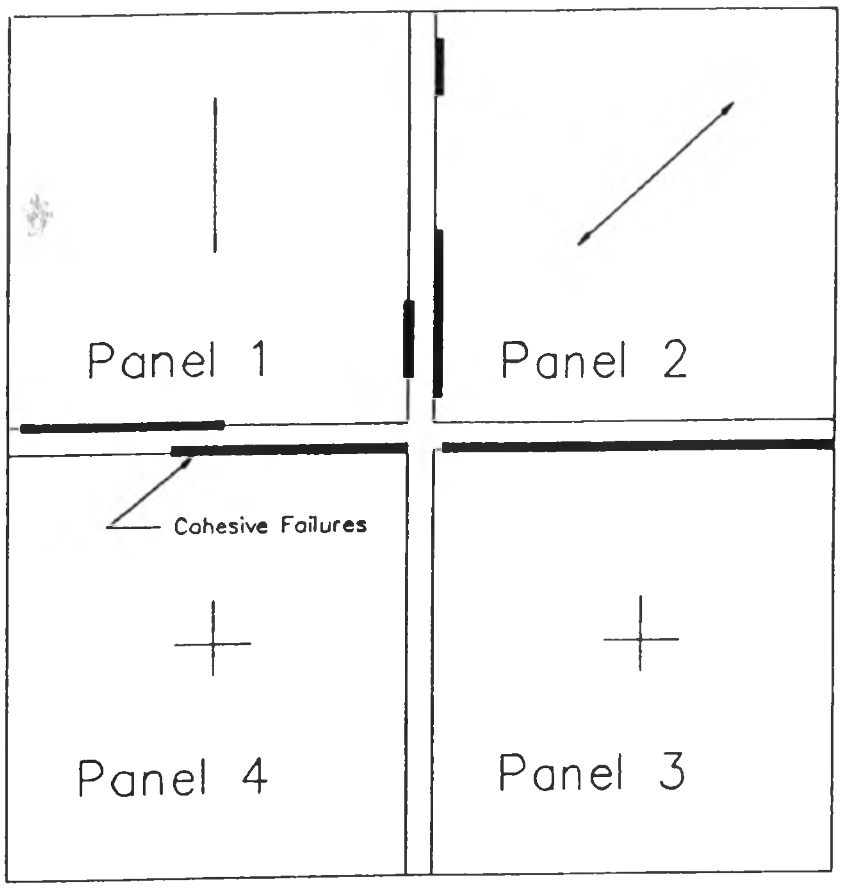
Joint #3: Generic Face Seal to Finish Coat



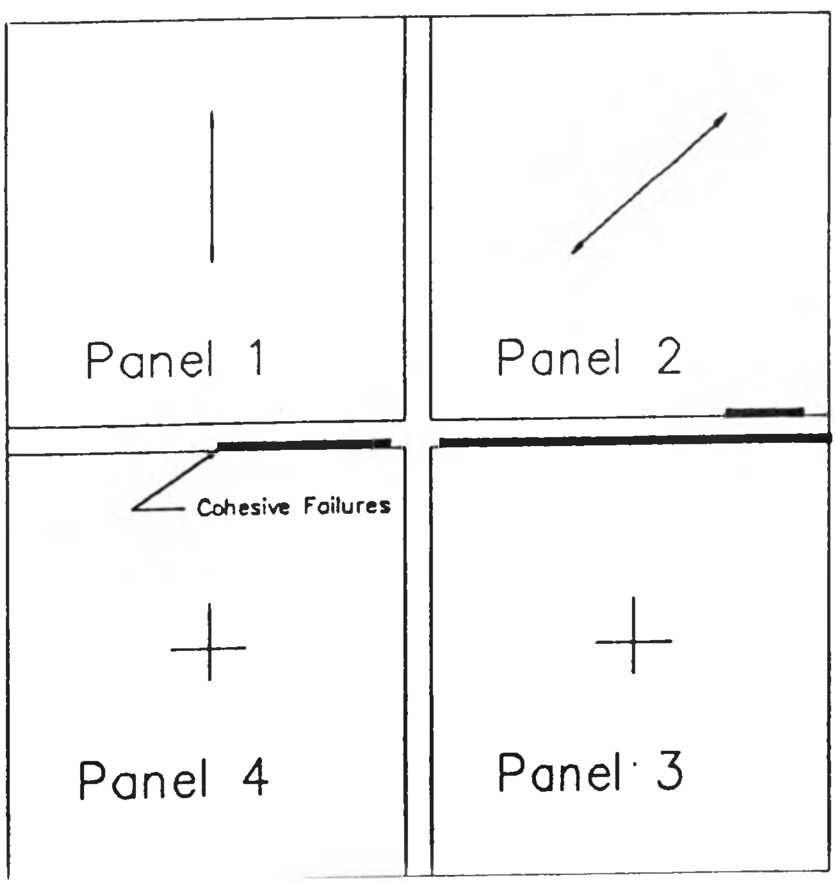
Joint #4: Generic Face Seal to Aluminum Frame



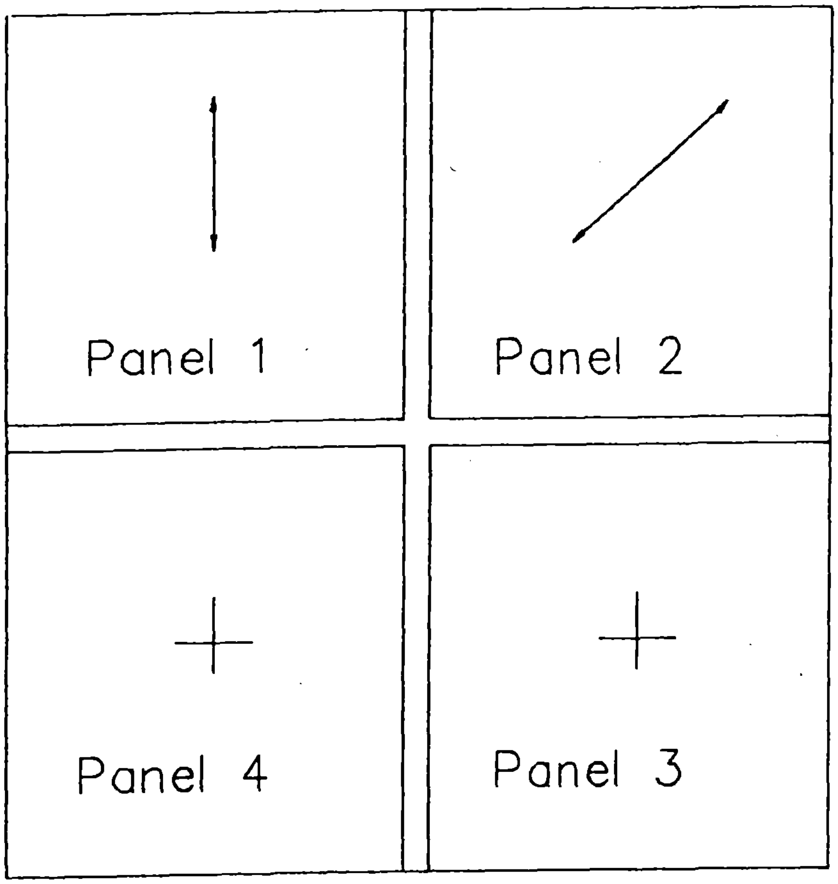
Joint #5: Silicone to Basecoat with Emseal



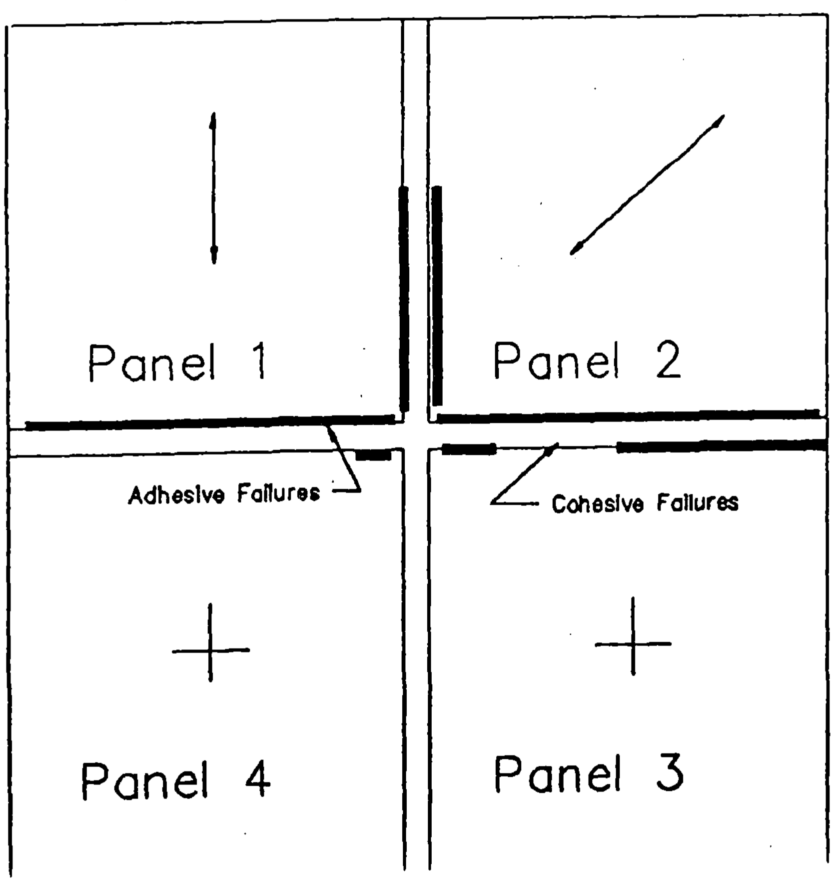
Joint #6: Dymeric to Basecoat with Membrane



Joint #7: Flashing with Membrane Backing



Joint 8: Recessed Dymeric Joint



APPENDIX 4

REFERENCE STANDARDS

ASTM C531

Shrinkage and Coefficient of Thermal expansion of Chemical-Resistant mortars, grout and monolithic surfacing - covers methods of measuring drying shrinkage and thermal expansion. Samples are laid up and then the length and width measured accurately during drying and during exposure in a constant temperature oven at various temperatures.

ASTM D638

Tensile Properties of Plastic - covers the determination of the tensile properties of un-reinforced and reinforced plastics up to thickness of 10mm.

ASTM D1682

Breaking load and Elongation of Textile Fabrics - covers the procedures for determining the breaking load of textile fabrics using the Cut strip method. In this case samples were cut into 25mm wide test samples.

ASTMD2898

Accelerated Weathering of Fire-Retardant Treated Wood for Fire Testing - covers the durability of wood under exposure to cycles of exposure to water, by spray rack and drying, using UV lamps and 40°C. temperature with air circulation.

ASTM E96

Water Vapour Transmission - cover the determination of water vapour transmitted through a sample under controlled temperature and humidity conditions. The test sample is sealed to an impermeable container which contains a desiccant to control the inside humidity at 0%, while the outside humidity is controlled at 50%. The assemblies weight is then recorded as water migrates through the sample. The water vapour transmission rate is then calculated from the exposed area and the average weight gain versus time.

ASTM G53

Q-UV Weather-O-Meter, exposes samples to artificial UV light under controlled temperature and humidity conditions.

ASTM E289

Air Infiltration, measures the amount of air that passes through a sample under a known pressure differential, usually 75 pa. The sample is installed in one side of a sealed box, a pressure differential applied and the air leakage measured.

ASTM E 331

Water infiltration, is a similar test to the above air infiltration test with the exception that water is sprayed at the samples exposed side, a vacuum drawn (75 pa) and the unexposed side visually observed for water leakage.

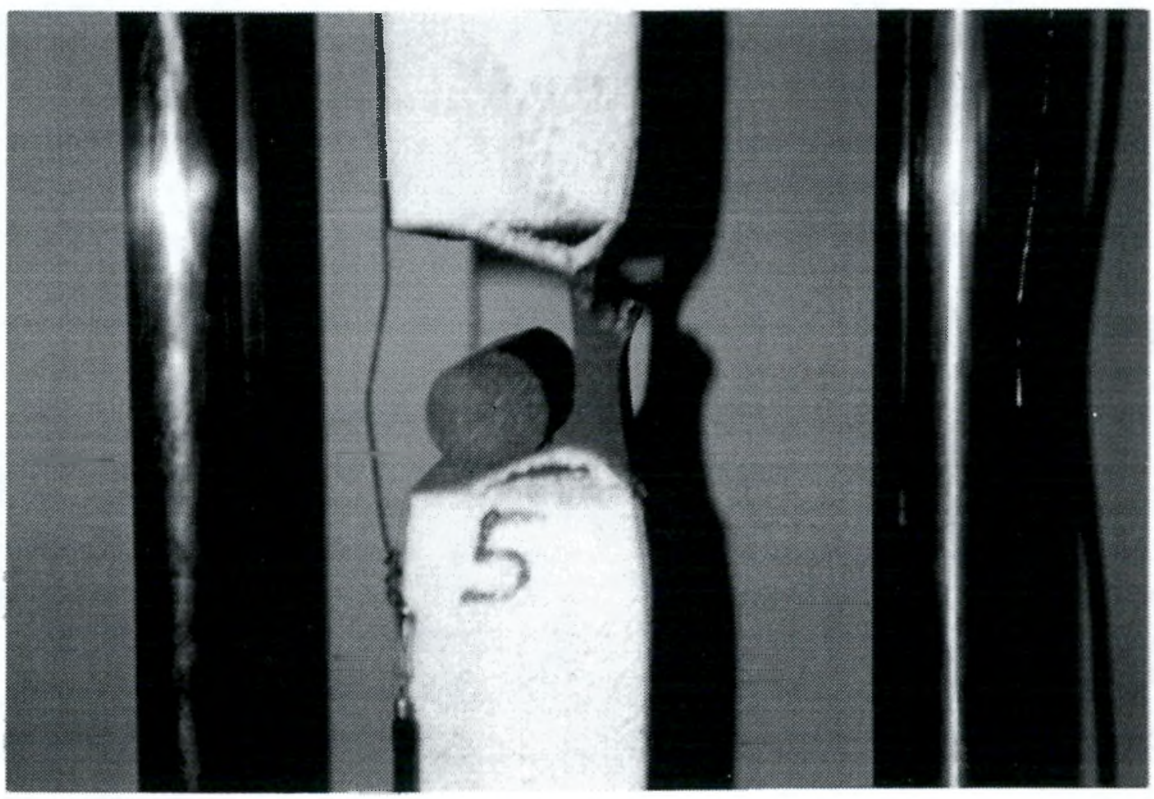
CCMC 07240

Section 6.5 Impermeability of Coating to Water - 200mm square samples of EIFS have their edges sealed and the centre $100mm^2$ of EPS foam removed. The samples are then floated on water at a test pressure of 50 pa. The passage of moisture through the samples is then visually noted.

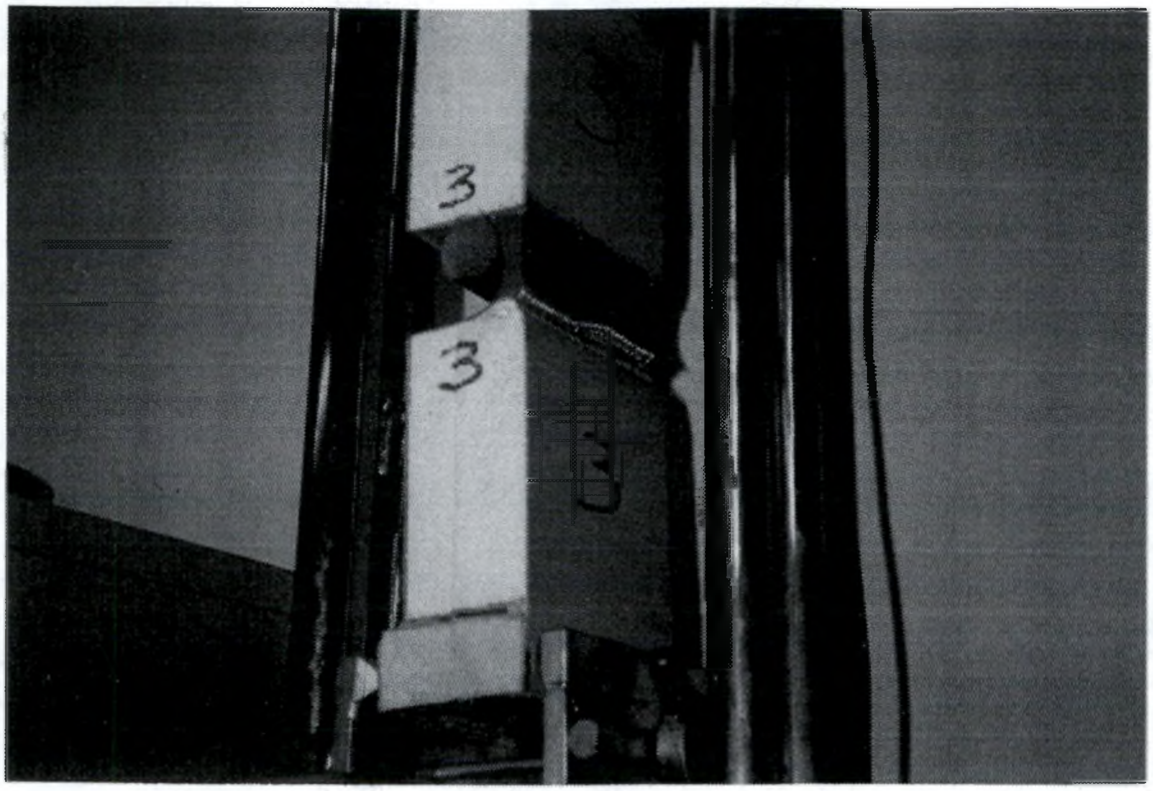
PHOTOGRAPHS

APPENDIX 5

1" MCU TO FINISH COAT, NOTE: DETAMINATION OF BASECOAT AT MESH

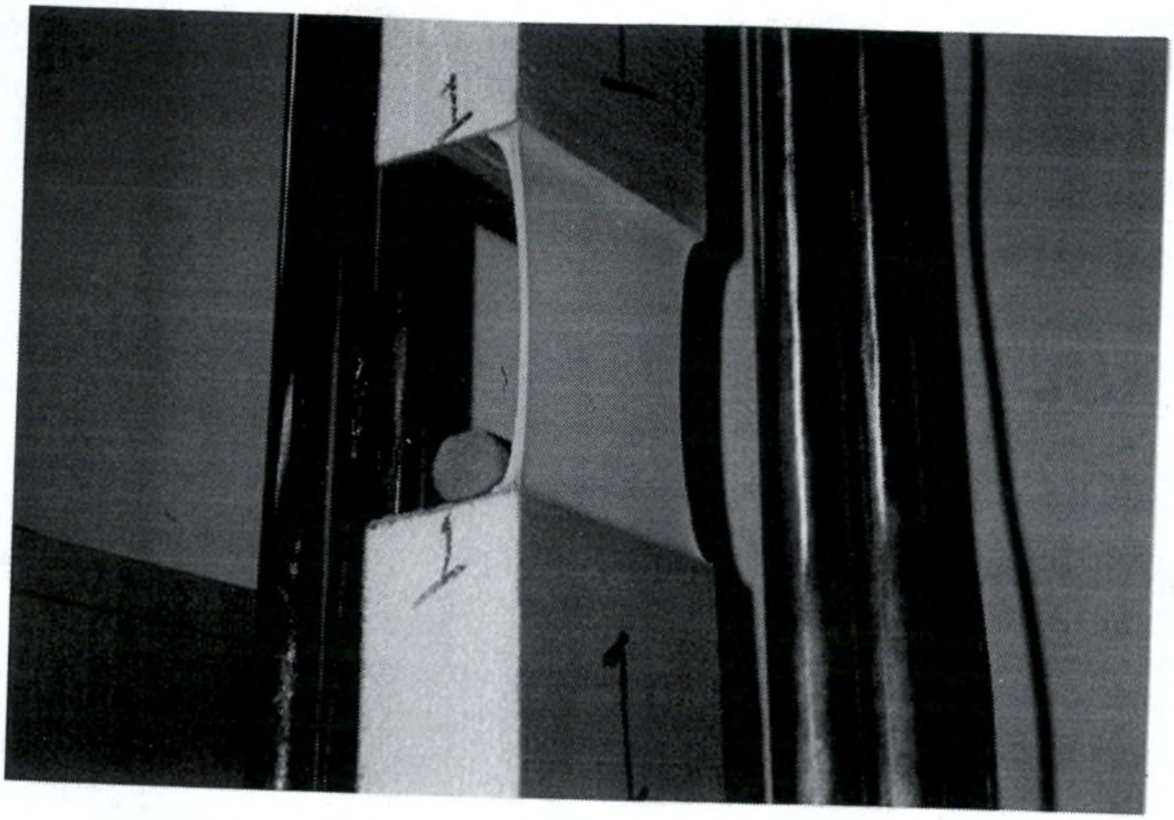


1" MCU TO BASECOAT, NOTE: FAILURE OF FOAM

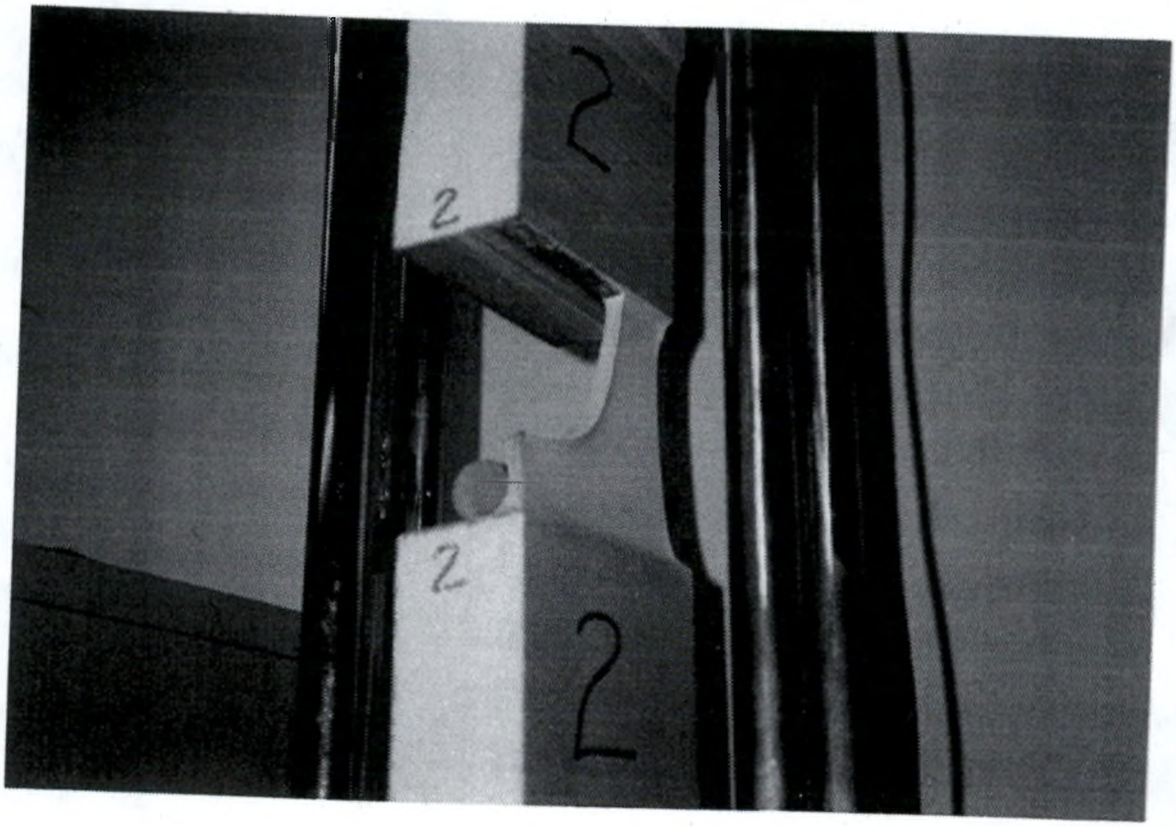


1 1/4" MCU TO PRIMED BASE COAT, NOTE: BASECOAT FAILURE AT MESH & TEARING OF FOAM

1" MCU TO PRIMED BASECOAT, AGAIN FAILURE OF BASECOAT AT MESH

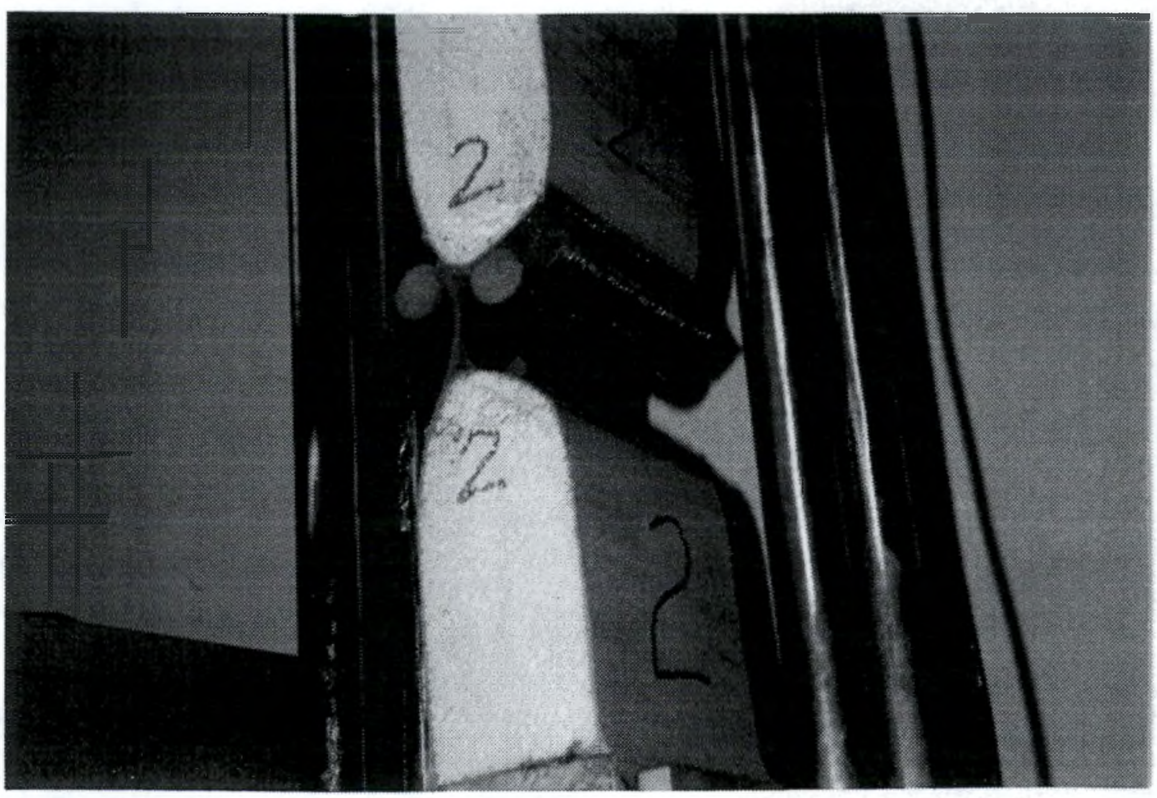


1 1/4" SILICONE TO BASECOAT, NOTE: LARGE JOINT ELONGATION WITH LITTLE DEFORMATION OF FOAM AND LAMINA

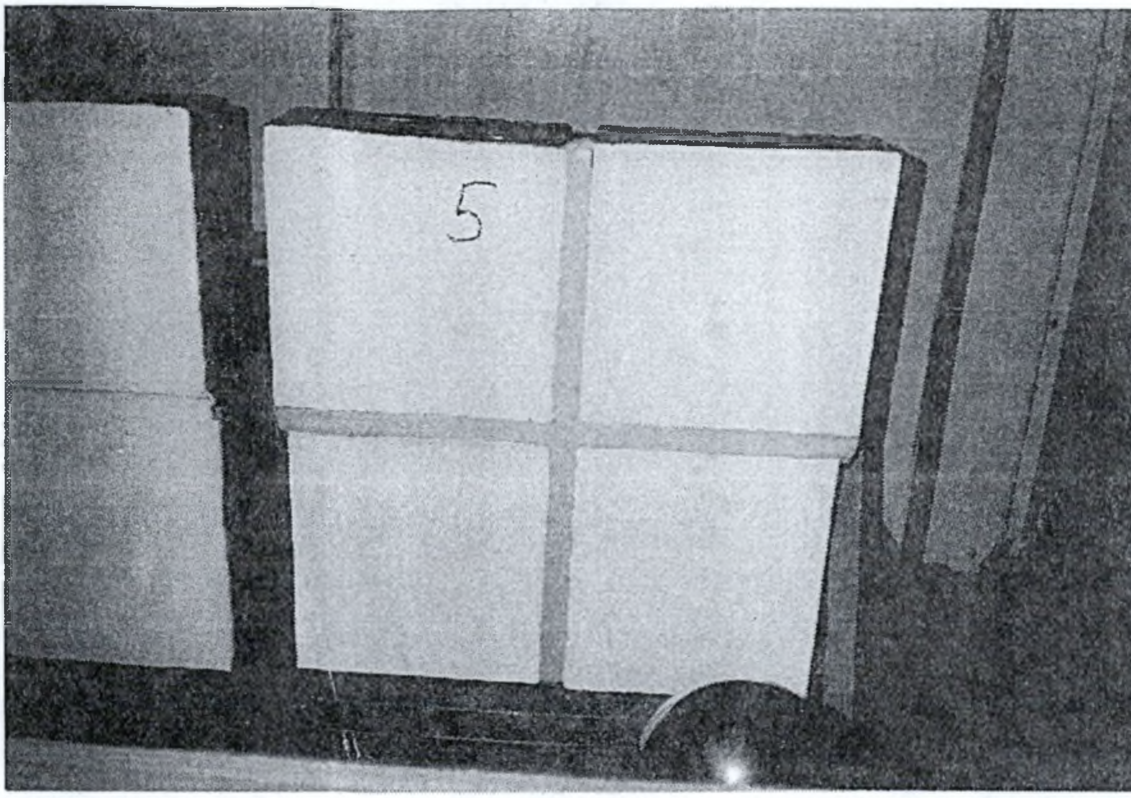


1 1/4" SILICONE TO BASECOAT, TYPICAL PEALING TYPE FAILURE AT BASECOAT SILICONE INTERFACE

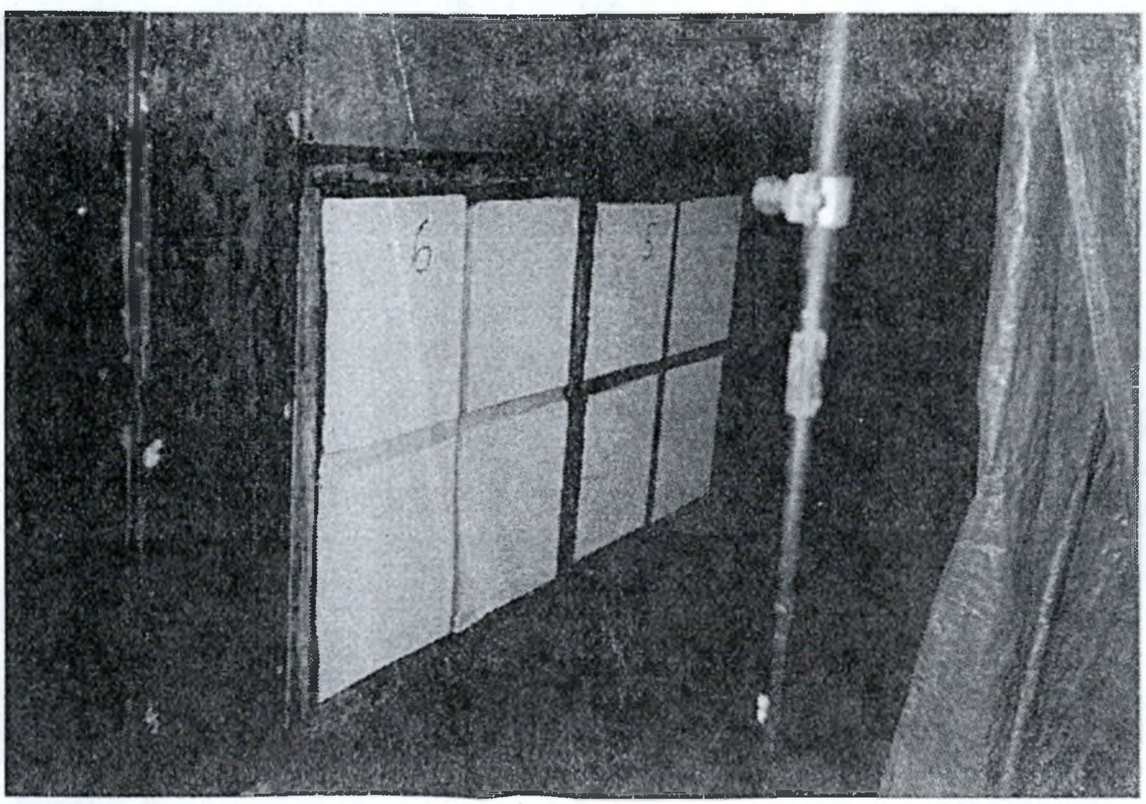
DOUBLE MCU JOINT, NOTE: FAILURE OF FOAM AT LOW ELONGATION



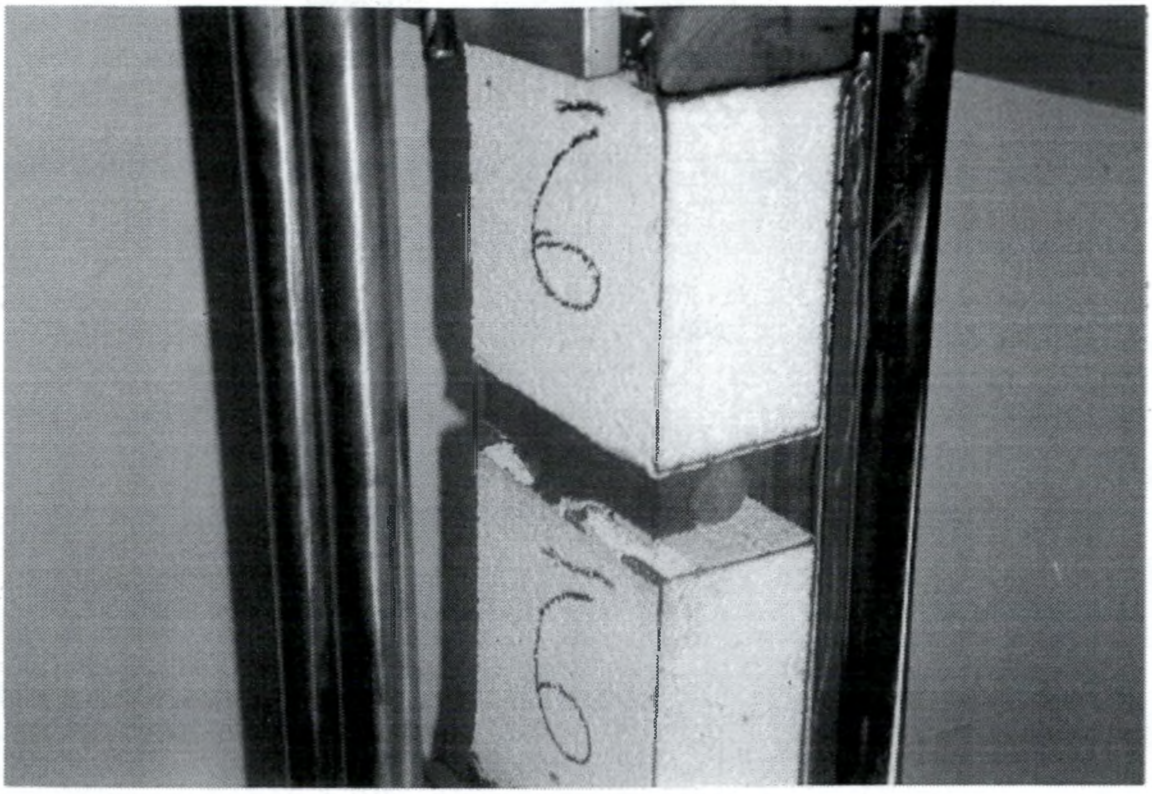
DOUBLE MCU JOINT, NOTE: LARGE DEFORMATION OF FOAM & LAMINA & TENSILE FAILURE OF MCU



JOINT DESIGN SAMPLES DURING WEATHERING



JOINT DESIGN SAMPLES BEING TESTED FOR WATER INFILTRATION



1" MCU TO FINISH COAT AFTER WETTING, NOTE: COHESIVE FAILURE OF FINISH COAT

WATER PERMEABILITY SAMPLES, SAMPLE IN LOWER LEFT & RIGHT BOTH ALLOWED WATER WITHIN 3 MINUTES