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Properties of sewn and adhesive bonded joints between geosynthetic sheets

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ABSTRACT: The authors have undertaken a program of laboratory testing to assess the benefits derived from the use of a modern adhesive in the joining of geotextile seams. A single application component product was used which depends upon atmospheric and textile-contained moisture to initiate the setting process. This adhesive is available world-wide and was selected as being ideal for civil engineering site applications. There is no batching or mixing required on site. The study also examined the benefits of combining the use of the adhesive with sewn joints to achieve high efficiency seams stronger than the geotextiles themselves. A number of different stitch/adhesive configurations were examined and tested.

1 INTRODUCTION

The 'efficiency' of a seam joint between geotextile sheets is the percentage of the ultimate tensile strength of the textile which the joint can bear before rupture. Ideally, the joint would be stronger than the fabric being joined and would thus never fail in tension.

In practice, in the field, high efficiencies are rarely obtained. Publications generally mention that laboratory obtained efficiencies are usually higher than field efficiencies. This is of little help to the field manager trying to meet a consultant's specification.

Publications suggest that high efficiencies are obtainable, but do not emphasise sufficiently that this tends to be with low strength textiles only. The efficiency of higher strength textile seams is low. Clearly seam stitching alone will not be able to meet this demand. Adhesive jointing has been looked at briefly in the past, but with adhesives that have been pronounced impractical - such as epoxy resins.

Some of the myth of high efficiencies has been perpetrated by odd test specifications such as the ASTM method of comparing test results from different widths. A 250 mm wide specimen of sewn seam is compared to a 200 mm specimen of entire textile. This enhances the apparent strength of the seam, leading to artificially high values of seam efficiency.

The technical note by Wayne, Carey & Koerner was an exception to the rule in that it presented a description of seam strengths most effectively. The graph published in that note showed that it was not possible to obtain a seam strength by field sewing stronger than 100 kN/m. The note examined the use of epoxy resin and its conclusions were not optimistic.

Murray et al undertook research work into the seam strengths obtained from both sewn and adhesive bonded seams. Their work was comprehensive and stated that 100 % efficiency could be obtained using adhesives. With sewn joints, they described efficiencies up to 90% but they drew attention to the large deformations that are experienced and are rarely - if ever - mentioned by others. These displacements can be up to 100 mm and it is to be argued whether a seam that fails at 80% stress level, with a displacement of 100 mm can really be considered to be successful or even permissible on a site. Usually, with such a large displacement, the sand tightness of the joint is nil.

Furthermore, it is difficult to find any research work examining the effects of creep on the textile fibres and sewing threads being used. In fact, creep is something that is discussed and recognised all the time in connection with reinforced soils. In that context, it is widely recognised that reinforcing fabrics should not be long term stressed beyond their creep capability. In the case of polyester, this might be taken as 50% of its ultimate load capacity; for polyethylene, it might be 38%, and for polypropylene, it might only be 20%. In the light of this, the authors consider that more research work is needed to look into the stress levels being experienced in sewing threads and sewn fibres, in order to know what overall kN/m stress levels can be imposed before creep causes failure.

The definition of performance of sewn joints really needs overhauling in view of the above factors, so that designers can specify a successful seam which is meaningful in terms of the function that it has to achieve. Furthermore, the specification of tests to assess the real performance of sewn joints needs much development before such specification can be said to be acceptable for all geotextiles.

2. EXPERIMENTAL WORK

2.1 *Experimental program*

The scope of the program included four types of textile only:-

1. PP woven SG 60/60
2. PP needlepunched NW 16/16
3. PE woven HS 150/150
4. PE woven HS 100/50

In order to simplify this testing research project, for the purposes of initial analysis, the authors limited the number and type of joints to be researched. The logic was followed that the most economic and quickest types of field joint are the simplest ones. These simple joints have the weakest test strengths. If, therefore, through this research, an improvement can be shown on the weakest joints or indicate where weaknesses originate, then this will have made a contribution to the understanding of the behaviour joints generally.

There were a number of interesting research points borne in mind in the preparation of the test program. For example, one objective was to comparatively test the Prayer and J Seam types; a second was to demonstrate the benefit of confining pressure on adhesive joint strength.

In many publications there are several different types of seam joints shown. For this research, the authors selected:-

a) The simple 'prayer' joint.
b) A double sewn 'overlap J joint'.
c) The 'Z' type joint which is impractical as a field joint if sewn, but not if glued.

The prayer joint was chosen because it is simple and weak and it was therefore possible to make a number of variations on it to demonstrate the benefits of threads and adhesives. The overlap J joint was chosen because it has not been used elsewhere and because it was developed by the authors to provide improved practical sewing on site. It is more practical than the normal J seam. The Z joint was chosen as the last option since it is practical as a field joint when used with adhesives and can also utilise the benefit of confining pressure induced friction to assist its resistance to separation.

Fig.1, shows the configurations of test conducted for each fabric. There were ten tests on the eight configurations for each fabric. Each configuration was tested a number of times to provide statistical reliability. Thus, for each fabric type there were 30 individual machine tests. For the four fabrics above there were a total of 120 individual machine tests.

In all joint types but one, the standard test wing tear type procedure was adopted. In the 'Z' configuration, the test was a tensile shear test of a 'strip test' type.

Two types of thread were used - high tenacity polyester and Aramid.

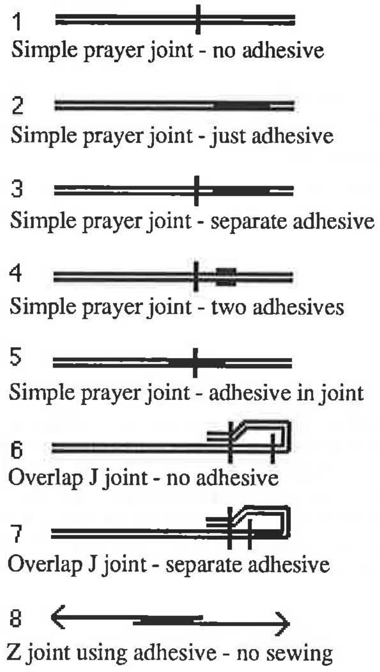

Fig.1 The eight different types of seam joints assessed.

The following describes the tests undertaken, the numbers corresponding to the diagrams in Fig.1.

1P. Simple Prayer type - single sewn seam (Polyester yarn). In this test, the two selvages are sewn together by a high tenacity polyester yarn. The object here is to set a lower bound limit of results for the weakest type of joined seam that is normally constructed.

1K. Simple Prayer type - single sewn seam (Kevlar aramid yarn). In this test, the two selvages are sewn together by a Kevlar yarn. The object here is to demonstrate the strength increase produced by using Kevlar.

2. Simple Prayer type - adhesive only.
In this test, the two selvages are joined together by adhesive only. The object here is to assess whether this moisture-set adhesive can provide a joint strength of comparable or greater strength than a sewn joint.

3. Simple Prayer type - Sewn and separate adhesive bond.
This test uses Kevlar thread and adhesive. In this test, the two selvages are joined together by adhesive in the first instance and then a sewn seam is constructed. This

attempts to assess whether the adhesive helps to provide additional peeling strength to the joint by letting the sewn joint take the initial strain and then adding the peel strength of the adhesive to the sewn joint peel resistance.

4. Simple Prayer type - sewn with two adhesive zones - not bonded.
   This test uses Kevlar thread and the adhesive. In this test, the two selvages have a small zone of adhesive placed on each separately and allowed to set. Then, after the adhesive has set, the two textile sheets are sewn together. This experiment attempts to see if the separate adhesives are useful in preventing pull-through of fibres without assisting the peel strength of the joint.

5. Simple Prayer type - sewn with adhesive placed into the sewn seam.
   This test uses Kevlar thread and the adhesive. In this test, a single seam is sewn and then treated directly with adhesive. This experiment attempts to assess whether the integration of the adhesive directly into the sewn joint aids the peel strength and slide-through mechanism more than that in configuration 4.

6. Overlap J type - double sewn seam.
   This test uses Kevlar thread. In this test, a single seam is sewn at a distance of about 100mm from the selvage. Then both loose flaps are bent back in a J form (but onto the same side of the fabric) and are sewn with a second seam. This attempts to see if this second seam is much stronger than the simple prayer seam of test 1B. This type of joint has the advantage of being able to utilise the frictional strength of the overlap to assist the mechanical bond.

7. Overlap J type - double sewn seam with an adhesive bond.
   This test uses Kevlar thread and adhesive. In this test, a single seam is sewn at a distance of about 100mm from the selvage. Then the adhesive is applied between the loose flaps and into the sewn joint. After setting, both loose flaps are bent back in a J form (but onto the same side of the fabric) and are sewn with a second seam. This attempts to see if the adhesive can make the composite seam much stronger than the Overlap J Seam which just uses thread (test 6).

8A. Z Overlap type - using adhesive bond alone.
   In this test, the two selvages are joined together by adhesive only. The object here is to assess whether this different type of joint which takes stress in direct shear rather than peeling, can provide a useful low strength joint for general textile holding applications. Normally, this type of joint, when sewn, can only be realistically undertaken in a factory environment with large scale machinery. However, with adhesives, it becomes practical to consider this configuration as a field joint. Therefore, the outcome of this test has important implications

8B. Z Overlap type - With adhesive only, but with lateral confining pressure applied.
   In this test, the two selvages are joined together by adhesive only and are confined between two hydraulically pressured bags. The object here is to assess whether this more realistic configuration can provide a stronger joint than the same joint unconfined as in test 8A. Under normal site conditions, geotextile joints are stressed under confining conditions. Therefore, it is necessary to consider this configuration as a field joint under those circumstances. The outcome of this test has important implications. Also, with an overlap glued joint, the confining friction can also be taken into account on the rest of the fabric, which is not the case in sewn joints except the overlap J joint shown above.

2.2 *Practical limitations of test procedures*

Tensile testing was were conducted at 200 mm width in accordance with EN ISO 30321. Stress/strain behaviour of the samples was automatically recorded and plotted by the test machine, using Zwick PC Software Z1005 on a standard PC.

In order to remove random assistance from the selvage, which can be constructed in many different ways for different textiles, all the tests were conducted on weft edges that were cut parallel with the machine direction, away from the original selvage. This is a worst-case condition for a sewn joint and also a more consistent one. It was therefore ideal for the research in hand.

Apart from the numerical output from the tests, the graphical output demonstrated some important points about the mechanisms of failure. In particular, they demonstrate that the use of sewing for creating a seam is an inefficient and counter-productive method. The grip of the sewing thread causes such large stress concentrations and deformations on the fabric fibre that it breaks prematurely in all cases. The grip is sufficiently poor to permit very large 'strains' to occur as the joined textile moves apart. Of course, these are not real strains in the sense of the fabric polymer straining, but are large movements experienced at the joint and measured as a percentage strain in relation to the original dimensions of the fabric in the jaws of the testing machine.

The plots and visual observation of the apparatus informed the authors of the following in connection with sewn-only seams.

1. The sewing threads only broke with the strongest fabric.

2. Where the geotextile failed, the weft threads tore immediately adjacent to the stitching, where the threads would be most stressed. This was the most common mode of failure.
3. The level of strain recorded shows that the stitching at first slips continuously along the weft fibres.
4. When the fibres are increasingly stressed and strained, isolated marked stress fluctuations occur which repeat rapidly.
5. In the case of the woven fibres, this leads to an individual thread breaking, followed by a 'domino effect' as adjacent filaments become over-stressed and snap, leading to a 'tear' type failure.
6. The tear type failure meant that fabrics failed at less than 50% of their ultimate tensile stress.

This might be an indication that the fibres are suffering from rapid creep failure induced by the combination of high grip forces from the sewing thread, geometrical distortion in that region and high tensile forces from the test apparatus.

This supports the warning given by Murray, McGown et al, that insufficient consideration has been given to the effect of creep failure on over-stressed fibres in the vicinity of the sewn threads.

Each group of fibres which are gripped by a loop of sewing thread will be experiencing a radial constriction pressure. Of any given group, the outer threads in immediate contact with the sewing thread will be held in friction and if the friction coefficient of the thread to fibre is greater than that of the fibre to fibre, then the external fibres will tend to have to absorb more of the group's stress than others. In the event that fibre-to-thread friction is less than that of fibre-to-fibre, then the stress distribution will tend to be more evenly distributed throughout the fabric. The authors believe that this is a matter of significance and should be the subject of further research.

Since the breakage of individual threads is a problem in the testing procedure and since the authors were using an ISO standard method of testing, this calls into question not the ISO method per se, but whether the ISO method actually reflects what would happen in the ground during in situ induced failure. It is difficult to avoid the conclusion that it may not.

Fig.2 shows a standard tensile test graph of the SG 60/60 woven polypropylene product, without any seam. i.e. standard tensile test.

The autoplotted curve is shown to be smooth, rising to about 55 kN/m at an extension of about 20%. (For those not familiar with the software, the three tests would overlap and be difficult to distinguish, so the program automatically moves each test plot 5% to the right, in order that each curve can be seen).

When the same product is tested across a sewn seam, the output curve is significantly different. This is shown in Fig.3. The contrast with the curve in Fig.1 (superimposed) is very marked. The movement across the seam results in an increase of strain from 20% to 135% or thereabouts. The slippage appears to have two phases - a continuously smooth phase and a phase made up of a series of intermittent snatching movements.

These snatching movements are represented by sudden falls in the stress level, which immediately rise back again as soon as the sewing thread re-grips

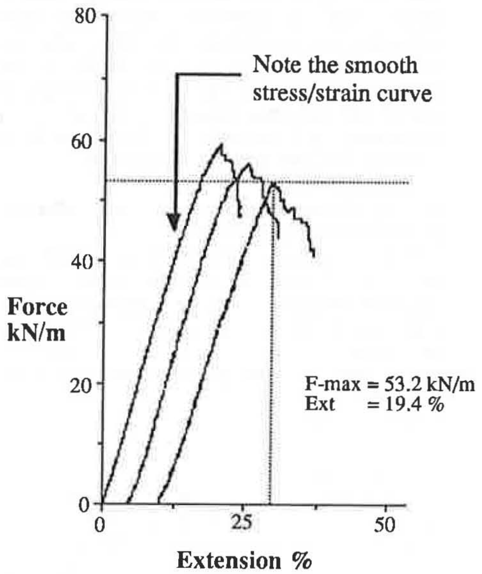

Fig.2 Standard tensile test on SG 60/60 woven polypropylene textile in the weft direction. No seam.

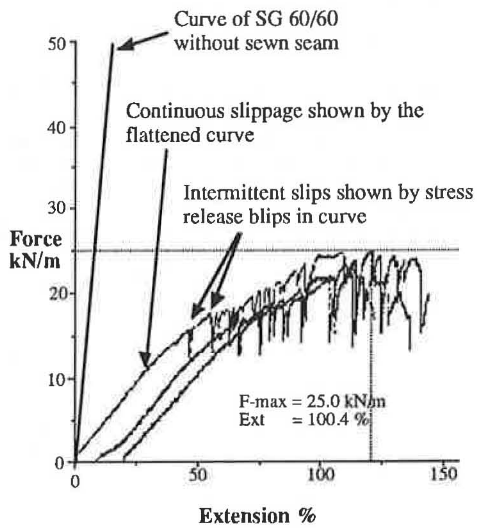

Fig.3 Standard tensile test across a weft J seam, double sewn with Kevlar on SG 60/60 woven polypropylene textile.

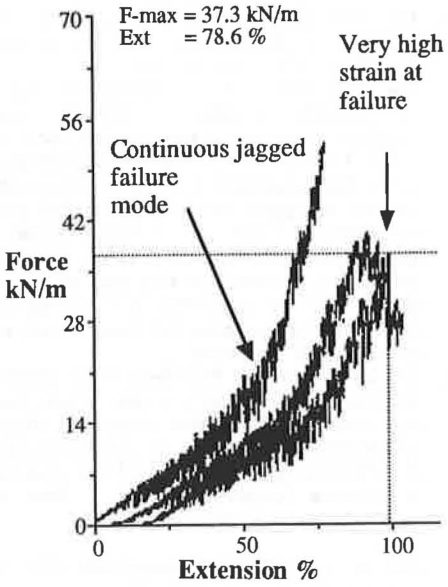

Fig.4 Very high strain before failure in a polyester woven HS 150/150. Simple prayer seam. Note the jagged form of the stress/strain curve.

the weft fibres. This rapid change in stress levels could be the mechanism which generates the snapping of the first weft threads prior to overall failure. This would account for the tearing effect observed in the samples as the characteristic mode of failure, leading to the fabric weft failing before the stitching fails.

In the extreme case, as shown in Fig.4, there is no smooth phase to the strain curve; rather the entire curve consists of a series of slips and snatches. Under these circumstances, it is impossible for the fabric to ever be stressed near its full capacity. In the case of this strong fabric, the stitching broke before the weft threads in nearly all tests.

2.3 *Possible mechanisms of seam failure*

The large extensions generated across the seams in the testing of normal sewn seams are probably caused by a combination of the opening of the sewn stitches and the sliding of the weft yarns through the loops of the stitching. The authors considered that the tightness of the sewing threads on the weft fibres might be causing premature failure by over-stressing. In order to assess whether the slide-through behaviour could be prevented, the configurations of test numbered 3 and 4 in Fig.1 were devised, using adhesives to act as a 'stopper'.

The test results proved that this approach was correct as shown in Figs.5 onward.

Although not a part of this research, it is possible that by reducing the tension on the sewing yarns whilst at the same time preventing slide-through, it would be possible to increase the efficiency of the sewn joint by allowing the weft fibres to accept a higher level of stress before failure.

The problem that has beset seam construction is that the very mechanism that is used to grip the weft fibres is the same mechanism that over-stresses the fibres. The loops of the stitching form the friction grip on the weft fibres. To increase the grip, the engineer specifies tighter loops and higher tenacity sewing thread. The tighter loops generated by the stronger thread simply over-stress the weft fibres and cause them to fail prematurely.

Only with the HS 150/150 did the sewing threads fail. In the case of the simple prayer seam, often the Kevlar seam performed less well than the polyester seam, so the benefit of Kevlar is not apparent from this work. This appears to support the authors' views on over-stressing of the fibres. Further, if grip is reduced and the mechanism of stress absorption changed to one of preventing pull-through, then there is a much better chance of permitting stress redistribution along the seam junction and thus preventing the failure of individual threads which leads to the premature tearing failure observed throughout the testing program.

The authors proposed, and have demonstrated in the testing program, that just gluing alone of seams that are to be stressed as wing tear seams (all standard prayer and J seams), is of little use. In fact the results show that a simple adhesive wing seam is so weak that it can hardly hold the fabrics together.

The tests show that when adhesive is used in addition to the sewing (adhesive and stitches together), it does not have much benefit. The research did confirm that when adhesive was used separate from the stitching, in the form of an adhered mass which has to be pulled through the loops of the stitching, then there was a distinct improvement, increasing the efficiency of the seam. However, although the improvement is clear, thus suggesting that the proposed mechanism is operating, nonetheless, the benefit was small and would probably not be cost effective to implement in practice. These results do, however, open the door for research work into decreasing the grip of the sewing thread with the possibility of increasing efficiency even further to economic levels.

The final outcome of testing showed that the only really successful seam was the Z-configuration adhesive joint. This method carries the potential for generating a seam stronger than the fabric (more than 100% efficiency) whilst keeping strain down to the original fabric levels. This opens the door to research into the best means of applying adhesives and - in particular - into the best modern adhesives for the purpose.

It is very interesting to consider the implications of this. In particular, it is valid to consider that research into grip, adhesives, thread/adhesive composite seams and adhesive application systems may well change our present approach to this subject over the next few years.

3. DESCRIPTION OF EXPERIMENTAL SEAM TESTING RESULTS

3.1 *Overall test results*

The simplified overall test results are shown in Fig.5. This graph shows the ultimate failure stress of three of the textiles tested, using the 8 configurations specified in Fig.1 and the 10 testing procedures outlined in section 2.1.

Points to be noted in Fig.5 include the following:-

a) The fabrics illustrated are the three with properties which are the same in both warp and weft directions. The asymmetrical HS100/50 behaved differently, as was known from its field performance, and is described later.

b) All three of the symmetrical textiles performed in a similar way in nearly all tests. This is illustrated by the way the plots in Fig.5 follow each other.

c) The Kevlar prayer seam (1k) was stronger than the double sewn J seam (6). This conforms to field behaviour observed by the authors in practical conditions.

d) The addition of adhesive slide blocks to a prayer seam (configurations 3 and 4) only marginally improve on the prayer seam alone.

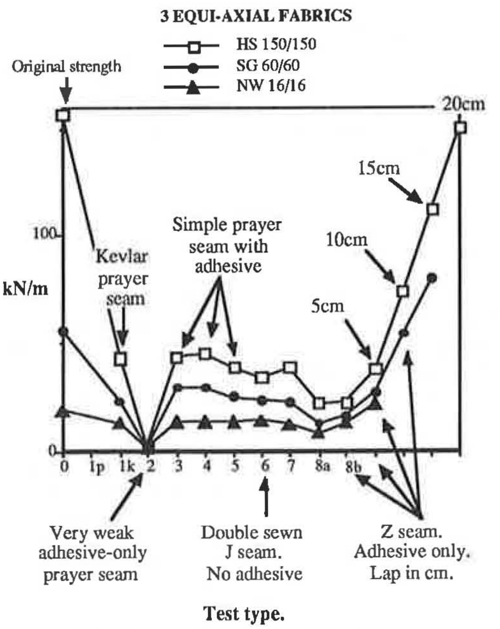

Fig.5 Relative tensile performance of the tests configurations illustrated in Fig.1.

e) The overlap J seam is not as good as the prayer seam alone, whether the J seam has no adhesive (6) or has adhesive (7).

f) The depth of the adhesive overlap necessary to provide ultimate efficiency was extrapolated for the purposes of this graph at 5, 10, 15 and 20 cm. The area of adhesive is therefore multiplied by 100 to obtain the number of square centimetres needed per metre run of seam. These figures assume that the adhesive is confined in the ground, so that the adhesive layer is kept flat, thus helping it to resist peeling. The validity of direct area extrapolation has been shown to be valid by Wayne et al.

g) Unlike sewn seams, the adhesive can always respond to the strongest textile. Note that extrapolation suggests that it may only take a 20 cm band of adhesive to completely grip the 150 kN/m polyester with a force close to its ultimate breaking strength. This is presently being investigated.

3.2 *Results of testing the high strength HS 150/150 woven polyester fabric.*

The results for this fabric are shown in a bar chart format in Fig.6.

There are a number of interesting points relevant to the test results of this fabric. Firstly, it is interesting to note that, for this strong fabric, the use of Kevlar aramid sewing thread in the simple Prayer Seam configuration (1k) produced a significant increase in seam strength over that of the polyester seam (1p). This was also true of the other polyester product, but not for either of the two polypropylene products. This is an important matter, since it is

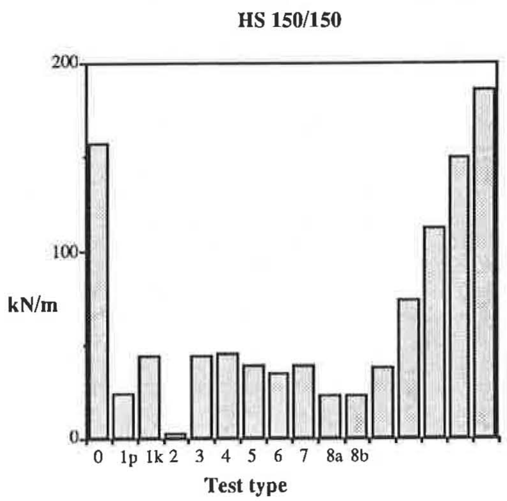

Fig.6 Results of tests on HS 150/150 polyester woven fabric. Test types are numbered to match those shown in Fig.1.

generally held that Kevlar will always produce a stronger seam. However, this research work has shown this to be not true. More detailed research is needed. Is this a generic feature of polyester vs polypropylene?

As with all textiles, the attempt to create an effective Prayer Seam with adhesive alone failed. This has been reported previously and the present work was no exception. The low levels of result obtained were expected from the chosen method of application of adhesive. The researchers were not trying to force the adhesive into the fabric, but apply it in a superficial manner which would most likely have to be adopted in the field.

Configurations 3, 4 and 5, being Kevlar prayer seams with added adhesive assistance, performed no better than the prayer seam alone. In fact it is interesting to observe that, in Configuration 5, where the adhesive was placed into the stitching, the performance was less. It is likely that the adhesive acted as a lubricant, minimising the friction grip of the stitches on the weft fibres. This was an important result.

Configuration 8a was an unconfined Z seam with an adhesive lap width of 4 cm. Configuration 8b was the same 4 cm, but confined with lateral pressure to prevent possible peeling. However, it is interesting to note that in the case of this strong polyester, there was no improvement in performance.

Beyond 8b, the area of the adhesive has been extrapolated to show that a 20 cm wide band of adhesive would be sufficient to fail the fabric at its 100% maximum failure stress. Adhesives are not expensive - especially when considering their speed of application in comparison with having to sew two or three seams by hand. They do not require on-site electric power or the hiring of expensive sewing machines. The authors have applied adhesives in the wet and in snow conditions, with very satisfactory results. More research needs to be done on types of adhesives, application methods and setting times.

Stress is not the only performance criterion of seam failure. Strain (or in reality fabric seam extension) is very important since it controls the sand tightness of the seam under stress. The variation in strains experienced with different configurations was very significant and is described later.

3.3 *Results of testing the SG 60/60 woven polypropylene fabric.*

The results for this fabric are shown in a bar chart format in Fig.7. In particular, of interest here is the comparison of the seam strengths of a simple Prayer Seam with a polyester thread and with Kevlar. In the case of this fabric, the Kevlar thread produces a lower efficiency seam. This is annotated on Fig.7.

In this case, again, similar to the polyester fabric, the addition of adhesive to the simple prayer seam hardly produces any benefit. Also, it can be noted that the much-used J Seam offers less performance than the Prayer seam without (6) or with (7) adhesive. In the case of the Z seam, the attachment of the adhesive to the textile is clearly improved by the addition of confining pressure, as shown in 8b.

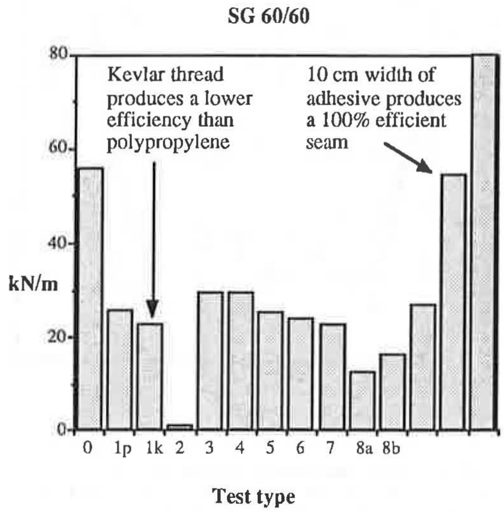

Fig.7 Results of tests on SG 60/60 polypropylene woven fabric. Test types are numbered to match those shown in Fig.1.

Fig.8 is a graph intended to show the different test behaviour of the asymmetrical polyester woven product HS100/50. This product has a warp strength of 100 kN/m and a weft strength of 50 kN/m. Its behaviour under seam conditions is not similar to the other fabrics, since the low density of weft fibres makes it difficult for the sewing machine to gain any substantial frictional grip.

It is interesting to see, at a glance, that the three symmetrical products respond in a very similar way to the various test configurations. As is forecast by other researchers, the highest efficiencies were obtained on the weakest fabric. This is because the fabrics tear at similar force levels, being a function possibly of their creep and stress response characteristics as polymers - particularly in respect of the tightness of grip of the sewing thread onto the weft threads of the textile.

With the asymmetrical HS 100/50, the efficiency of joint obtained with the simple Prayer Seam was very low at about 15%. However, the J Seam improved matters, raising the seam efficiency to above 35%. Test 8b is the most interesting, in that it shows that just 4 cm width of adhesive will provide an efficiency of over 60% and 5 cm properly cured could take the figure up to the 100% level. There is no other way known to the authors, to obtain this kind of efficiency level in high strength asymmetrical polyester products of this kind.

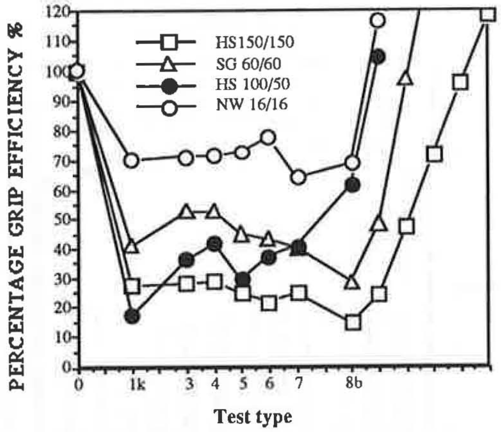

Fig.8 Results of some tests to show the percentage efficiency achieved with different configurations and to show the marked benefit of adhesives when applied to the asymmetrical product HS 100/50.

Fig.9 shows one of the most important results of the work. This is the extension experienced by the seams during testing.

In Fig.9, Test type 0 on the left hand axis gives the percentage extension (true strain) of the samples when failed without seams. In all other cases, except types 8a and 8b, the extension is not a true strain, since it is predominantly caused by slippage of the sewing threads along the weft fibres of the textile. It really represents how much the seam has opened up. Failure usually comes by ripping of the fabric close to the sewn thread seam.

% EXTENSION AT FAILURE

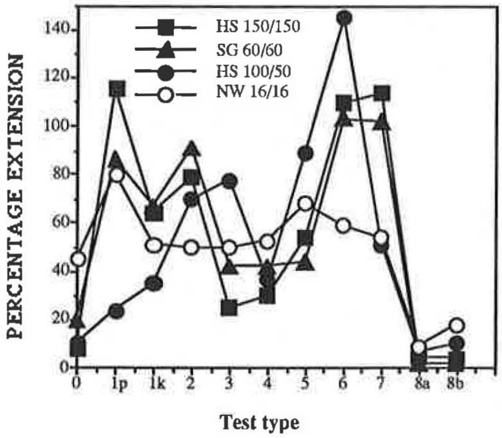

Fig.9 Graph showing the percentage extension experienced across seams for different configurations, compared with seamless samples (Test type 0)

One item to note is that the Kevlar threads, although not contributing much to the grip efficiency, did improve the strain levels experienced. Reductions of 50% were experienced. The HS 100/50 demonstrated little strain because it failed at such a low stress level, as can be seen in Fig.8.

Perhaps of more potential importance to note is that, although the adhesive did not make much difference either to the failure stress and grip efficiency of simple Prayer seams and J seams, it made a very big difference to the extension experienced at failure. Note in the case of tests 3 and 4 that the very marked reduction in extension shows that the 'pull through' concept put forward by the authors was correct and that the adhesive prevented the pull through of the fibres, thus reducing extension and maintaining the sand tightness of the joints. Examination of the two tests 6 and 7 shows that the J seam has equally high extensions to the simple prayer seam and that for slippy fibres such as the HS 100/50, the use of adhesive made a very large difference to the extension experienced.

The most promising observation from the graph is the very low strains promised by the Z type joint with adhesives only. These can be seen in Fig.9 at test type 8a and 8b. It can be appreciated that these samples had only 4 cm of adhesive and failed at relatively low levels of stress, so the strain experienced will be low. However, as larger areas of adhesive are applied and as higher stress levels are experienced, it can be hoped that strains will not rise significantly above those for the original material. To take one particular example, in an unseamed condition, the HS 100/50 had an ultimate strength of 52 kN/m at 10% strain. With adhesive, in a confined Z configuration, the joint failed at 32 kN/m with a strain of only 10%. There is real hope here that failure extensions at 100% efficiency can be kept down below 20%, which is unheard of presently by any standard sewing technique. Also, if these low extensions can be obtained, then the sandtightness of the seams should be ensured.

4. CONCLUSIONS

The authors have shown that a number of beliefs concerning sewn seam behaviour and performance are not always strictly true. Firstly, there is no certainty that the use of a higher tenacity sewing thread such as Kevlar, will ensure a higher seam strength. Secondly, a J Seam is not always better than a simple single seam Prayer joint in terms of efficiency or strain. Thirdly, the use of new types of seams and adhesives can reduce seam extension dramatically. Finally, there is the real possibility that, given a period of research and development, adhesives could become a standard method of joining textiles. The research has shown that a confined adhesive Z joint provides the best grip efficiency with the minimum extension of any type of joining mechanism.

The work described in this paper was of a limited nature. More work needs undertaking and the authors have made mention of those areas needing research within the body of the paper.

5. MATERIALS SPECIFICATION

The adhesive used was a one component polyester based polyurethane adhesive. It was a moisture curing adhesive in a non-flammable solvent. The adhesive was tested after 48 hours from application. This seemed a useful practical time, but in the authors' view, the adhesive was still increasing in strength at that time. Longer setting periods and different moisture exposures are being investigated.

The sewing threads used were Kevlar yarn 455 tex; 502 Newton; 4%; 1.10 Newton/tex. And polyester yarn 364 tex; 195 Newton; 18.1%; 0.54 Newton/tex.

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