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Intermixing Twin Ferrule Tube Fittings—Is it Safe?

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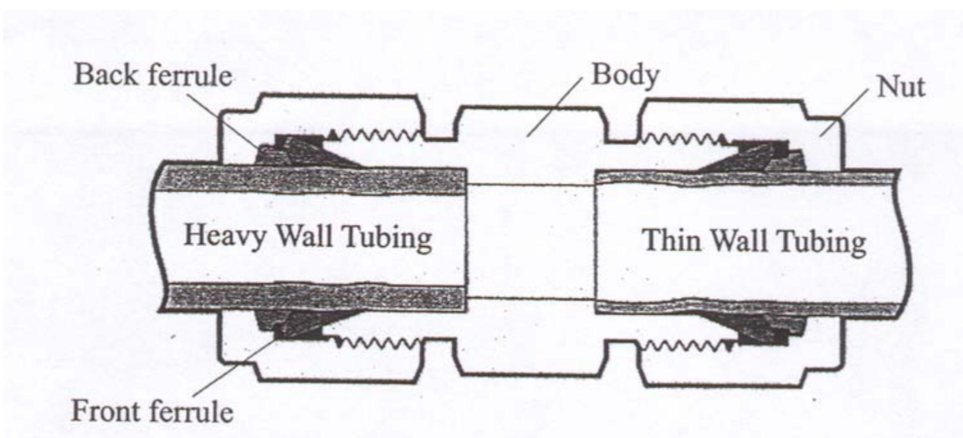
SUMMARY
This paper presents the findings of an independent study carried out to examine the effects of intermixing the component parts of twin ferrule tube fittings manufactured by four different companies. Experimental tests and finite element analysis has shown that the swaging and sealing mechanisms of fittings are different despite seeing geometric similarities. It was evident that no two companies produced components to the same dimensional or metallurgical specification and that pressure testing alone should not be used as the only means of validation.

*The ERA plots of intermixed fittings show that a form of sealing occurred in some combinations which could lead **to** acceptance. However, **it** was not until further engineering assessment was made could it be seen that the sealing methods were not as originally designed and therefore a high risk factor must be applied. In addition **to** the design safety factors being compromised any intended sealing mechanism either became superfluous or overstressed Other components were stressed **to** levels in some unintended way and often were found **to** impede the movement of other parts and acting as a conduit or fatigue failure.*

1. Introduction

Twin ferrule tube compression fittings shown in Fig. 1, were first designed and developed in the USA shortly after the Second World War [1] to meet the ever increasing demands of high-pressure fluid containment. The design has been an unqualified success and as such is used throughout the world, where safety and long-term reliability are of paramount importance. These fittings have many advantages, some of which include:

Back ferrule



Front ferrule

FIG. 1. Union—twin ferrule compression fitting.

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- Ease of assembly.
- Ability to seal repeatedly under make and break conditions.

. • Able to contain pressure up to the burst point of the tube.
. • Work under vacuum as well as low and high pressure.
. • Some manufacturers produce the component parts so precisely that the fittings can be inspected prior to use with a go, no-go gauge.
. • Seal consistently over a wide range of temperature cycling.
. • Made from a wide range of materials to suit the containment of corrosive and harmful fluids.

Twin ferrule tube fittings comprise a body, front ferrule, back ferrule and a nut. They are delivered from the suppliers already assembled and ready to accept the appropriate size tube. The assembler simply inserts the tube end into the fitting until the end of the tube bottoms up against a shoulder inside the body. Once the tube is located, the nut is turned until it is 'finger-tight' and then using a spanner; it is tightened 1.25 tunes. During this tightening process the nut forces the back ferrule forward onto the front ferrule, which then sits on the tapered seat, formed inside the body. During the tightening process the torque increases forcing the noses of both ferrules to just penetrate the outer diameter of the tube creating a swaged metal to metal seal.

There are, worldwide, a large number of different manufacturers of these fittings, most of whom produce well-engineered products that have stood the test of time in terms of quality and reliability. Often, the engineer is spoilt for choice and sometimes the decision to purchase a particular manufacturer's product is based solely upon commercial rather than technical merit. This has led, in a number of cases, to companies using products from more than one supplier and the inevitable inadvertent or deliberate intermixing of component parts. Indeed, there are some suppliers who openly declare that their fittings are 'totally component intermixable'.

The UK's Health & Safety Executive, Offshore Division [2J, has recorded over. 1000 hydrocarbon releases between October 1992 and March 1997, many of which are from tube and piping systems that are less than 2 inch in diameter. A number of these reported releases are attributable wholly or in part to pressure fittings with intermixed components.

This paper details the results of an independent study carried out to evaluate the practice of intermixing and report its findings. The study has included the establishment of fundamental design and manufacturing data obtained from a rigorous examination of stainless steel 316 fittings supplied by four major suppliers.

The data was used to create Finite Element Analysis (FEA) models of each company's design so that quantitative baseline (pure fitting) engineering analysis of the sealing mechanisms could be established. Further FEA modelling and experimental tests were then undertaken on a series of intermixed combinations to study and quantify the effects of intermixing component parts.

1.1. Aims of Study

In order to assess the effect and potential scale of intermixing, four of the leading manufacturers of twin ferrule tube fittings were chosen, some of whom advocate intermixing and some who do not. Throughout this paper the four manufacturers will be referred to as companies 'A', 'B', 'C' and 'D'.

Baseline data in terms of design, dimensions, metallurgy, hardness and sealing mechanisms of pure fittings were established. These data have been used in the later stages of the project to compare the performance, both numerically and experimentally, of intermixed fittings against pure fittings.

A number of fundamental tasks were needed to support a quantitative comparison between the pure and intermixed fittings. These tasks were to:

. • Undertake a dimensional analysis of a quantity of three different sizes of tube fittings manufactured by four different companies to establish dimensions and statistical data.

- Conduct metallurgical analysis and production of hardness profiles of the component parts to provide fundamental material properties data for the FEA study.
- Establish the sealing mechanism for each company's design and identify any differences.
- Review the geometry and manufacturing tolerances of each design to identify potential sources of incompatibility.
- Conduct a series of controlled torque measurements of each size and type of fitting using different wall thickness tubing to help understand the sealing mechanisms and the forces required for final pull-up.
- Undertake a series of simple low and high-pressure leak tests on all baseline and intermixed fittings to correlate with data from FEA models.
- Produce four FEA baseline models and validate elastic/plastic deformation against actual sectioned fittings to verify numerical analysis.
- Using these models select a series of intermixed combinations and evaluate their performance against the pure fitting(s).

1.2. Hardware purchased

Three different sizes and two different types of stainless steel 316 'off-the-shelf' tube fittings were purchased from each company in the following quantities:

- Fifteen each 1/4 inch, 3/8 inch Tees and thirty 1/2 inch Tees.
- Twenty each 1/4, 3/8 inch Unions and forty 1/2 inch unions.

In addition, the following quantities of stainless steel 316 tubing were obtained complete with material certificates:

- 1/4 inch x 0.036 inch wall x 18 metres, random lengths
- 3/8 inch x 0.064 inch wall x 18 metres, random lengths
- 1/2 inch x 0.036 inch wall x 54 metres, random lengths
- 1/2 inch x 0.080 inch wall x 54 metres, random lengths

All tools and measuring instruments used throughout this work had valid calibration certificates traceable to national standards in accordance with the ISO 9001 Quality Systems Standard.

2. Experimental Programme for Baseline Analysis

2.1. Metrology

In order to achieve a highly accurate and reliable set of dimensional data, a Ferranti Co-ordinate Measuring Machine located in a lockable temperature-controlled room was used to measure all critical dimensions of the bodies, nuts, front ferrules and back ferrules. Three separate programmes of work were undertaken whereby actual manufactured dimensions of ten samples, of all (1) 1/4 inch, (2) 3/8 inch and (3) 1/2 inch fittings were accurately measured in inches to five places of decimals.

Some inaccessible dimensions, angles and radii were measured using a Nikon Profile Projector. However, in a few cases low shrink epoxy resin moulds were made to reproduce the internal geometry and measurements made either manually or using the Profile Projector. Unfortunately, this necessitated a number of components being destroyed to enable the male moulds to be released. Despite the application of a mould release agent, during the process of releasing the moulds from inside the nuts produced by company 'C' the silver plating applied to all the nut threads, peeled off. This problem did not occur with any other company's product.

Measurements were made from a mixture of 10 unions and tees of each size, which were randomly selected from the batches supplied.

2.2. Metallurgy and Hardness

Samples of each manufacturer's components together with samples of tubing were analysed using a scanning electron microscope and energy dispersive analysis of X-rays (SEM/EDAX) system.

A Leitz Microhardness Testing Machine was used to examine a small selection of each company's fittings to determine hardness profiles and to identify those component parts that have been hardened throughout or surface hardened. Every component examined had to be carefully cut, trying to avoid local work hardening and then cast in 'Bakelite' mounting compound prior to final polishing.

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1. *2.3.1. Method used to measure hardness of bodies.* Indentations were made approximately 0.04 mm from the surface within the thread and tube location regions, using the Leitz Microhardness Testing Machine with a 200p load. (The unit 'p' is referred to as a pond which = 1 gram.)
2. *2.3.2. Method used to measure hardness of nuts.* The hardness measurements were the average of five hardness readings per nut in the core regions using a 200p load.

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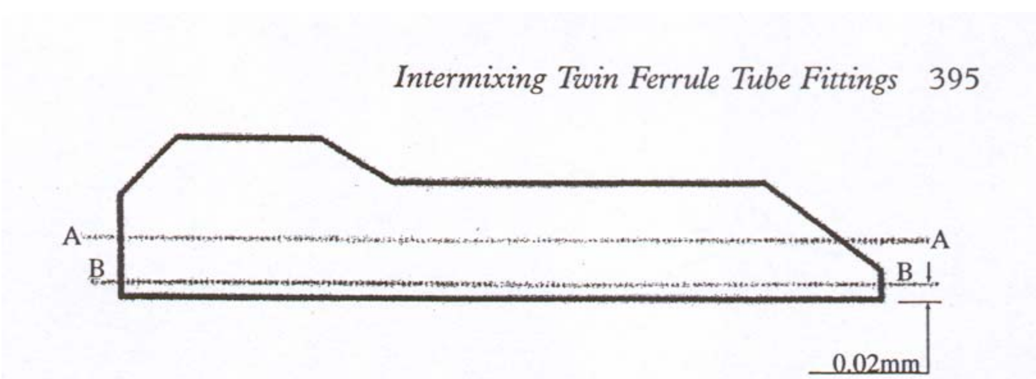


FIG 2. Hardness tests indentation lines.

2.3.4. Method used to measure hardness profiles of back ferrules. Hardness test indentations using a 200p load were made along two lines parallel to the bore of the ferrule in steps which varied between 0.20 and 0.10 mm as shown in Fig. 2. Line A—A was along the centreline of the section

and line B—B was approximately 0.02—
0.05 mm from the edge of the bore.

1. *2.3.5. Method used to measure the hardness of tube.* Hardness tests were carried out on the four tube samples and great care was taken to remove, by grinding, the areas at the end of the tube where the tube cutter had caused local surface work hardening. All measurements were made using a Vickers hardness-testing machine with a 10 kg load and the results were an average of five readings.

2. *2.4. Pull-up Torque Tests*

A series of controlled pull-up tests were made for each size of fitting using a calibrated digital read-out torque wrench with a range of 13.55—135.5 N m. Pull-up torque's varied, depending upon the size of fitting and tube wall thickness, and from company to company, as shown in Table I.

Two further observations made during the pull-up torque tests were:

.(1) Following a pull-up torque of 60.2 N m on one of company 'C's 3/8 inch tee fittings using a 0.064 inch wall tube, it was noticed that not only was the nut difficult **to** undo, but it was also impossible to reassemble without using a spanner. Further investigation showed severe permanent deformation in the form of 'belling' of the end of the body diameter *B* (see Fig. 3) of 0.3 mm just above the thread and some ovality of 0.066 mm.
.(2) During the disassembly of one of company 'A's 1/4 inch fittings, it was noticed that both front ferrules had split along the outer coned surface. The cause of this malfunction was not investigated and the local distributor has been informed.

2.5. Cross-sectioned Pulled-up Assemblies

A number of fittings were pulled-up, sectioned and polished to provide actual baseline measurements and to observe the different sealing mechanisms under a microscope. Care was taken to ensure that the fittings did not stress relieve during the cutting process by making a cut a millimetre or so above the centreline. This offset was accurately measured and used in the calculations to assess the actual deformed dimensions used to validate the FEA models.

TABLE I. Pull-Up Torque Statistics	Mean (Nm)	Standard deviation (Nm)	Range (Nm)	Maximum (Nm)	Minimum (Nm)
1/2 inch x 0.080 inch walltube					
Company 'A'	76.06	10.69	32.94	93.14	65.62
Company'B'	74.58	11.68	45.69	99.92	54.23
Company 'C'	86.65	31.72	80.67	138.97	58.3
Company'D'	45.29	8.33	37.69	77.12	34.43
1/2 x 0.036 inch wall tube					
Company 'A'	52.63	7.37	23.35	73.07	47.72
Company 'B'	49.77	11.44	48.13	73.75	25.62
Company 'C'	80.8	26.34	68.33	108.46	40.13
Company 'D'	38.77	11.49	46.64	72.13	24.49
3/8 inch x 0.064 inch walltube					
Company 'A'	36.85	4.65	17.62	43.65	26.03.
Company 'B'	36.07	9.12	30.5	52.47.	21.96
Company 'C'	58.7	13.05	42.3	77.55	35.38
Company 'D'	26.07	2.89	9.89	31.72	21.82
1/4 inch x 0.036 inch walltube					
Company 'A'	22.15	2.275	10.43	28.47	18.03
Company 'B'	11.91	1.88	8.2	17.08	8.81
Company 'C'	20.67	5.08	19.8	34.16	14.37

Company ‘D’	12.42	0.91	2.98	13.83	10.84

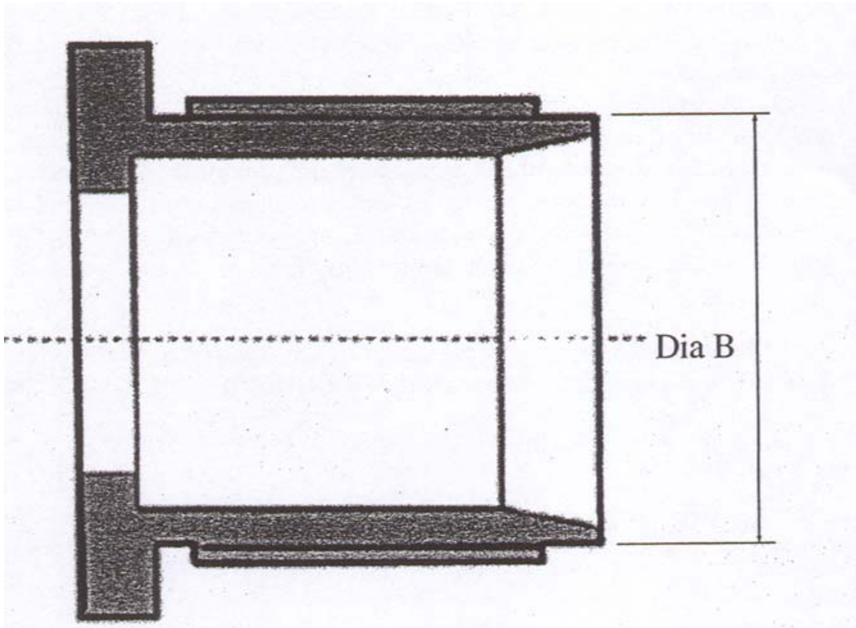


FIG. 3. Body diameter ‘B’.

3. Experimental Results from Baseline Analysis

3.1. Metrology results

The results from measuring the dimensions of the 1/2 inch fittings are as follows:

.(1) Company ‘B’ not only produced ferrules which were of a different design, but the back ferrule was made differently and was smaller in overall length than those produced by the other companies. The front ferrule was longer and had a stepped collar located on the outer surface, while the other companies’ ferrules were shorter and conical along their length. Due to the back ferrule being manufactured by what is believed to be a stamping and forming process, great difficulty was experienced trying to measure the complex blending of angles and radii produced by this process. Eventually, they were copied directly from the screen of the Profile Projector and then digitised for the purpose of creating accurate FEA models. The same problem was encountered when attempting to measure the radii that were evident on the inside edge at the top of company ‘B’s front ferrule. A number of precision mouldings were made of this region and the shapes carefully traced, digitised and transferred to the FEA models. From these initial findings, it became clear that the sealing mechanism employed by company ‘B’ was different in design and geometrically incompatible with other systems.

.(2) By studying the sets of statistical data produced from the component measurements, manufacturing tolerances used by the four companies were found to be different, as might be expected, for components manufactured by entirely independent companies.

.(3) As a general observation, diameters and lengths seemed to be controlled reasonably well by all companies for all three sizes of fittings used in the study. However, angles were not so well controlled by companies ‘A’, ‘B’ and ‘C’ as they were by company ‘D’.

(4) The nut and mating body threads have been identified as the American Standard Unified [3] where the thread form is practically the same as the American National form.

.(5) All the union bodies were made from bar stock and the tees were forged and then machined to size.

3.2. Metallurgy and Hardness Testing Results

Results from the SEM/EDAX machine confirmed that all the samples provided for metallurgical analysis were stainless steel 316 (17% chrome, 12% nickel and 2% molybdenum).

All sizes and makes of nuts were plated with a layer of silver to help reduce friction and to prevent thread galling.

It was decided, during the early stages of the project, that the 1/2 inch fitting would be used for FEA modelling as it was easier to measure, cross-section and observe differences, being the largest size studied. Component hardness tests, therefore, were limited to a selection of the 1/2 inch fittings only.

3.2.1. Results from hardness tests carried out on 1/2 inch front ferrules. Company 'A' front ferrules had the highest hardness values of between 331 and 334 Hv in the core of the ferrule, whereas company 'B' had the lowest hardness values of between 276 and 279 Hv. The company with the widest range of hardness readings was company 'C' with a range of 304—330 Hv.

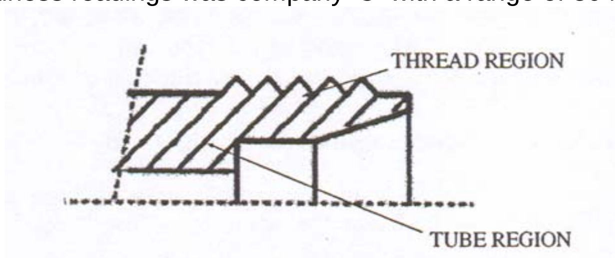


FIG. 4. Hardness regions tested.

There was no evidence of any surface hardening and the differences observed can be attributed to strain hardening of the original barstock during the manufacturing process and subsequent machining operations.

1. *3.2.2. Results from the hardness tests carried out on the 1/2 inch nuts.* The nuts made by company 'C' had the highest core hardness value, where a range of 305—333 Hv was measured. The lowest core hardness values were those measured on company 'B' nuts where a range of 253—258 Hv was recorded. Again, the differences can be attributed to strain hardening of the original bar stock and machining operations.
2. *3.2.3. Results from the hardness tests carried out on 1/2 inch bodies.* Two sets of hardness measurements were made on each of the bodies, both tees and unions, one in the thread region and the other in the tube region, as shown in Fig. 4.

Differences were expected in hardness reading between bodies made from bar stock (unions) and the forged tees. This assumption was confirmed as, generally, the tee **bodies** were found to be softer than their equivalent unions. Also, hardness measurements taken in the tube region were shown to be lower than those taken in the thread region, where it is believed the higher hardness values were induced by thread rolling to provide additional strength.

3.2.4 Results from the hardness rests carried out on the back ferrules. Company 'A' produces a back ferrule which is hardened on all the surfaces to a maximum hardness value of 956 Hv, decreasing with depth to 473 liv at 0.04 mm and 180 liv at 0.4 mm. It is believed, following further research, that the hardening method used is called 'Kolsterizing' which is a surface hardening process developed by the Dutch company, Hardiff BV [4]. The 'Kolsterization' process changes the carbon concentration, creating a very hard surface, which is consistent in depth and covers all external surfaces.

Company 'B' back ferrules are unique in their design, method of manufacture and hardness profile. The results confirm that the ferrule is hardened throughout with some internal values being as high as 412 liv and as low as 286 liv, with surfaces averaging 334—375 liv. The hardness is created by the manufacturing process, which is believed to be a stamping and forming operation. Further examination of the ferrule revealed that the outer surface is nickel-plated.

Company ‘C’ produces a back ferrule which is similar in geometry to those made by companies ‘A’ and ‘D’. However, the main difference is in the hardness profile, depth and degree. For example, the maximum surface hardness was measured at 642 Hv, and this decreased with depth to 299 Hv at 0.06 mm and 150 Hv at 0.4 mm. The surface hardness is not as high as that produced by Company ‘A’ but it is deeper, which could affect the stiffness and bending behaviour under compression, which in turn could contribute towards the high pull-up torque’s measured.

Company ‘D’ has a back ferrule which, although similar geometrically to those made by companies ‘A’ and ‘C’, behaves very differently during pull-up. The reason for this difference is that only the nose portion of the ferrule is surface hardened at 640 Hv, decreasing to 466 Hv at

1. 0.06 nun and 205 Hv at 0.4 nun. Hardening the nose only causes it to rotate inwards, penetrating the tube, while keeping the rest of the ferrule parallel to the tube surface, providing the tube with additional radial support. This design would be particularly effective under vibrational conditions.
2. **4. FEA Programme for Baseline Study: Basis for Study**

FEA models of each of the four company’s 1/2 inch ‘pure’ *fittings* were produced to establish a set of data in terms of material strain, Von Mises stress and elastic/plastic material deformation. Intermixing of parts, during the final stages of the project, were also based upon 1/2 inch fittings.

All manufacturers state that once the tube has been inserted into the fitting the nut must be turned until ‘finger tight’ and then tightened with tools or by using a hydraulic swaging unit for the equivalent of 1.25 turns. The thread pitch on the 1/2 inch nut was measured and found to be 1.27 mm therefore, the axial movement produced during the 1.25 turns of the nut was calculated to be
1.58 mm. This dimension was used throughout to simulate the axial movement of the nut after
1.25 turns.

The model was constructed for use with the ANSYS [5] FEA program and version 5.4 was used throughout the study.

Measured hardness values were used to determine the yield strength of the various layers and components of all fittings analysed. Yield strength and hardness data have been obtained experimentally by Hart [6] for materials with hardness values Hv, of up to 500, and were used in this study. For materials with higher hardness values, a correlation factor of 2.1, normally used for weld materials by Pargeter [7], was chosen.

5. FEA Results from Baseline Study: Validation of Model Results

The method used to validate the FEA baseline models was to make a comparison between measured deformed diameters of the back and front ferrules, taken from the cross-sectioned fittings and the calculated equivalent diameters produced by the FEA program.

Measurements of ferrule diameters taken from pulled-up fittings were compared with the equivalent modelled diameters. An overall average error of 2.3% was found, which was well within the self-imposed target of 10% that allowed for some experimental and numerical errors. Comparison between the experimentally deformed geometric profiles and those predicted by the FEA models, showed similar accuracy. This confirmed the engineering judgements made in the choice of material properties and the coefficient of friction values.

6. Sealing Mechanisms and Design Differences

6.1. Company ‘A’’

The first difference found was that the entire outer surface of the back ferrule was significantly harder (956 Hv) than those produced by any of the other three companies.

The hardening, although clearly effective, was surprisingly shallow, being only 0.02 mm deep compared with company 'C's and company 'D's back ferrules which were hardened to a depth of 0.04 mm. Hardening the outer surfaces of the back ferrule causes it to stiffen and resist bending. This influences the sealing process to the extent that much of the axial force required to pull up the fitting is expended in compressing the back ferrule, which is confirmed by the relatively high pull-up torque (average 76 N **in).** Meanwhile, as the nose of the back ferrule penetrates the wall of the tube, the axial load causes about a third of the inner surface of the ferrule, from the nose, to tipple demonstrating a classic buckling effect. This can be seen on the baseline FEA plots for company 'A' shown in Fig. 5.

The design of this ferrule and the resulting sealing mechanism is unique to company 'A' and similar to company 'C' but differs greatly from those observed for companies 'B' and 'D'.

The second difference observed was that after 1.25 turns, the outer diameter of the back ferrule (see Fig. 5) did not bow outwardly under the compressive load to the same extent as the ferrules designed by companies 'C' and 'D'. This again is probably due to the strength imparted to the ferrule by the high level of surface hardening.

6.2. Company 'B''

Out of the four company products studied, the most different in terms of design, geometry and material properties were fittings made by company 'B'. Externally, they appear to be identical to the other makes of fitting but when a comparison was made with the front and back ferrules, major differences were evident. Further investigation revealed that the internal design of the nut was also different as it contained fewer internal steps between the end of the thread and the back of the nut, as shown in Fig. 6.

The back ferrule is shorter by one-third than the other three companies' back ferrules. It is thought that the ferrule is made by a stamping and forming process, which results in strain hardening the entire component to an average hardness of 320 Hv (half of the surface hardness of ferrules made by companies 'C' and 'D').

The front ferrule was found to include what can be best described as a stepped collar running parallel to the axis, as shown in Fig. 6. The outer surfaces of the other companies' front ferrules were conical throughout. A further significant difference was found in the bore of the front ferrule where a double curved profile exists. to accommodate the curved nose of the back ferrule. All other company designs show a chamfered entry angle of approximately **9Q0** inclusive, to receive the coned nose of their own back ferrules. As the section geometry of company 'B' back ferrules is mainly made up of curves and blending radii, it is difficult to see them being used successfully with other front ferrules as the geometry is incompatible. Intermixing company 'B' ferrules with other designs produced wrongly deformed shapes and no evidence of swaging. This is clearly demonstrated when a 'B' back ferrule is mixed with a 'C' assembly, as shown in a photograph of the sectioned intermixed assembly (Fig. 7)

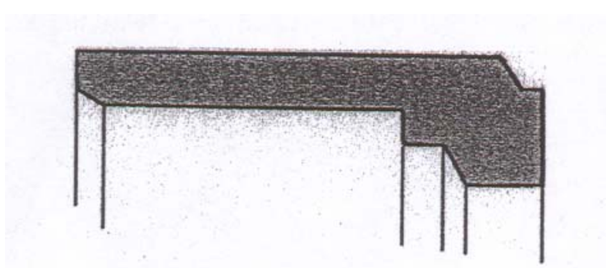
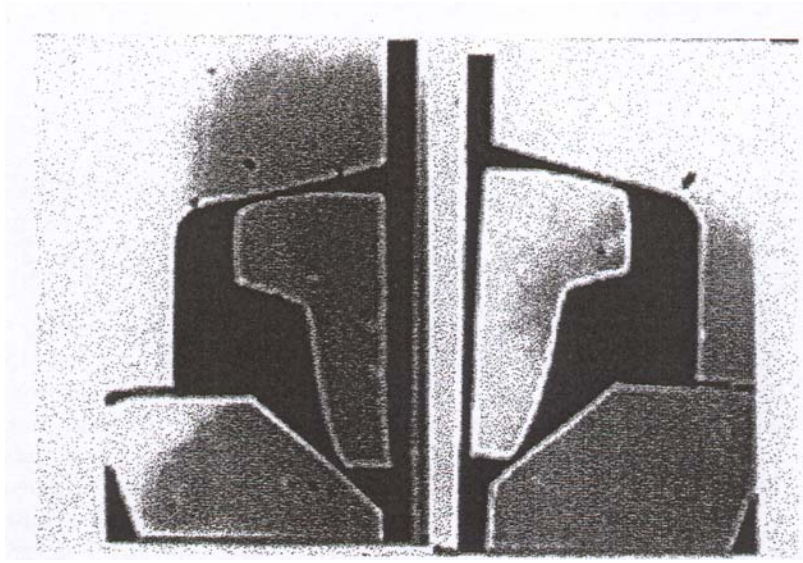


FIG. 6. Company ‘B’ nut design. FIG. 7. Sectioned intermixed assembly.



Further evidence of differences in company ‘B’s design was seen in the sealing mechanism. As the nut compressed the back ferrule, the nose entered the curved entry recess and followed a route which deflected the nose, causing it to rotate inwardly to penetrate the tube, while the top surface rotated in a congruent arc away from the tube. The other three designs of back ferrule have more of an axial wedging action than a rotary action.

6.3. Company ‘C’’

The design of fitting produced by this company is again different and these differences are manifested in the metallurgy and high pull-up torque’s. The entire back ferrule is surface hardened to between 618 and 642 Hv to a depth of approximately 0.04 mm. The method of surface hardening was not investigated but whatever process is used, it appears to influence the stiffness of the back ferrule. This affects the sealing mechanism, resulting in high pull-up torque’s where the average for the 1/2 inch fittings was 85 N m and some were as high as 127—138 N m.

A photograph of the cross-sectioned back ferrule, shown in Fig. 8, shows ripples along the surface of the ferrules caused by the high compressive load applied by the nut during the swaging process. One possible reason for the difference in pull-up torque between companies ‘A’ and ‘C’ is that company ‘A’ uses a hardening process for the back ferrule which, although harder, is thinner than the surface produced by company ‘C’ to harden their back ferrule. Evidence to support this view was provided by the torque tests where company ‘A’ fittings needed an average pull-up torque of 76 N m. Company ‘D’ fittings required an average torque of 44 N m, as the ‘D’ back ferrule is hardened only on the surface of the nose leaving the remaining ferrule body soft.

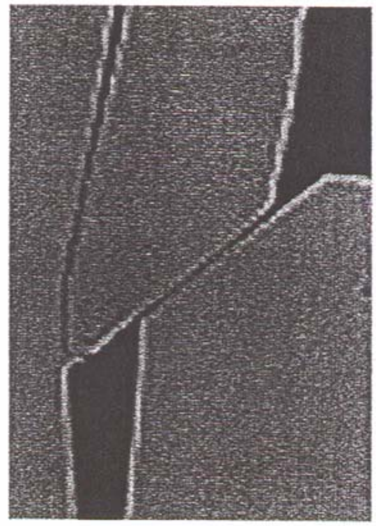


FIG. 8. Cross-sectioned back ferrule.

6.4 Company ‘D’’

It became evident that as the study progressed the designs of fittings made by companies ‘A’, ‘C’ and ‘D’ were geometrically very similar any differences were deliberate and subtle. This is the case with fittings designed by company ‘D’, where the main difference, when compared with the other three, is in the design and manufacture of the back ferrule. These ferrules are hardened to 640 Hv on the surface of the nose only, to a depth of 0.06 mm. Further study revealed that as the fitting was pulled-up to the full 1.25 turns, the nose moved slightly towards the tube rotating about a line which separated the surface of the hardened nose from the rest of the ferrule.

Another difference, which again is probably related to the design of the back ferrule, is the low pull-up torque required for company ‘D’ fittings. Statistically, they were 30% lower than companies ‘A’ and ‘B’ and 60% lower than that of company ‘C’.

7. Intermixing Study: Basis for Study

It was decided to limit the intermixed combinations to six, four combinations that were geometrically incompatible, but could possibly produce a seal, and two combinations that may seal for a limited period depending upon operating conditions. All the tests carried out used new components and were pulled-up in the following combinations:

Test 1: ‘B’ Assembly + ‘C’ back ferrule
Test 2: ‘D’ Assembly + ‘B’ back ferrule
Test 3: ‘D’ Body + ‘B’ ferrules and nut
Test 4: ‘D’ Body ± ‘C’ ferrules and nut
Test 5: ‘A’ Body + ‘B’ front ferrule **+** ‘C’ back ferrule + ‘D’ nut
Test 6: ‘C’ Assembly + ‘B’ back ferrule
Test 7: 1/4 inch ‘D’ Body + ‘A’ ferrules & nut
Test 8: 1/4 inch ‘D’ Body ± ‘A’ back ferrule + ‘D’ front ferrule & ‘A’ nut
Test 9: 1/4 inch ‘D’ body + ‘C’ back ferrule + ‘D’ front ferrule & ‘C’ nut
Test 10. 1/4 inch ‘D’ body + ‘C’ back ferrule + ‘C’ front ferrule & ‘C’ nut Intermixed assemblies, tests

1—6, were then cross-sectioned and the deformed dimensions used to check against the FEA models.

Tests 1, 2, 3, 4 and 6 were selected to represent possible sets of intermixed components where a company could be using two sets of different suppliers of fittings and the component parts inadvertently intermixed. Test 5 was chosen to demonstrate to those that advocate intermixing that they must also accept the possibility of multiple combinations. Any company that supports intermixing cannot then specify only certain combinations or conditions as users of these fittings will not necessarily know the details of the subtle differences.

Tests 7—10 were selected on the basis that 1/4 inch fittings are a commonly used size and companies ‘A’, ‘C’ and ‘D’ are dimensionally and geometrically similar.

Photographs of cross-sections, Figs. 9 and 10, were used for the analysis with no corroborating FEA modelling.

8. Interchanging Geometrically Similar Bodies after Pull-up: A Replacement Issue

Four of the intermixed tests (Tests 1, 2, 5 and 6**)** produced considerable evidence that would seriously question the advisability of intermixing. However, when the results of Tests 3 and 4 were reviewed, it was realised that these combinations represented situations which frequently occur in practice—involving replacing a component such as a valve or controller where the end fittings are bodies produced by another manufacturer. In this case, the only component that changes is the body and, as three companies produce bodies that are geometrically similar, evidence was needed to provide support for not intermixing bodies of fittings from other companies after pull-up of pure ferrules and nut.

A series of important measurements were made of the dimension between the end of the swaged front ferrule and the tube end—length *‘P’* shown in Fig. 11. They were all different and in one case the difference was as much as 0.9 mm.

The length *‘P’* is determined by the swaging mechanisms used by each company, which in turn is controlled by geometry, material properties and dimensional tolerances. It is a combination of these variables which produces a wide variation in length *‘P’* rather than the influence of just one. Each company is able to control these variables within a range to suit the individual company’s manufacturing tolerances such that bodies of pure fittings can be interchanged, but not with bodies of those fittings produced by other companies. For example, if a swaged tube assembly produced a length *‘P’* in a pure fitting that is greater than the equivalent length·*‘P’* produced by another manufacturer, then when the ‘foreign’ tube end, which has a greater length *‘P’,* is inserted into a different manufacturers body, it would be forced up against the shoulder inside the body, preventing the seating of the front ferrule. The only way such a combination may work is if excessive force is used to force the nose of the front ferrule away from the tube and onto the body sealing face. This action may cause the nose of the front ferrule to shear off or tear the tube, none of which is intended or expected by the designers of these fittings. Alternatively, as in the case with thinner walled tubes, the tube may buckle and break away from the swaged front ferrule seal, providing a leakage path.

9. FEA and Practical Testing of the Intermixed Fittings

9.1. Intermixed Test 1

The first intermixed test was a combination of company ‘B’ assembly, body, nut and front ferrule, together with an extraneous company ‘C’ back ferrule. The torque required for pull-up on the right-hand side was 35 N m and the left-hand. side was pulled-up with a torque of 60 N m.

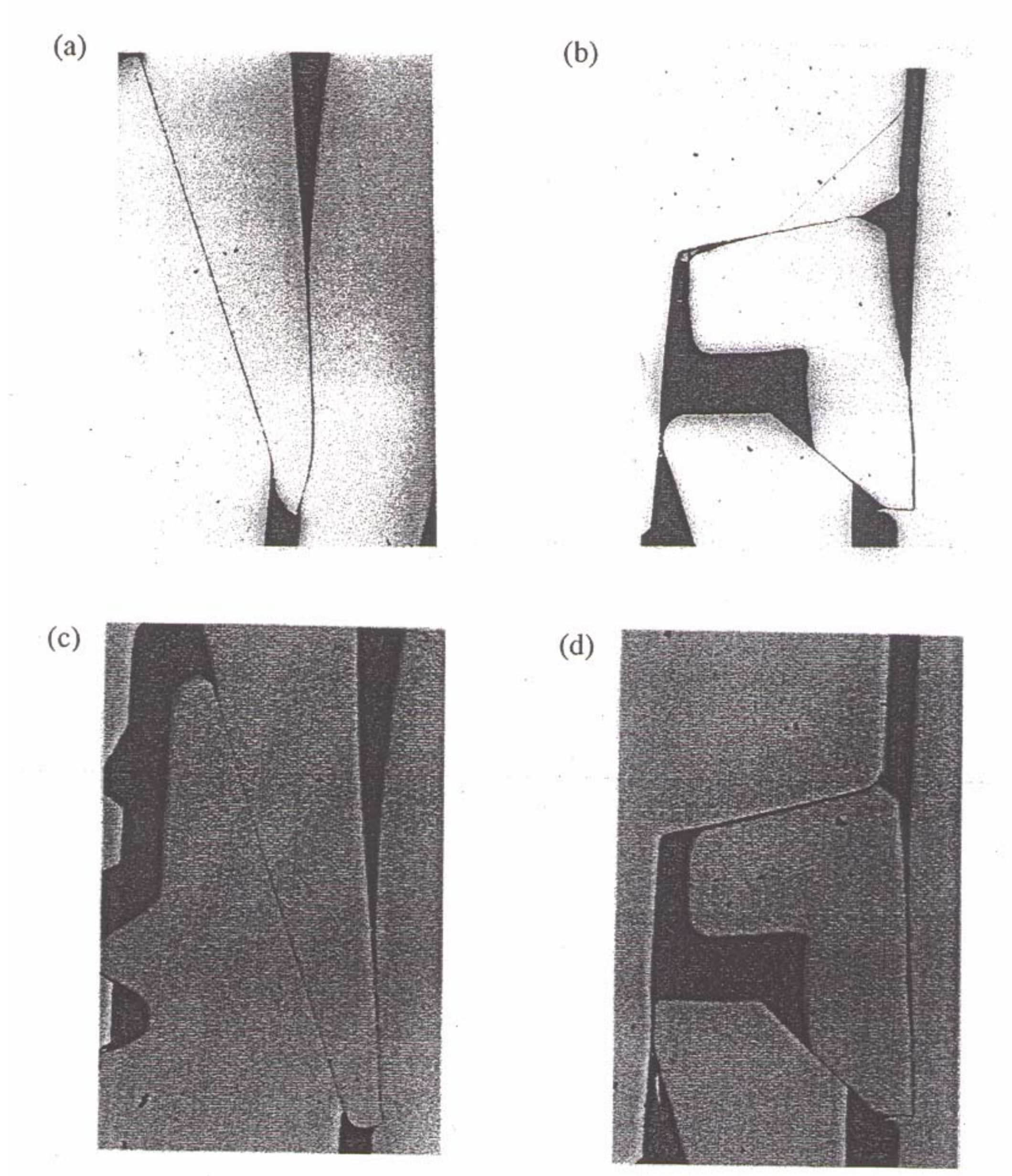
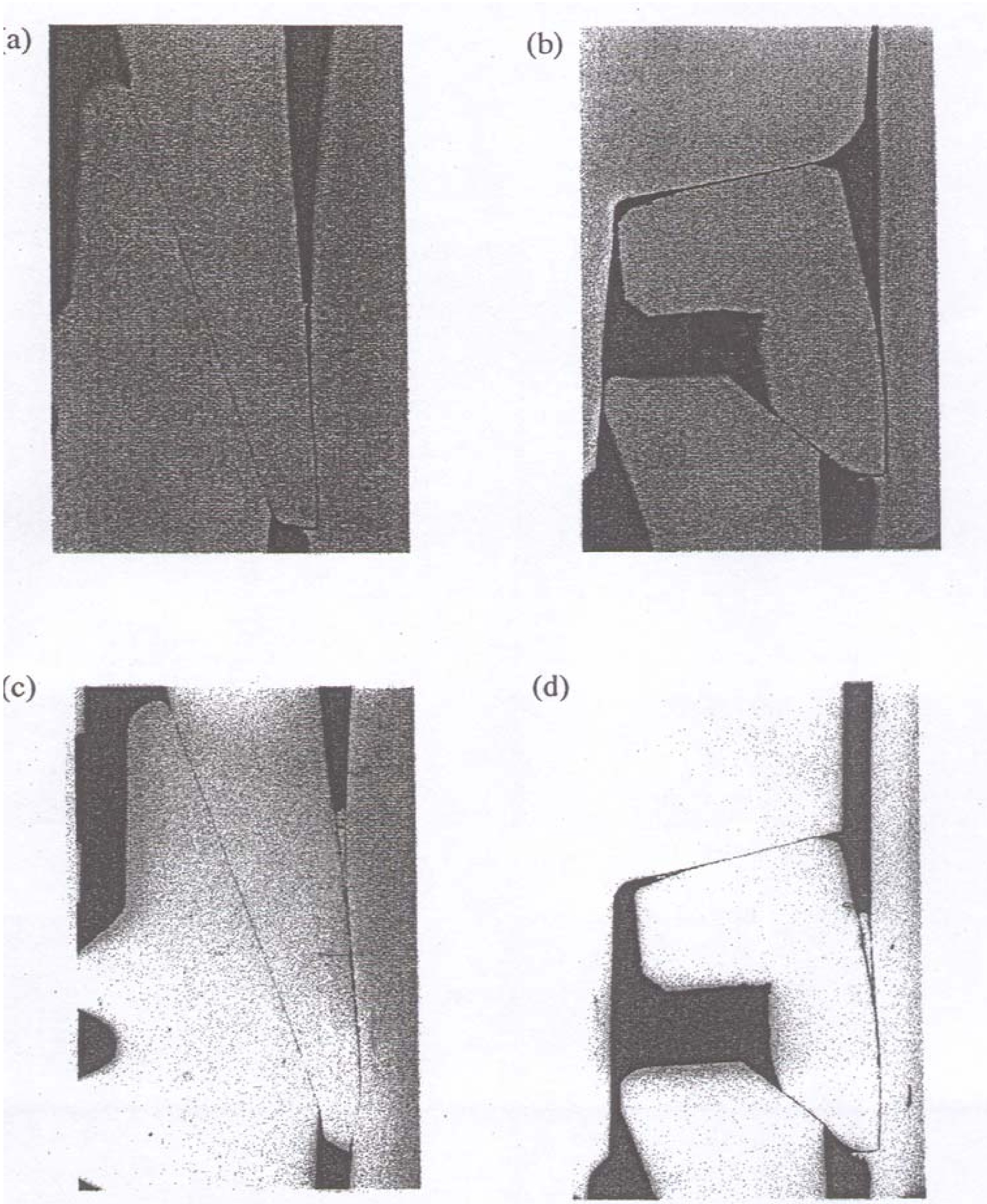


FIG. 9. (a) ‘D’ body, ‘A’ back ferrule, ‘A’ front ferrule and ‘A’ nut; (b) ‘D’ body, ‘A’ back ferrule, ‘A’ front ferrule and ‘A’ nut; (c) ‘D’ body, ‘A’ back ferrule, ‘D’ front ferrule and ‘A’ nut; (d) ‘D’ body, ‘A’ back ferrule, ‘D’ front ferrule and ‘A’ nut.

The average pull-up torque for company ‘B’ 1/2 inch fittings was 74.5 Nm, indicting that one or both ferrules were not swaging. Photographs of the intermixed assembly are shown in Fig. 12, where it can be seen that the back ferrule has not swaged but has wedged itself between the front ferrule and the tube.

Figure 13a shows the FEA model of Von Mises stress profiles which are very different to the baseline profiles (Fig. 1 3b) produced by a pure company ‘B’ fitting.



Introducing a ‘C’ back ferrule into a ‘B’ assembly has resulted in an increase of 8% in maximum calculated Von Mises stress, and has introduced high stress concentration areas at the interfaces between the back ferrule and the tube, the back ferrule and the nut, and the back ferrule and the front ferrule. Further study of the FEA profiles and photographs of the cross-sections demonstrates how the nose of the back ferrule has deformed in a manner that follows the shape of company ‘B’s front ferrule but has not swaged as intended by a pure company ‘B’ back ferrule.

FIG. 11. Measurement of the dimension between the end of the swaged front and the end of the tube.

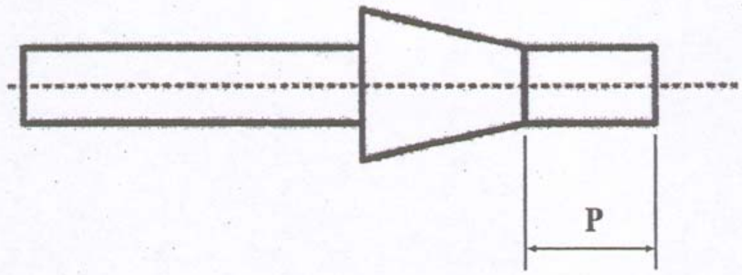


FIG. 11. Measurement of the dimension between the end of the swaged front and the end of the tube.

This combination passed a leak test using air pressure in increasing steps of 172 kPa up to 690 kPa. After *five* make and break tests, no leaks were evident up to 690 kPa. A high-pressure leak test was carried out at 62,050 kPa and again no leaks were detected. These simple tests do not constitute a safe fitting combination as they do not represent the conditions such fittings would be subjected to in operation, such as variations in temperature, vibration, pressure, and fitting make and break. The main conclusion for this combination that can be made is that it does not operate as the designer intended and therefore cannot be guaranteed as safe by any reputable manufacturer.

9.2. Intermixed Test 2

This test was a combination of ‘D’ body, nut and front ferrule mixed with a company ‘B’ back ferrule. Due to the geometry of the back ferrule being different to the other three designs, it was perhaps one of the extreme cases which demonstrates the shortcomings of intermixing.

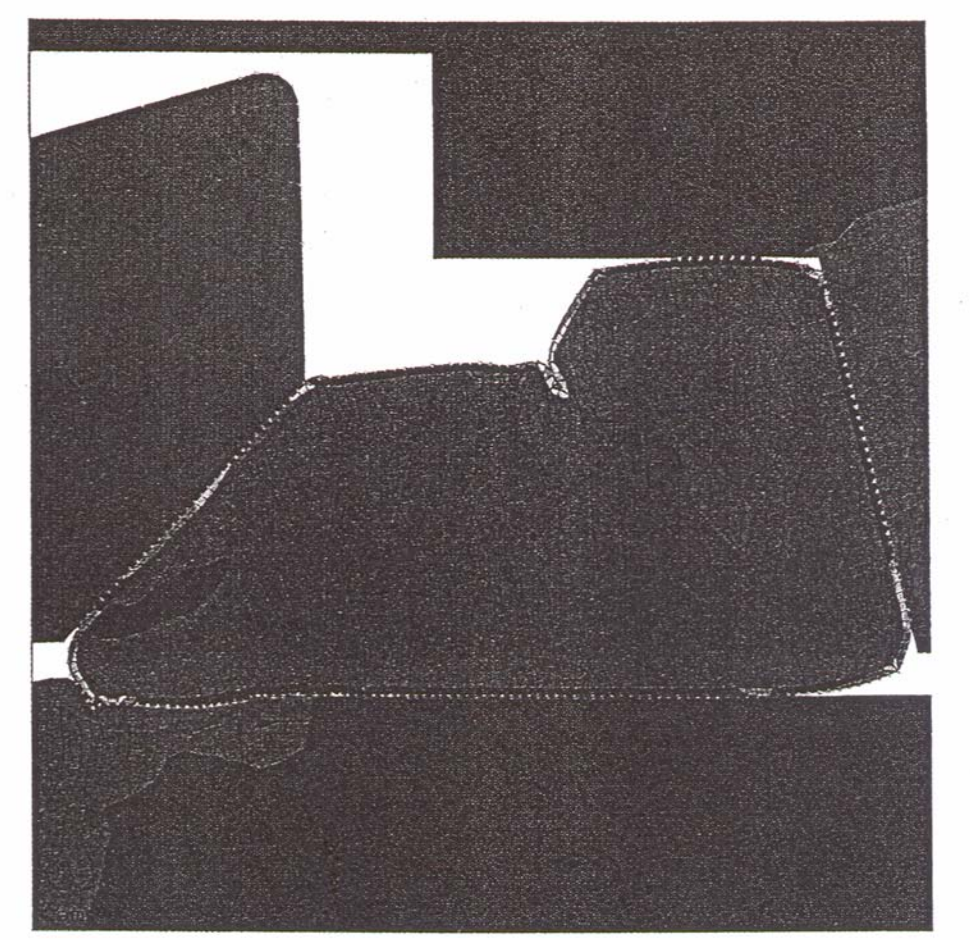


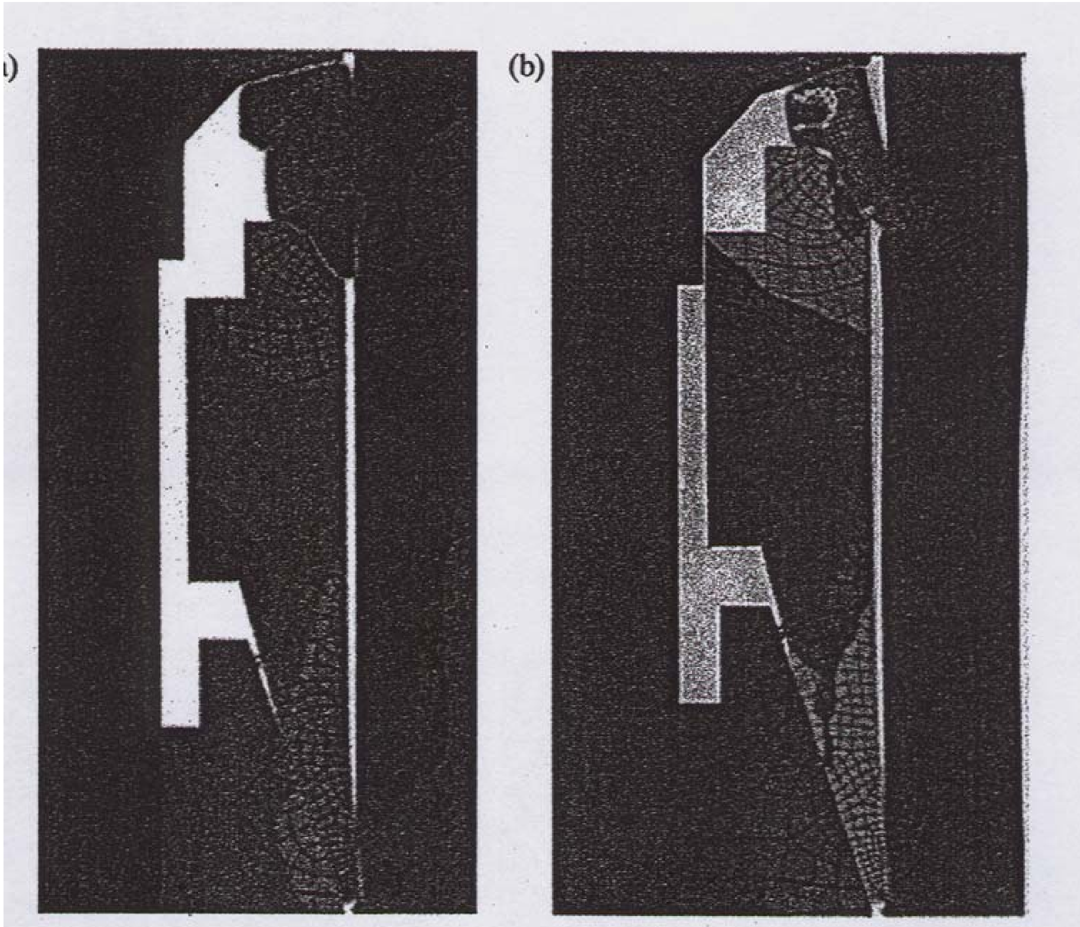
FIG. 5. FEA plot for Company 'A' back ferrule.

The pull-up torque's were high at 69 and 77 N m, respectively, compared with an average torque of 44 N m for pure company 'D' fittings. Photographs of the cross-sectioned fittings (see Fig. 1 4a) show that the back ferrule does not even touch the wall of the tube and in fact plays no part whatsoever in the sealing mechanism. Further study of the shape of the front ferrule shows good agreement with the photographs and plots (see Fig. 14b).

It is clear from these figures that the nut forces the front ferrule only down the outside of the tube, causing it to extrude past the body seat and radially compress the tube without swaging. Both high- and low-pressure tests were successful but, as previously stated, these intermixed fittings did not undergo any realistic operational testing and are not meant to work in the manner demonstrated.

9.3 Intermixed Test 3

Test 3 was selected on the basis that a company 'D' body could inadvertently be used with pure (unused) ferrules and nuts from company 'B' when two suppliers are used by original equipment manufacturers (OEMs). This test, therefore, is different from that presented in Section 8, which describes the situation of a body only interchange after a tube/ferrules make-up from a pure assembly.



The FEA models show only minor differences when compared with the FEA baseline models.

Pull-up torque's for this assembly were 69 and 77 N m for right- and left-hand sides, respectively, and no leaks were recorded following this initial pull-up. However, after five joint make and breaks, a leak was detected at 690 kPa. During the make and break tests, it was noted that the tube was extremely difficult to remove from the body and that the nuts had moved past the original 1.25 turn mark by some 3 mm. Further tightening of the nuts enabled the combination to be pressure tested and no leaks were evident. The reason why this combination appears to work is probably due to the nuts being over tightened.

9.4. *Intermixed Test 4*

This test combined a 'D' body and 'C' ferrules and nut. Again, this test was aimed at OEMs that could be using company 'D' and 'C' fittings. It must be stressed also that components used in this combination were unused. Pull-up torque's for right- and left-hand sides were 100 and 122 N m, respectively, and no leaks were observed during the 690 kPa leak test and the subsequent high-pressure test. Careful study of the two FEA models of Von Mises stress profiles show good agreement apart from a different stress distribution pattern and geometry at the tip of the front. ferrule (see Fig. 15). In this case, as the body is the only component to be intermixed from new, then such a combination may work under operational conditions. However, if these two companies' products are being used simultaneously, then other component parts could be intermixed inadvertently with unknown consequences.

FIG. 14. (a), (b). Intermixed Test 2 – Cross-section photograph and FEA plot of Von Mises stress profile.

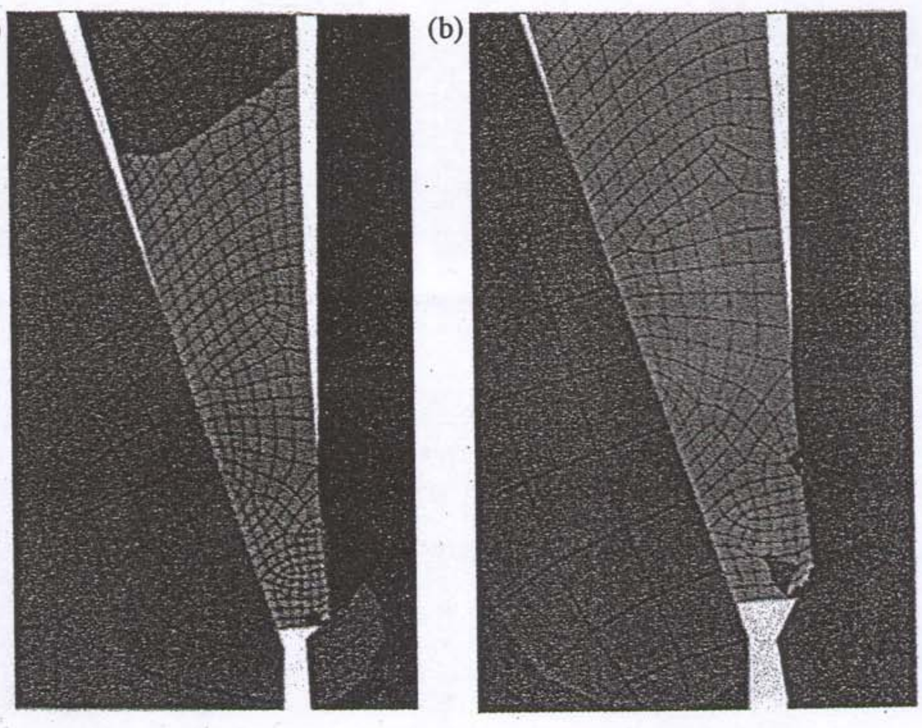
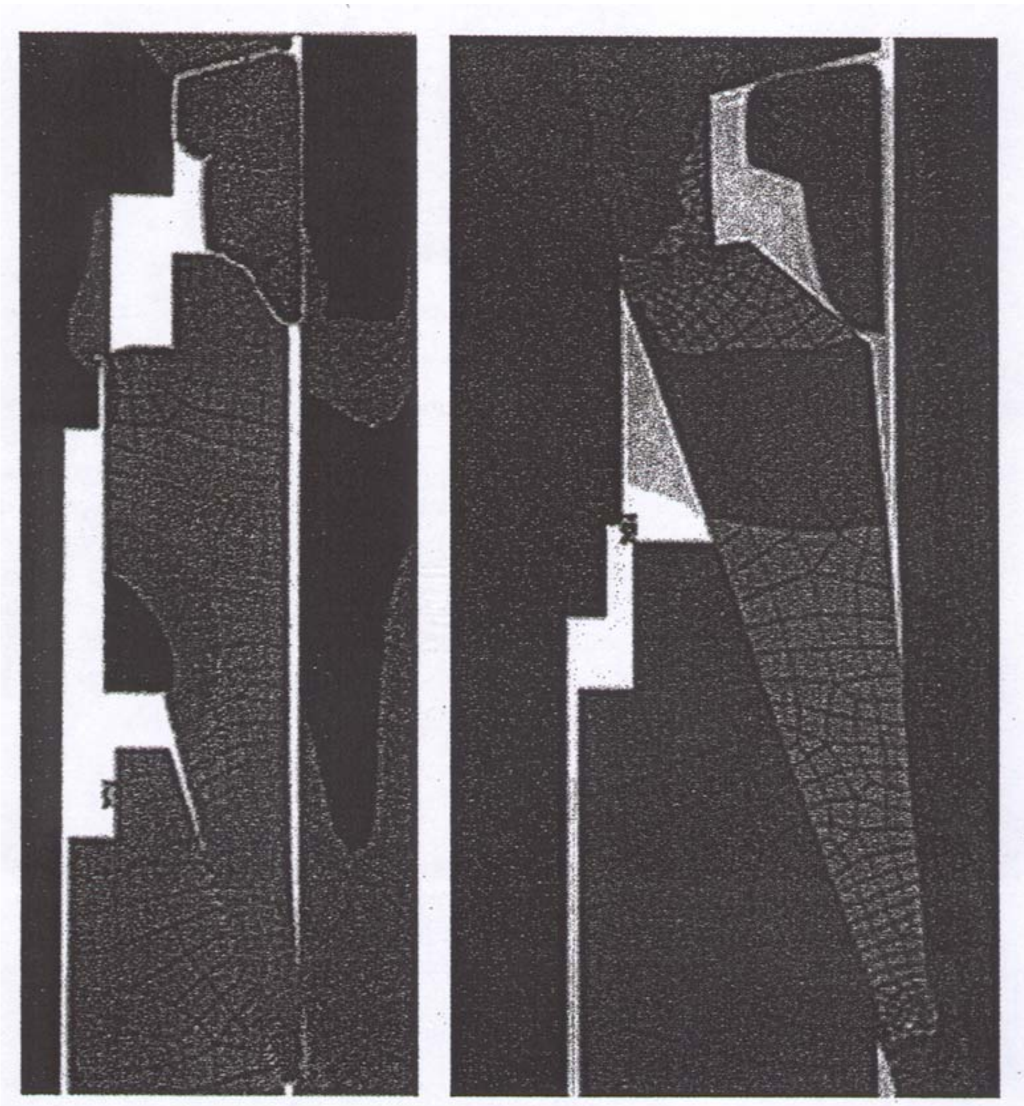


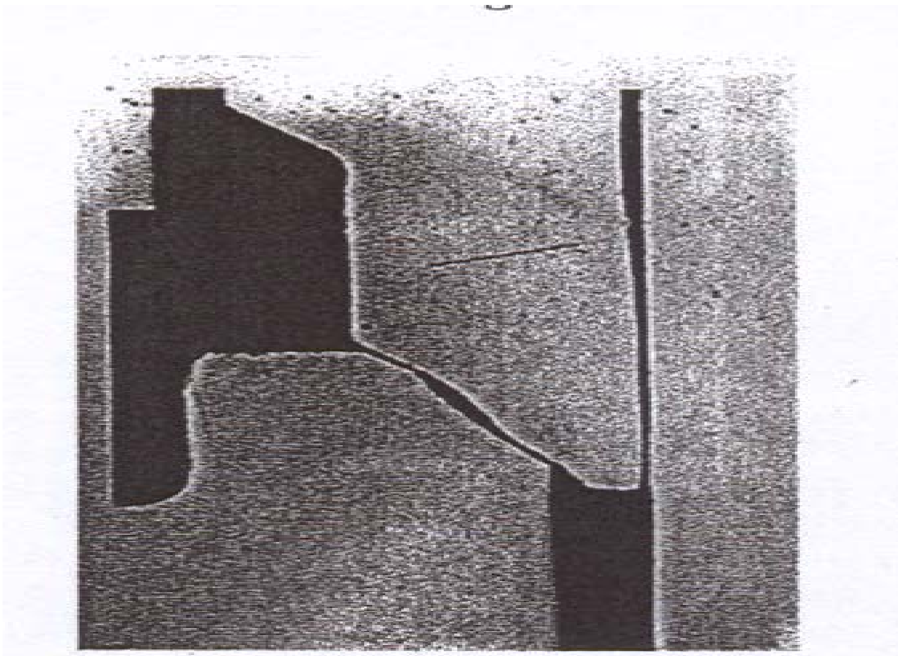
FIG. 15. (a), (b). Intermixed Test 4 – FEA plots of front ferrule differences.

9.5. Intermixed Test 5

As previously stated, any company advocating intermixing component parts has to accept the inevitable total combination intermix, not just products from the companies being reviewed in this study, but components manufactured by others. It was on this basis that a combination of ‘A’ body + ‘B’ front ferrule + ‘C’ back ferrule + ‘D’ nut was chosen.



The pull-up torque’s were quite low at 38 and 39 N m left- and right-hand sides, respectively. Figure 16 clearly shows that the back ferrule has wedged itself between the top end of the front ferrule and the tube, with little evidence of any swaging of the back ferrule hence the reason for the low torque encountered. However, the FEA model (Fig. 17) shows some indentation of the tube by the back ferrule but the depth is smaller than that produced by a pure company ‘C’ assembly. In addition, the FEA model shows that the front ferrule is making contact with the nut, causing the outer edge of the front ferrule to deform in a manner not intended. This combination proved leak-tight at both low and high pressures.



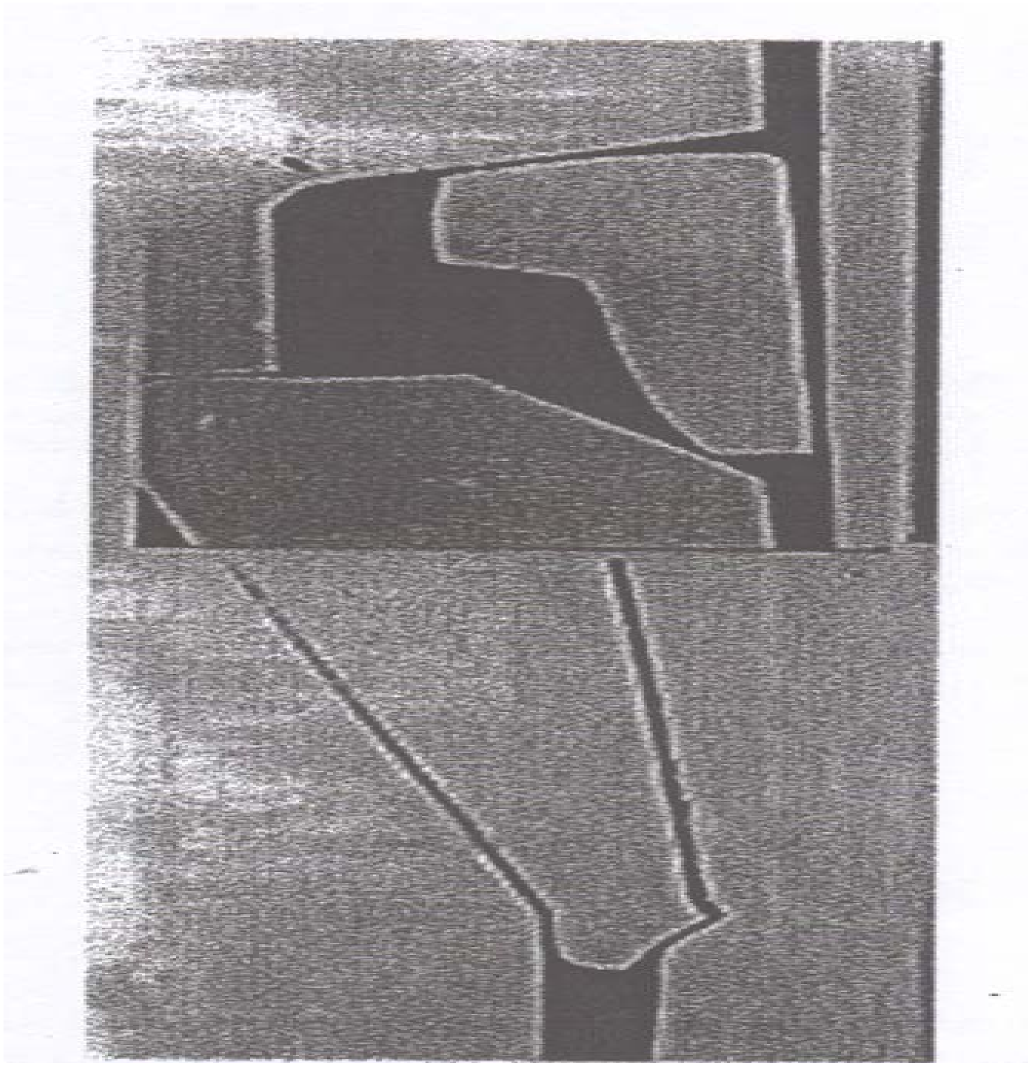
9.6. Intermixed Test 6

Test 6 was an intermix of a company ‘C’ assembly and a company ‘B’ assembly back ferrule. The FEA model of Von Mises stress profiles are showing in Fig. 18, where it is seen that the back ferrule plays no part in the intended sealing mechanism.

Due to the back ferrule being shorter in length than that designed by company ‘C’, the shoulder inside the nut makes contact with the back face of the front ferrule and forces it between the body and the tube, distorting the ferrule nose and creating a stress riser.

A photograph of the assembled cross-section (Fig. 19) confirms the FEA result. This intermix combination demonstrates the deviation from the intended parent assemblies and showed that it relied entirely upon material being forced into the wrong places, and imposed stresses on the nut in places where it is not designed to take stresses.

This combination passed both leak and pressure tests, and, out of interest, the pressurised assembly was mounted onto a vibrating machine and subjected to a frequency of 1400 Hz at an amplitude of 3.5 mm; after 67 h it fractured at the point where the front ferrule indented the tube.



9.7. IntermixTest 7

The back ferrule, shown in the cross-section photograph, Fig. 9(a), has swaged onto the tube as intended but it has moved further down the back face of the front ferrule than it would if it were a pure Company 'A' fitting, i.e. 1/2 way down as opposed to 1/3 way down. The photograph shown in Fig. 9(b), indicates the reason why this has occurred as it shows the nose of the front ferrule being distorted as it squeezes between the body seating face and the outside diameter of the tube. It is possible, due to the geometric tolerances known to exist, that the front ferrule angular tolerances were such that they did not match those of a pure Company 'D' body and front ferrule and hence the resultant diminished swaging by the front ferrule. Such a combination may pass an initial leak and pressure test, however, further FEA analysis of the fitting is required to determine the stress distribution. This will show whether any stress raisers have been introduced which could cause fatigue failure under operational conditions. It is therefore safe to conclude without further studies this combination should not be practiced or recommended.

9.8. IntermixTest 8

In this combination, Figs 9(c) & 9(d), the Company 'D' front ferrule is performing as designed with the nose swaging onto the tube as expected when in combination with a parent body. However, the mechanism that provides the swaging force is different and the pull-up torque would have been higher due to the design and hardness of the back ferrule. This is manifested when comparing photograph Fig.

9(d) with photograph Fig. 9(b). Here it can be seen that the angle between the bore of the back ferrule and the outside diameter of the tube is greater in Fig. 9(b) than that shown in Fig. 9(d). In addition, it can be seen that some extrusion is evident along the top inside edge of the back ferrule again providing evidence of high torque when compared with a pure Company ‘D’ fitting. As this intermixed test was assembled with a mixture of new components it may have initially held pressure but for how long and under what conditions is not known. Only extensive FEA simulating predicted conditions and practical evaluation would provide a user with sufficient data to establish long-term reliability of this combination.

9.9. *Intermixed Test 9*

Again this combination, see Figs. 10(a) & 10(b), demonstrates how effective Company ‘D’s body and front ferrule are together in terms of design, tolerances and operation. A good swage has been made with the nose of the front ferrule and no evidence of any extrusion beyond the body seat. Also, the Company ‘C’ back ferrule has swaged as intended but with more movement down the chamfered bore of the front ferrule than would normally be expected, similar to that shown in test 7. In a pure Company ‘C’ fitting the top outer edge of the front ferrule does not touch the inside of the nut whereas a Company ‘D’ front ferrule does. It is expected that this is by design to provide some lateral reactive force enabling the hardened nose of the back ferrule to swage deeper into the tube than it would without this support. Although this combination may initially pass leak and pressure testing its reliability and stability under demanding operating conditions is unknown and again, only further analysis and testing would confirm its long-term reliability.

9.10. Intermix Test 10

This test, see Figs. 10(c) & 10(d), was similar to test 7 in that non-Company ‘D’ components were used in a company ‘D’ body, the results therefore are not surprisingly the same. The nose of the front ferrule squeezing between the body and the outside diameter of the tube deforming itself and the tube with less indication of swaging. This is another good example of an intermixed combination that may pass initial leak and pressure tests but eventually would probably fail due to fatigue under vibrational conditions.

10. Discussion of Results

10.1. Premise for Study

The authors have no intention of using the results of this study as evidence to criticize or to make judgement on the relative strengths and weaknesses of the fittings designed and made by the four companies reviewed. It was reasonable to assume that they all produced well engineered products which, when assembled with original component parts and in accordance with the individual manufacturers instructions, behave in the manner for which they were designed, provided they are used within the stated performance limits. However, it is generally recognised that intermixed tube fittings have a greater chance of failing during service when compared with pure fittings. This assertion is founded on:

.(1) The authors’ personal experience of serious fitting failures during critical operations which were subsequently found to be caused by intermixed components.
.(2) Reported failures by the UK Health & Safety Executive, Offshore Division.
.(3) The fact that no two manufacturers claim to make these products in accordance with any commonly adhered to national or international design standard or code.
.(4) Several manufacturers appear to, or have admitted that they have continuous improvement policies and regard the design as dynamic, e.g. freedom to change manufacturing methods, hardening processes, manufacturing tolerances, surface finishes and minor alterations to the swaging mechanisms etc. All of which would have an effect on intermixing components with those made by others.
.(5) Lacking a common or co-operative purpose among the manufacturers the authors assumed that although the products made by four independent companies were similar in design and operation, there may be geometric, manufacturing, metallurgical and design differences. As the study progressed this premise was substantiated.

The results obtained during this study provide clear evidence to any engineer who is considering the deliberate or inadvertent intermixing of component parts that intermixing carries serious risks. Under such circumstances, rigorous analysis and a review of long-term integrity and consequences of fitting failure should be undertaken before such a decision is made. Inadvertent intermixing could occur when users have access to two or more different tube fittings used for the same or similar applications. Unless very strict quality control is imposed, the inevitable intermix will occur, where the level of consequences will be dependent upon the criticality of the application. Despite the fact that many companies openly advertise and condone intermixing, no scientific or engineering evidence to support this policy has been produced and made available for public scrutiny by any of the companies reviewed.

The three main areas were identified where differences can have an influence on tube fitting performance. These are in the design geometry, metrology/tolerances, and material properties of the individual component parts. Intermixed FEA stress/strain profiles and cross-sectioned photographs clearly show the effects of intermixing when compared against those produced by pure fittings. In addition, design safety factors are compromised and any intended sealing mechanism either becomes redundant or overstressed. Other parts are stressed to levels not intended and often impeding movement of other parts, all of which leads to potential fatigue failure.
Investigations into the effects of intermixing the bodies only, after pull-up, have shown that even this practice should not be recommended. This is due to the measured variations seen in the dimension *'P'* and the permanent diametric deformation observed in pulled-up bodies. Bodies from pure fittings which have either been pulled-up or unused can be assembled with a pulled-up tube assembly because the manufacturers have allowed sufficient tolerance in their own swaging mechanisms, dimensions and exercise adequate control over material properties that bodies can be readily and safely replaced.

Those who support intermixing must consider the freedom that other manufacturers have to make changes to their design, tolerances, methods of manufacture, materials · and material properties, all of which have an influence on the sealing mechanisms. Companies are under no obligation whatsoever to inform other manufacturers of changes no matter how small, so logically, how can intermixing be supported in a market where continuous improvement and change is expected?

11. Conclusions

.(1) Both experimental and FEA results show that the swaging and sealing mechanisms used by each fitting are different. This is mainly due to the differences in design and construction of the back ferrules, which was manifested in a widely divergent range of pull-up torque's.
.(2) Further differences in sealing mechanisms are due to different geometric designs, dimensional tolerances and material properties of the constituent components of each assembly. It is evident that no two companies produce components to the same dimensional or geometric specification.
.(3) This study has concluded that intermixing component parts analysed under conditions stated in this paper could compromise the original design assumptions of pure fittings. For example, in some of the intermixed combinations, the back ferrule was not utilised.
.(4) This study has also demonstrated that additional and potentially undesirable stress concentration areas could be introduced by intermixing. These areas could act as a conduit for fatigue failure. For example, certain front ferrules do not accurately align with body seats producing unintended deformation with diminished swaging.
.(5) A series of measurements from the end of the tube to the nose of the front ferrule of pulled-up pure fittings provide strong evidence that the resultant swaged tube and ferrule assembly should not be used with the pulled-up body of a fitting or component from another supplier. This is due to the combination of differences between swaging mechanisms, hardness of components and variations in tolerances associated with the bodies and the front ferrules of fittings made by the four companies reviewed.
.(6) Pressure testing alone should not be used as the only means of validating the integrity of intermixed fittings. The FEA plots of the intermixed fittings demonstrate that a form of sealing occurs in some combinations, which could lead to acceptance. However, it is not until further engineering assessment is made that it can be seen that the sealing method is not as originally designed, and a high

risk factor must be applied in such combinations.
.(7) Only extensive theoretical and practical evaluation of intermixed fittings, simulating predicted operating conditions, would provide a user with sufficient data to establish long-term reliability.

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