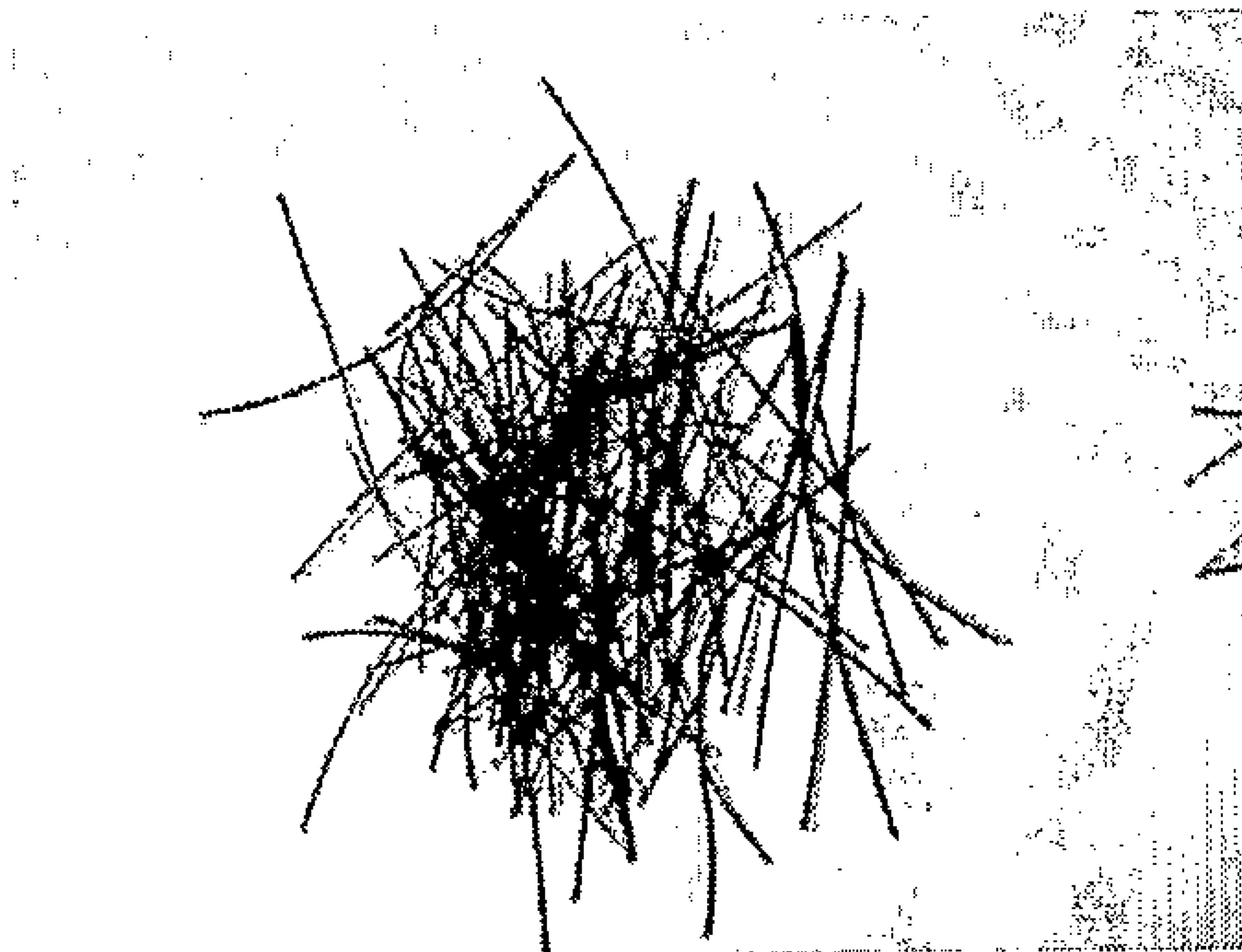




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(54) Titre : BETON ARME PAR FIBRES
(54) Title: FIBRE REINFORCED CONCRETE



(57) Abrégé/Abstract:

Fibre reinforced concrete comprises thin steel wire of diameter between 0.05 and 0.3 mm such as cut from recycled vehicle tyres. To avoid the problem of balling when mixing, two alternatives are suggested. The first consists of strands of fibre, which demonstrate excellent bond characteristics. The second consists of a mixture of fibre lengths and thicknesses, giving a wide distribution of l/d ratios not exceeding 250, which has the effect of reducing balling tendency so that significant densities can be achieved.

ABSTRACT**Fibre reinforced concrete**

5 Fibre reinforced concrete comprises thin steel wire
of diameter between 0.05 and 0.3 mm such as cut from
recycled vehicle tyres. To avoid the problem of balling
when mixing, two alternatives are suggested. The first
consists of strands of fibre, which demonstrate excellent
bond characteristics. The second consists of a mixture of
10 fibre lengths and thicknesses, giving a wide distribution
of l/d ratios not exceeding 250, which has the effect of
reducing balling tendency so that significant densities
can be achieved.

FIBRE REINFORCED CONCRETEField of the Invention

The present invention is in the field of fibre
5 reinforced concrete.

Disclosure of the Prior Art

It is known to reinforce concrete using steel cages
of welded rods, or indeed individual rods tied together.
10 It is known that these kinds of reinforcements present
some problems, primarily because that type of
reinforcement is on a "macro" level. Where concrete is
required to be locally tough, or the geometrical shape to
be reinforced is complex, such reinforcement is not very
15 effective.

It is known to reinforce concrete using fibres,
often of steel. Fibres are effective in reinforcing
concrete locally, preventing cracking and surface
20 deterioration, as well as providing structural
reinforcement.

A problem with such fibres is that, if they are long
and rigid (which, with steel, means having a length to
25 diameter (l/d) ratio in excess of about 100, especially
when volumes of fibres above 1% are used) then the fibres
tend to ball together and prevent even mixing and
distribution of them throughout the concrete. Indeed,
the more they are mixed, the more they ball together
30 which, thereafter, prevents the concrete from being
poured or pumped or cast, as is normally desirable with
concrete.

It has been proposed to glue fibres together with
35 water soluble adhesive. By such means, l/d ratios of the
individual fibres of as much as 80 can be used even for

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5 fibre volumes higher than 2%. This is achieved because, when the bundles of glued fibres are first introduced to the concrete mix, the bundles can be evenly distributed before the moisture in the cement and aggregate mix dissolves the adhesive. At this point the individual fibres separate from the bundle, but they need distribution then only over a local space. Relatively even distribution of the entire stock of fibres is thereby achieved before balling can start to occur.

10

However, even with this measure, performance is lacking in two key areas.

15 The first is simple, and this is that if fibre densities approach or exceed 2% by volume, mixing problems become an issue. From the latter perspective, it is more usual not to exceed ½%. Therefore, the reinforcement capacity of the fibres is limited.

20 The second problem is more complex. To be effective, the fibres must be anchored in the concrete. This is so that strain in the concrete is immediately shared by the reinforcement, "mobilising" the reinforcement to provide tensile support to the concrete
25 to resist its cracking.

Steel presents a relatively "slippery" surface to concrete and, as a general rule, l/d ratios of the order of not less than 100, and ideally about 200 for high
30 strength fibres, are needed to ensure complete mobilisation of the reinforcement. But with l/d ratios not exceeding 50, or at best about 80, such mobilisation cannot fully occur. For similar l/d ratios, smaller diameter fibres are more effective in transmitting loads.

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This problem is overcome to some extent by kinking

the ends of fibres to form anchors (as disclosed in DE-A-4315270). This means that a crack developing across a fibre, even relatively near one end of the fibre, will transmit load to the fibre. However, the fibre becomes essentially free along its length (at relatively high stresses) within its sleeve of surrounding concrete because there is insufficient area of the fibre on which the concrete can bond. Consequently, the body of the fibre becomes unbonded and the stress is developed over the entire length of the fibre. This means that substantial strain must be imposed before the tension in the fibre balances, and counteracts, the stress in the concrete. This, in turn, means that a developing crack will widen more before it is halted. More, that is, than if, for example, a much shorter fibre spanned the crack while still being anchored at either end: the extension of such a short fibre would be much less for the same stress than a longer fibre.

Furthermore, using high tensile strength steel adds little benefit because the strength capacity of the fibre is substantially under-utilised. At stresses at which such material would normally yield (that is, exploiting their full strength capability) the fibre would long previously have pulled itself out, even with the anchoring provided by a kinked end.

Consequently, not only can insufficient quantity of reinforcement be employed to provide adequate reinforcement (at least for more significant structural loads) but also the capacity of what is, or could be, employed cannot be fully exploited.

To address this problem many other solutions have been proposed, including modifying the surface of the fibre as in US-A-5451471, DE-A-4242150, US-A-4960649, US-A-

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4804585, DE-A-3435850 or EP-A-105385, or modifying the cross section of the wire as in DE-A-1941223, US-A-4298660, or even using chains as JP1153563. All of these methods result in expensive reinforcement.

5

EP-A-861948 suggests thin, high tensile steel wire with anchorages formed across and along its length. The thickness is about 0.08 to 0.3 mm, and the length is from 3 to 30 mm. The tensile strength is about 2000 MPa. Because of the high bonding and high strength, small volumes are adequate to achieve the desired reinforcement (1 to 4% by volume is suggested), which small volumes eliminate mixing problems, at least with l/d ratios below 100. DE-A-3347675 likewise suggests thin wires with surface roughening to improve adhesion to the concrete. Both these arrangements suffer from the expense of the special working of the wire required.

NL-A-7108533 suggests reinforcing concrete material with steel cord of the type used in car tyres where the cord comprises several threads wound together with between 50 and 100 twists per metre.

BE-A-1003656 discloses packaging steel reinforcement fibres by gluing with water soluble adhesive, or otherwise temporarily securing, the ends of the fibres to a paper carrier.

The Summary of the Invention

It is an object of the present invention therefore to provide a concrete reinforcement fibre composition and a concrete composition that does not suffer from, or at least mitigates the effects of, the aforementioned problems.

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In accordance with a first aspect of the present

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invention there is provided a fibre reinforcement composition for concrete, comprising clean steel fibre of between 0.05 and 0.3 mm diameter, wherein the fibres are stranded together in a strand (or cord) of at least five, and preferably at least twenty, fibres, characterised in that the ends of the fibres in the strand are permanently and structurally secured together, for example by welding.

10 Preferably, each fibre has an l/d ratio in excess of 150. Preferably, there is little or no twist of the majority of the fibres in the strand.

By "clean" is meant less than 5% by volume rubber or other contamination of the fibres and sufficiently grease- and contamination- free to permit bonding of concrete cement to the fibres.

With such thin wire, and such a large l/d ratio, secure bonding of the fibres in the concrete can be assured. This means that cracks open less before the stress is applied to the fibre which, over such a short length of it, tensions rapidly to balance the stress with only a small strain at the concrete crack. Consequently, the crack is not opened much, and so secondary effects such as environmental contaminant or moisture entry are minimised. Since more secure bonding is achieved, higher stresses can be absorbed, thereby more efficiently utilising the full strength capacity of the fibre.

30

Furthermore, the problem of balling or clumping with the high l/d ratio fibres is overcome by virtue of the stranding of the fibres. When mixing in concrete, the strand behaves as a single fibre having an effective l/d ratio determined by the length and diameter of the strand. In a twenty-fibre strand, for example, this

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reduces an l/d ratio of 150 of a single fibre to about 30 of the strand. However, because the cement, when hydrated, can penetrate all around the outside fibres and about half way around each of the fibres underneath (ie effectively about fifteen out of twenty in a twenty-fibre strand), the net result is that bonding to the strand is over a much greater surface area. It is up to an order of magnitude greater than bonding to a single fibre (of equivalent l/d ratio of the strand as a whole - ie about 30).

Since the strand can, therefore, have an l/d ratio of as little as 30, clumping is not a problem and so the volume of the reinforcement can be increased to as much as 2% by volume or more. Consequently, not only can more reinforcement be provided, but what reinforcement there is is used to greater efficiency because of the improved bonding of the concrete to the strand.

Indeed, although the improved bonding of the outer fibres of the strand to the concrete causes more instant mobilisation of those fibres to minimise the strain in the concrete, the inner fibres are, to a certain extent, free. At least, they are free intermediate their ends but they are, nevertheless subject to frictional constraint against their neighbours. However, over and above such frictional constraint, should the strain in the concrete develop such that outer fibres of the strand begin to yield, reinforcement remains through the inner fibres which have their full length with which to absorb the strain.

Preferably, the bulk of the fibres in the strands have less than one hundred twists per metre. This has the effect of maintaining the axial stiffness of the strand, but it also permits some lateral flexibility,

which helps reduce the effect of balling and enables the strand to flex around large aggregate.

Preferably, the strands are made by cutting to
5 length cord or wire strands from recycled car and vehicle
tyres. Preferably said tyres have been subject to
pyrolysis or anaerobic microwave heating to strip
elastomer from the wire strands, without damage to, or
leaving much residue left on, the steel. Preferably,
10 said tyres have been subject to a process as described in
WO-A-01/03473.

Thus not only can effective reinforcement for
concrete be provided, but also it can be got from vast
15 stocks of waste material in the form of old tyres. The
raw material is therefore almost cost-free, the necessary
processing to remove rubber from the strands not causing
the cost of the strands to become excessive.

20 On the other hand, such processing of tyres is not
completely without cost, and it would be desirable to
have fibre-reinforcement, perhaps to a lesser degree,
using unwanted steel from tyres without such processing.

25 DE-A-4104929 discloses using wire from tyres, but
mixes rubber-bound-fibre mixed with non-flammable
concrete components, the rubber being burnt off prior to
cooling and adding of cement and water. The rubber is
left in place during mixing with concrete components to
30 avoid balling problems. It does not appreciate that
strands can have a low "macro" l/d ratio and still
provide effective bonding to concrete. Consequently,
they do not require the protection against balling
suggested.

35

On the whole, tyres are presently recycled to a

certain extent by repeated shredding, combing, magnetic separation and sifting to release rubber granules which can be employed in numerous applications. However, the steel waste has hitherto defied efficient usage because
5 of the contamination with rubber and textile fibre and is generally baled and deposited in landfill. Some less sensitive furnaces can use the waste as raw steel source, but it is not very cost-effective.

10 DE-A-3923971 describes a process for mechanically and cryogenically stripping wire "nails" from tyres for the purpose of recycling the nails. In the situation that the nails still have rubber connected, they are used as a filler to improve elasticity of the filled material.

15 Accordingly, in an alternative aspect of the present invention, there is provided a fibre reinforcement composition for concrete comprising steel fibre obtained by shredding vehicle tyres and physically separating
20 therefrom non-steel material until "clean" wire fibres remain, about 90% or more of them being individual fibres and substantially none having an l/d ratio of more than 250, characterised in that a majority of the fibres are less than about 0.5 mm in diameter, any wider diameter
25 fibres having an l/d ratio less than 100.

It is also preferable that a majority of the fibres are about 0.3 mm or less in diameter and have an l/d ratio between 150 and 250. Better still, if more than
30 80% of the fibres are about 0.3 mm or less in diameter and have an l/d ratio between 150 and 250.

In this aspect, the quantity of fibres being referred to is their number.

35

It is suggested above that an upper limit of 100 for the

l/d ratio of fibres is needed if balling when mixing sufficient amounts of fibre (i.e 2% by volume) is to be avoided. However, when the flexibility of the fibre is high (as it is with steel wire of less and 0.3 mm diameter) it is found that balling can be avoided to a sufficient extent when mixing concrete if the l/d ratio does not exceed 250, and especially if kept below 200. On the other hand, at these lengths, even though there may be a certain contamination that interferes with bonding where it occurs, no surface preparation of the wire, such as suggested in EP-A-861948, is needed to ensure adequate bonding. In addition, the wires of tyres having been processed as described are far from straight, so that there is inherent kinking of them, which assists locking of the fibre in the concrete.

Consequently, the essence of the present invention in this second aspect is to avoid as much as possible long, wide-diameter, and therefore stiff, wires, but at the same time maximise long, thin diameter wires. This can be achieved through appropriate mechanical processing of the tyres. Thus, the environmentally challenging methods employed in DE-A-4104929 are unnecessary, since essentially only thin wires are permitted to have longer l/d ratios that guarantee good bonding, but which do not cause balling problems to the same extent as thicker, stiffer wires of the same l/d ratio.

In order to achieve substantially no fibres of l/d ratio above 250, repeated shearing of the fibres is required. However, this has the side effect of also shearing shorter fibres so that even those below 250 may also be sheared. Consequently there needs to be separation of shorter fibres from the mix as they are produced and so that they are not chopped further. This is with the aim of achieving most fibres having an l/d

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ratio range of between 150 to 250. At the same time longer, wide (that is, stiff) fibres (for example, fibres greater than 0.3 mm in diameter) need to be removed so that they, on the whole do not have an l/d ratio greater than 100.

"Clean" as used in this aspect of the invention has the same meaning as that given to it above. Wire fibres, resulting from such a shredding process, surprisingly provide an effective concrete reinforcement composition. Firstly, despite not providing perfectly clean fibres, a physical shredding process is found to be adequate to achieve sufficient bonding between the fibres and concrete cement, particularly given the l/d ratios suggested. On the other hand, the invention does not specifically exclude further treatment to remove more contamination. Secondly, although the invention requires a minimum quantity of high l/d ratio fibre, it is, in fact, this quantity that determines, and limits, the mixability of the composition. With such long fibres, balling becomes an issue the more long fibres there are. However, it is not found that any less long fibres can be introduced, merely because there is also a proportion of shorter fibres introduced as well. While very short fibres do little to enhance the quality of concrete, short fibres more than a few millimetres long do enhance concrete toughness and wear resistance.

Consequently, it is found that the density of steel that can be added to a concrete mix can be quite reasonable, and in the order of 1 to 4½% by volume of the final mix. Thus, tough fibre-reinforced concrete can be made wherein the reinforcement is used to its maximum extent. That is to say, the long fibres provide strength to the concrete, being highly resistant to pull out under tensile load. On the other hand, the shorter fibres,

while not detracting at all from the strength, provide, nevertheless, a substantial part of the toughness of the concrete and its resistance to wear. That toughness is also provided by the long fibres, of course, but the contribution made by the shorter fibres is no less important in this respect. By shorter fibres is meant those having an l/d ratio less than about 150. Thus the long and short fibres each perform complimentary roles in reinforcing concrete, the whole of the reinforcement being greater than merely the sum of their respective contributions.

Such a distribution of wire fibres can be generated by, indeed, is to a certain extent a natural consequence of, repeated shredding and shearing of car or other vehicle tyres, and with subsequent magnetic extraction of the wire from the remaining fabric and elastomer. However, care has to be taken that, in shredding and shearing to remove fibres of greater than 250 in l/d ratio, excessive cutting of fibres less than 250 in l/d ratio is minimised. It is desired that the proportion of fibres having l/d ratios in the range 150 to 250 is maximised. At the same time, thicker wires (ie greater than about 0.5 mm in diameter), even those with a large l/d ratio, are most desirably removed and limited to those with no more than about 100 l/d ratio. Indeed, the shorter that thick wires become, the less effective they are as reinforcement, and consequently their entire removal from the composition is preferred.

30

It is a feature of both aspects of the present invention that they provide outlets for the recycling of vehicle tyres, and an inexpensive source of effective reinforcement for concrete.

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An important element of the second aspect of the

present invention is the mix of the concrete. That is to say, the size distribution and make-up of the aggregate, as well as the type of cement, all have an impact on the tendency of the fibre element to ball when it is mixed.

5 Generally, an increase in fines reduces balling, but it remains that some trial and error might be required to find satisfactory mixes that achieve the aims of the present invention, at least in its second aspect.

10 In both aspects of the invention, the fibres could be used to produce (a) SIMCON (Slurry Infiltrated Mat Concrete), (b) SIFCON (Slurry Infiltrated Fibre Concrete), and (c) high-strength, high performance concrete.

15 SIMCON is particularly suited to the second aspect of the present invention, since a very thin mat (similar to glass fibre chopped strand mat) can be used to create thin structural elements of thickness not exceeding a few

20 millimetres. SIMCON is also suitable for near surface reinforcement of thicker elements. The thin mat of fibres can be produced preferably by using polymer adhesives or welding or stitching of the steel fibres.

25 SIFCON can be produced with both aspects of the present invention, in a much more economic way than with current systems, especially when recycled fibres from tyres are used.

30 For high strength high performance concrete, both aspects can be used simultaneously.

Detailed Description of Examples

Embodiments of the invention are described

35 hereinafter, by way of example and with reference to the following examples, in which types of concrete are

prepared as follows:

Example I - A Typical Normal Concrete

Total Weight	100
Ordinary Portland Cement	16.5
Water	7.5
Fine Aggregate	30
Coarse Aggregate (Crushed River Aggregate <20 mm)	46
Water/Cement ratio	0.45

5 **Example II - A High Strength Concrete**

Total Weight	100
Ordinary Portland Cement	15.4
Type of pulverised fuel ash	4.4
Micro-silica	4.4
Water	3.5
Fine Aggregate	29.7
Coarse Aggregate (Crushed River Aggregate <20 mm)	42.6
Superplasticizer	1.5 % (Weight of Cement)
Water/Cement ratio	0.23

Materials used

10 Ordinary Portland Cement

An ordinary portland cement (OPC) type I, manufactured by Rugby Cement Group: in accordance with BS 12: 1996, class 42.5N, was used through the study. The typical chemical and physical properties of the cement
15 are given in Table 1.

Table 1. Chemical and physical properties of the OPC used

Chemical Composition	Percentage	Physical Properties
Silica SiO ₂	20.5-21.8	Relative density: 3.1

Alumina Al_2O_3	5.1	Theoretical surface area: 3800 m^2/kg
Iron Fe_2O_3	3.7	pH in water N/A
Calcium CaO	64.6	Moisture content N/A
Magnesium MgO	1.3	Comp strength EN 196-1 Mortar Prisms
Sulphate SO_3	2.3-3.1	3 days 20.6-21.6 N/mm^2
Alkalis	0.57-0.74	7 days 34.8 N/mm^2
Chlorides Cl^-	<0.02	28 days 42.6-43.4 N/mm^2

Aggregates

The aggregate used (both coarse and fine) was fluvial dragged gravel. The shape of the aggregate was rounded, fully water-worn or completely shaped by attrition, i.e. river or seashore gravel; desert, seashore and wind-blown sand. The surface texture was smooth, water-worn, or smooth due to fracture of laminated or fine-grained rock, i.e. gravels, chert, slate, marble, some rhyolites. These classifications are made according to BS 812: Part 1:1975. The aggregate grading was made according to the BS 812: Part 1:1975, the results of this grading are shown in the Table 2, and Table 3. Other properties are given in Table 4.

Table 2. Coarse aggregate grading

Sieve size (mm)	20 mm aggregate Passing (%)	10 mm aggregate Passing (%)
37.5	100	100
20	98	100
14	57	100
10	12	95
5	05	7
2.36	-	0.65

Table 3. Fine aggregate grading

15

Sieve size (mm)	Fine aggregate sands Passing (%)
9.5	100
4.75	98
2.36	88
1.18	80
0.6	68
0.3	23
0.15	4
0.075	0.5

Table 4. Other Material Data

	Density	Water Absorption	Water Content
OPC	3150		
Sand	2590	0.59	0.10
C. Agg. (20)	2600	0.58	0.09
C. Agg. (10)	2600	0.60	0.34

Steel Fibres5 **Steel stranded wires (First Aspect)**

The stranded wires used were obtained from the process described in WO-A-01/03473 ("the AMAT process"). The wire was derived primarily from super-single tyres. The wires used had an overall average diameter of 1.38 mm. The wire consisted of an inner core of 12 strands of diameter 0.22 mm, an outer sleeve of another 15 wires of diameter 0.22 mm, and an overwound wire of diameter 0.22 mm at a pitch of 5.33 mm. The wires had traces of carbon black on the surface.

15

Fibres from Shredded Tyres (Second Aspect)

The fibres used to make the concrete of the second aspect of the present invention were obtained from a shredding process, dealing primarily with a mixture of truck tyres. The fibres were not completely free of

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rubber, having around 3% rubber by weight. The fibres used had the properties described below with reference to Figures 8 to 10 in terms of their length (L), thickness (D) and l/d ratio. The strength of the fibres varied from
5 2000 MPa to 3000 MPa.

The Brief Description of the Drawings

The invention is further described hereinafter, by way of example, with reference to the accompanying
10 drawings, in which:

Figure 1a and b are photos of stranded wire derived from the AMAT process, in Figure 1a, the strands being separated into their individual fibres, whereas in Figure 1b the strands are intact;

15 Figure 2 shows fibres from shredded tyres prior to further cleaning and sorting;

Figure 3 is a photo of a concrete sample according to Example I above demonstrating adequate workability;

20 Figure 4 is a graph showing deflection of a concrete sample according to Example I above with, and without, shredded fibres of the second aspect of the present invention;

Figure 5 is a similar graph comparing the first and second aspects of the present invention, in concrete from
25 Example I, and also comparing with the same concrete employing presently available commercial fibres;

Figure 6 compares normal concrete with no fibres, normal concrete with tyre strands according to the first aspect, and high strength concrete of Example II, with
30 tyre strands from the first aspect of the present invention;

Figure 7 compares increasing density of tyre strands in concrete of Example I;

35 Figure 8 shows the length distribution of fibres from shredded tyres (second aspect);

Figure 9 shows thickness distribution of fibres in

accordance with the second aspect of the present invention; and

Figure 10 shows the length/diameter ratio distribution of fibres according to the second aspect of the present invention.

Detailed Description

The steel fibres of Figures 1 and 2 were prepared as described above and mixed with two examples of concrete mix as also described above, and in various densities (percent by volume) of fibre to concrete, as indicated in Figures 4 to 7. To demonstrate workability, the concrete and fibre mix is poured into an open-ended cone, visible in Figure 3. When the cone is lifted, the slump of the concrete indicates the workability of the concrete and hence its capacity to flow when pumped or poured into the requisite mould. Depending on the degree of workability required, the density of fibre is adjusted accordingly.

With reference to Figures 4 to 7, standard concrete blocks are formed and cured and subjected to increasing load while the deflection of the sample is monitored. In Figure 4, it can be seen that, for normal, unreinforced concrete, load increases with minimal deflection up to a maximum point at which fracture occurs. However, with only 0.16% of shredded fibres, (in accordance with the second aspect of the present invention), substantial deflection of the sample occurs while still supporting a load.

In Figure 5, 0.64% density of fibres were included in three samples of normal concrete in accordance with Example I above. In the first sample, the fibres were in accordance with the second aspect of this invention, namely from shredded tyres. In the second sample, the fibres were from a commercially available source

(Novocon). The third sample comprised fibres in the form of strands in accordance with the first aspect of the present invention. It can be seen that the sample in accordance with the first aspect of the present invention exhibited the greatest loads and deflections, while the sample according to the second aspect demonstrated quite acceptable loads.

Figure 6 demonstrates the substantial loads that are accommodated with high strength concrete (according to Example II above) compared with normal strength concrete (according to Example I above).

Figure 7 demonstrates the increasing loads capable of accommodation with increasing density of fibre in accordance with the first aspect of the present invention.

Finally, in Figures 8 to 10, it can be seen that the distribution of fibres employed in the examples according to the second aspect of the invention have a wide distribution of lengths and four main thicknesses. This results in a length to diameter distribution in which the vast majority of the fibres, both in terms of number and volume per cent have an l/d ratio in excess of 150, and less than 250. The remaining fibres, about 30% in terms of frequency, have l/d ratios between 30 and 150. As mentioned above, while these will contribute less towards the tensile strength of concrete, they will add local toughness and wear resistance.

18a

Key to Figures 4 to 7

5 Fig.4

A = Normal concrete

B = 0.16% Shredded Fibres

Fig.5

10 C = 0.64% Fibres from Shredded Tyres

D = 0.64% 50mm Strands from Tyres

E = 0.64% 50mm Commercial Fibres

Fig.6

15 F = 1.6% 50mm tyre strands in High Strength Concrete

G = 1.91% 50mm tyre strands in Normal Strength Concrete

H = No Fibres - Normal Concrete

Fig.7

20 I = 1.91% 50mm tyre strands

J = 0.64% 50mm tyre strands

K = 0.32% 50mm tyre strands

Claims:

1. A fibre reinforcement composition for concrete comprising steel wire fibre obtained by shredding vehicle tyres and physically separating therefrom non-steel material until "clean" wire fibres remain, about 90% or more of them being individual fibres and substantially none having a length to diameter ratio (l/d) of more than 250, characterised in that a majority of the fibres are less than about 0.5 mm in diameter, any wider diameter fibres having an l/d ratio less than 100.
2. A composition as claimed in claim 1, in which a majority of the fibres are about 0.3 mm or less in diameter and have an l/d ratio between 150 and 250.
3. A composition as claimed in claim 1, in which more than 80% of the fibres are about 0.3 mm or less in diameter and have an l/d ratio between 150 and 250.

1/4



Fig. 1a

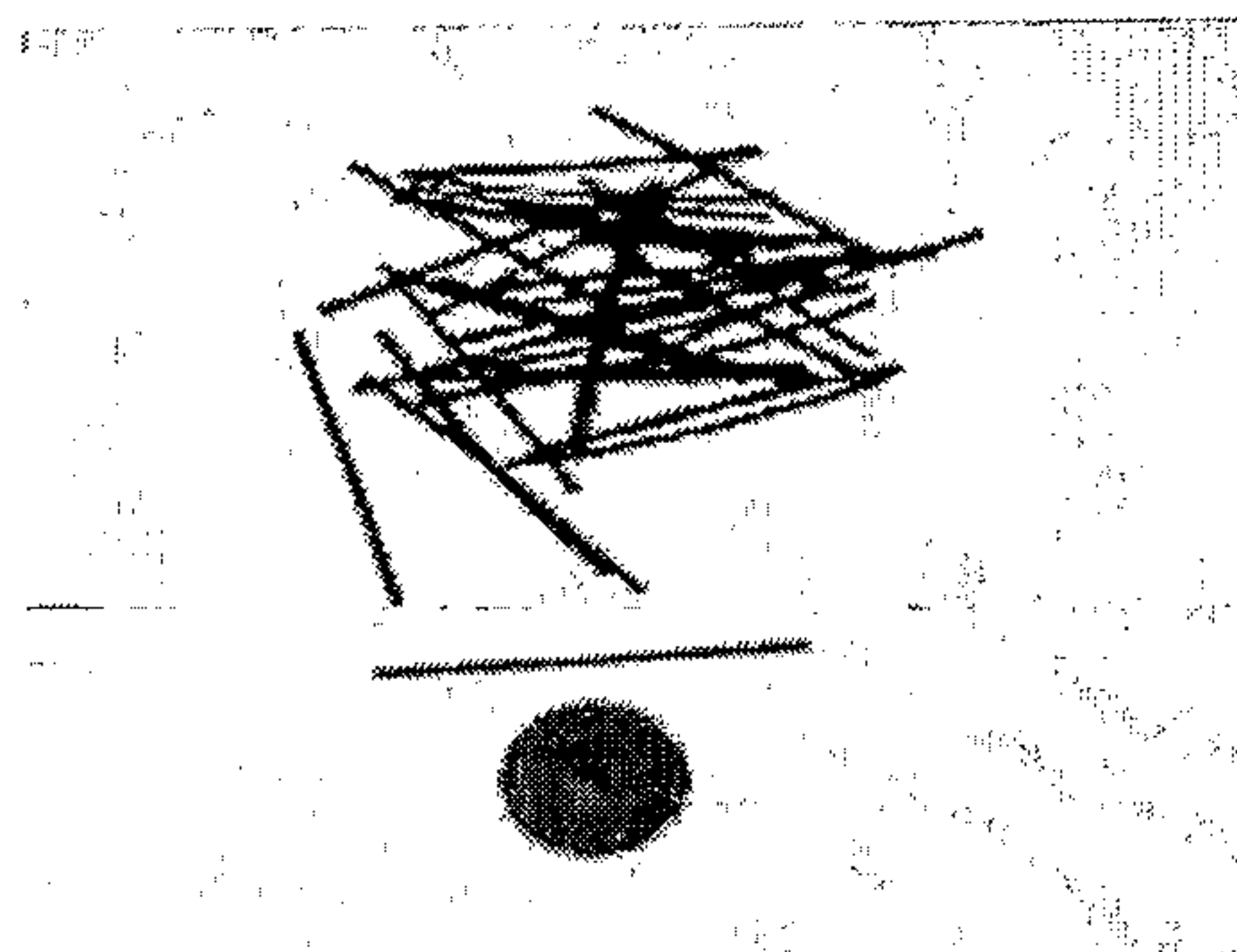


Fig. 1b



Fig. 2



Fig. 3

2/4

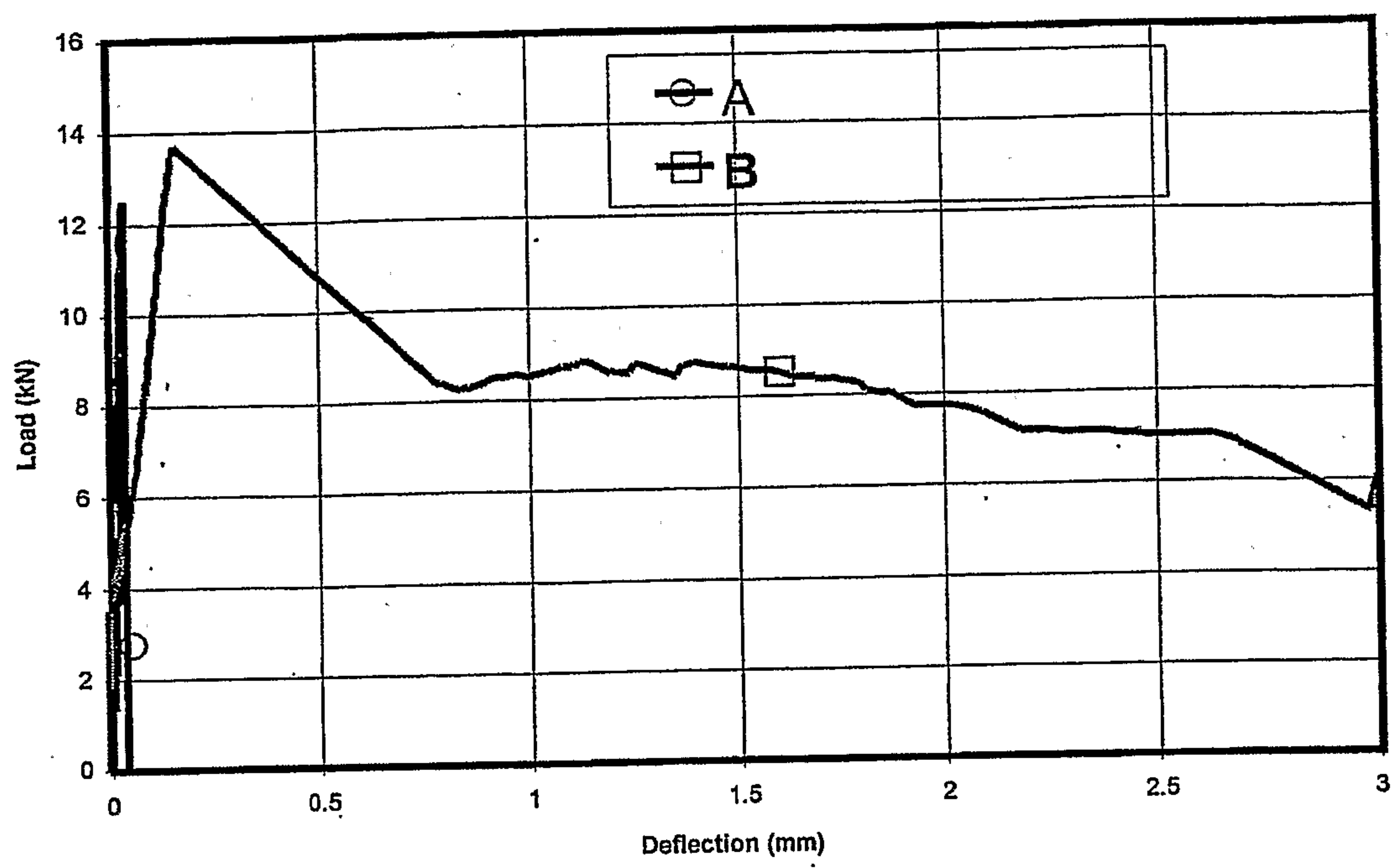


Fig. 4

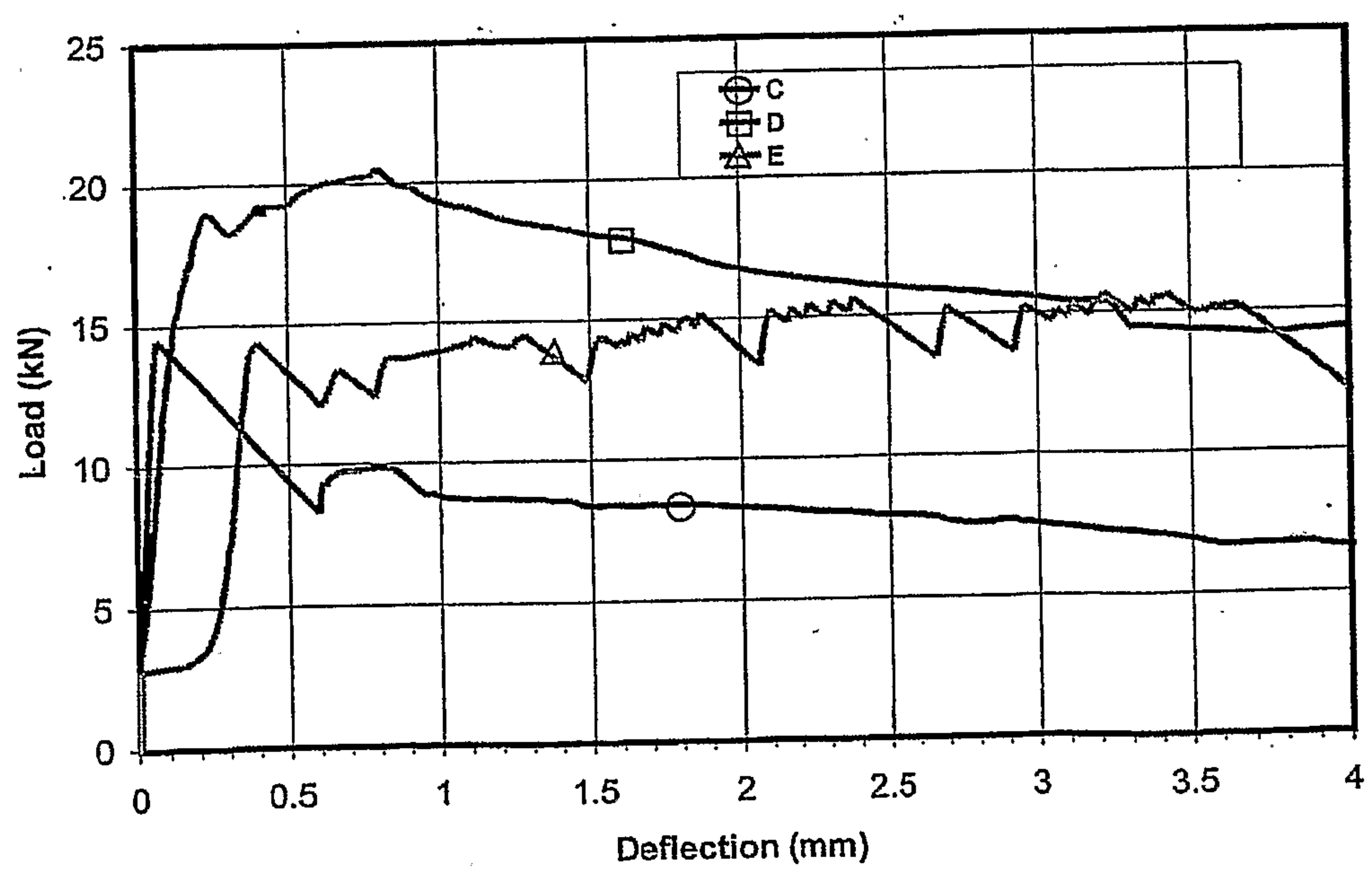


Fig. 5

3/4

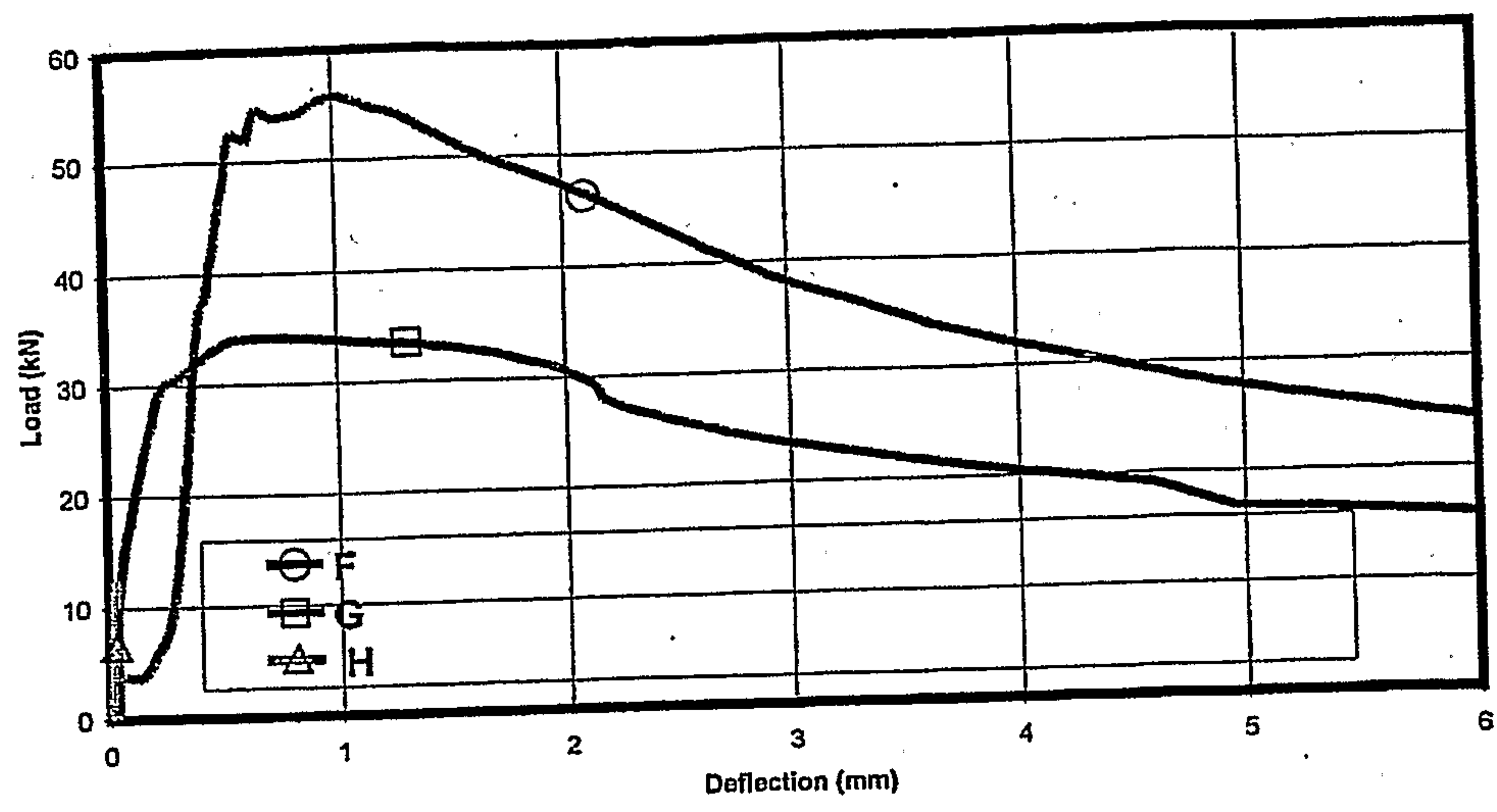


Fig. 6

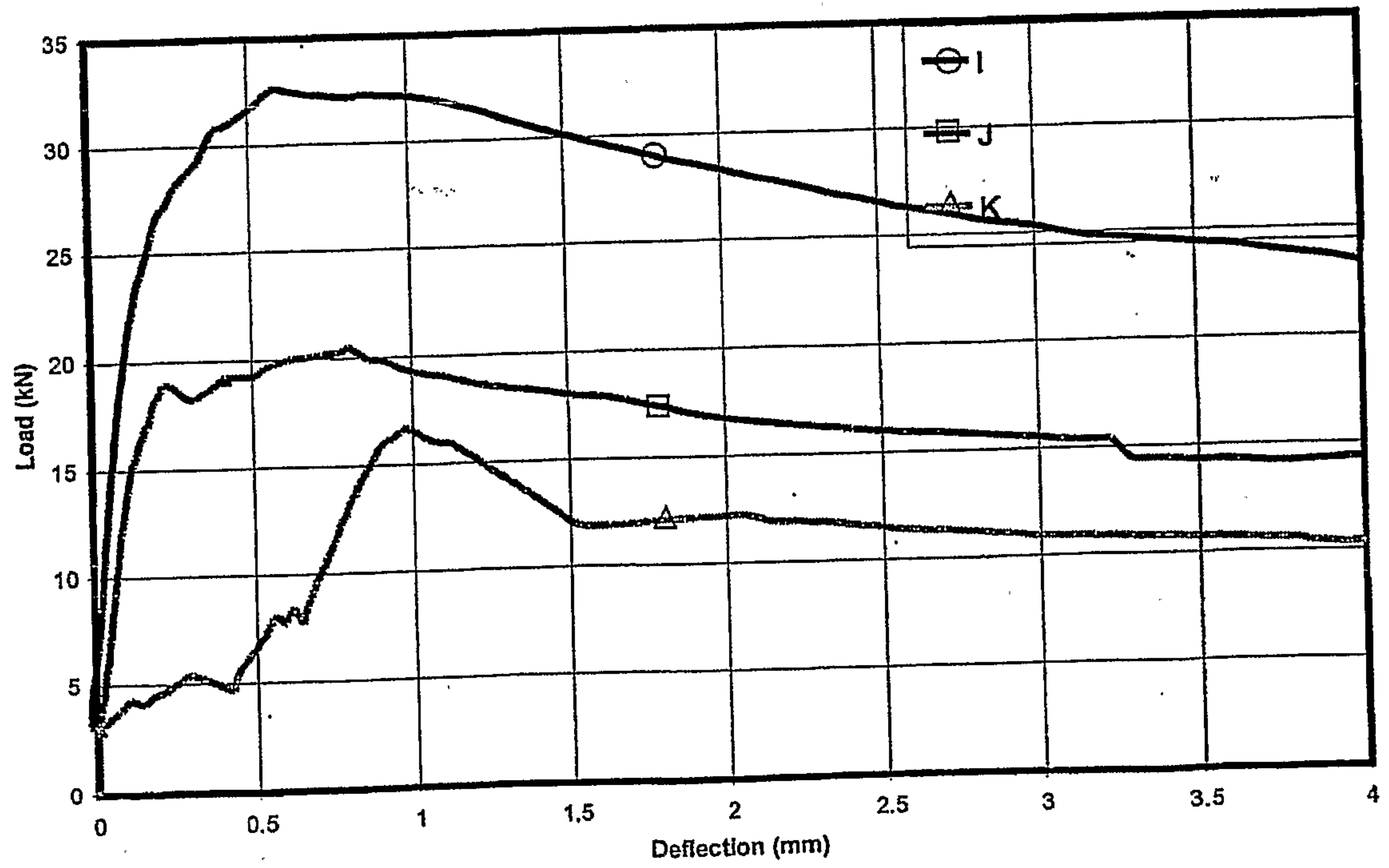


Fig. 7

4/4

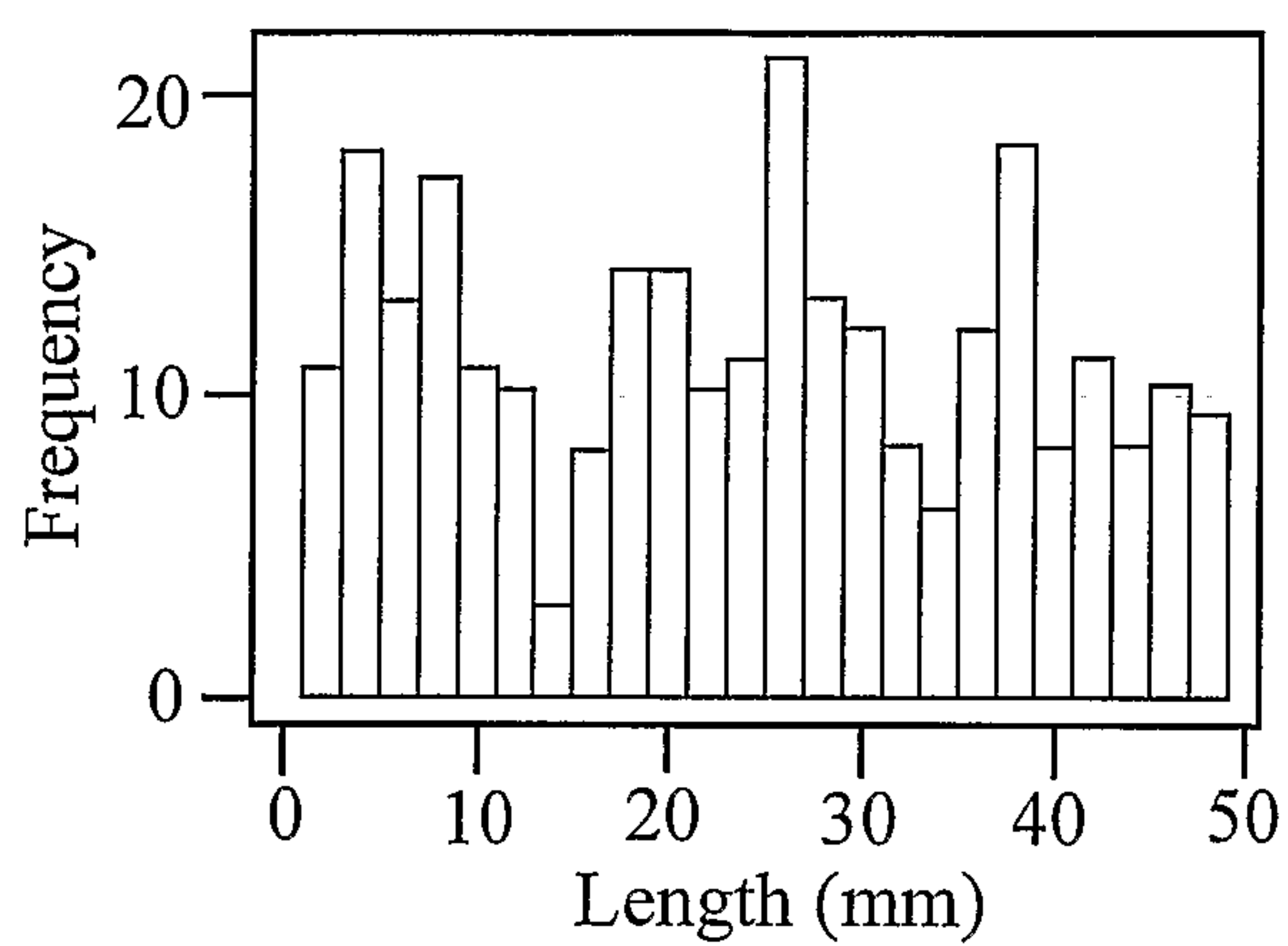


Fig. 8

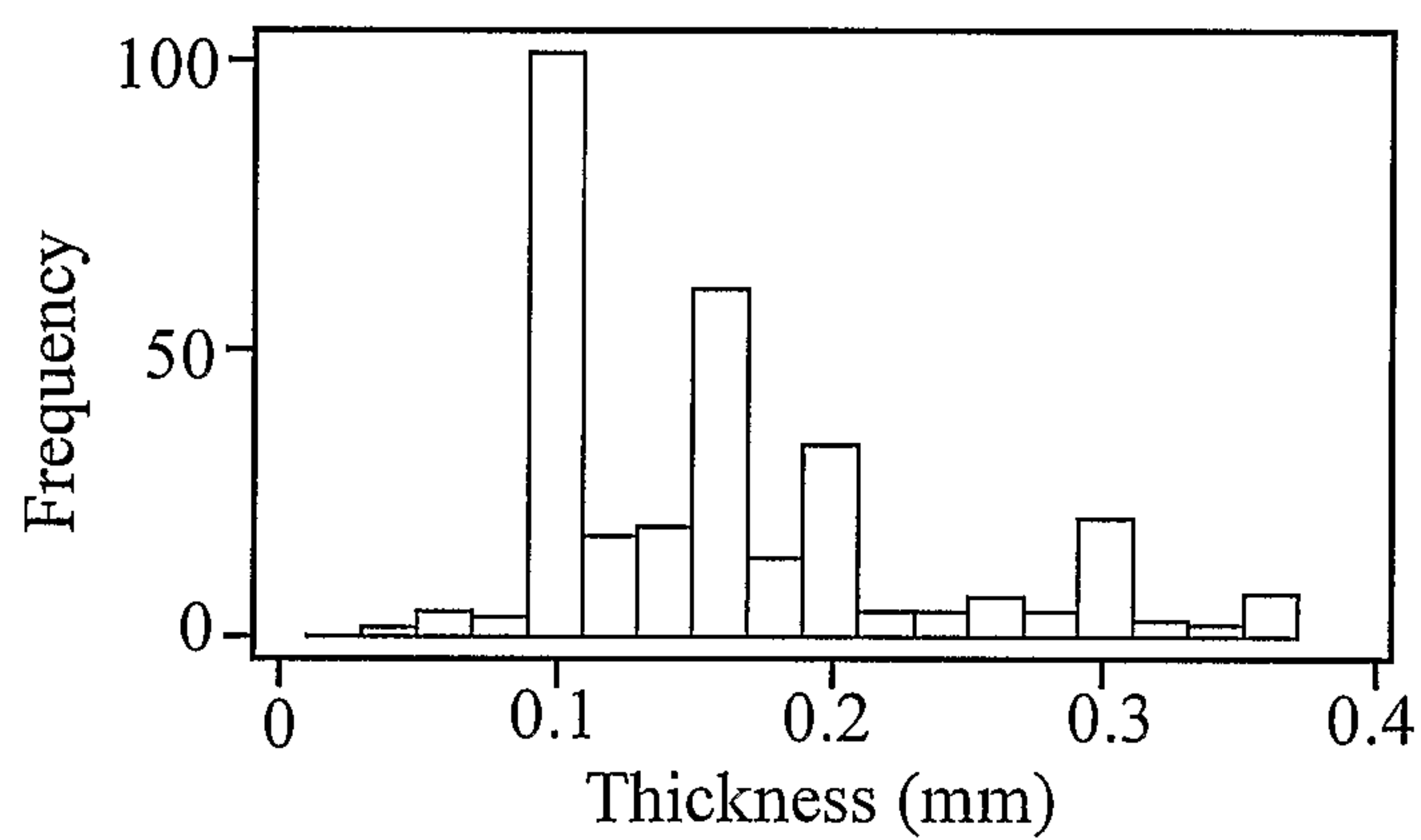


Fig. 9

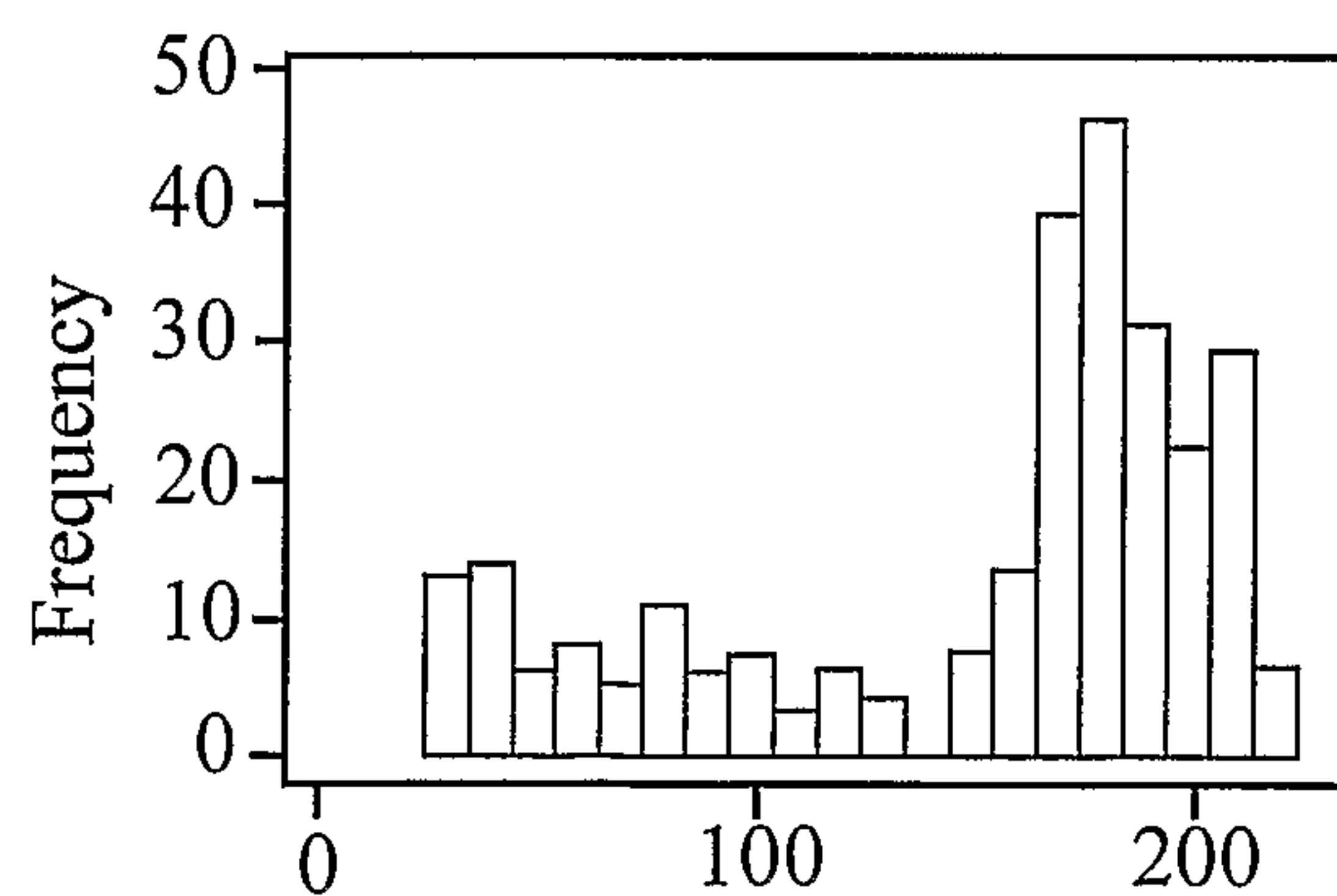


Fig. 10

