ASPHALT CONCRETE PAVEMENT REINFORCEMENT THROUGH THE ADDITION OF MICRO-FIBRES AND STEEL MESHES

Agostinacchio M.
*Full Professor of Roads, Railways and Airports – University of Basilicata, Italy***,** *michele.agostinacchio@unibas.it*
Cuomo G.
BEng, CEng , MSc, PhD – University of Basilicata, Italy, gianluca.cuomo@unibas.it

ABSTRACT

Nowadays the deterioration of the asphalt concrete superstructures is a critical problem in the area of road construction.

More specifically, the causes of the degradation can be addressed to the increase of traffic, of axle loads and/or to the use of larger wheel paths, the influence of the thermal stresses being also important in this negative phenomenon.

Form this standpoint, there is a wide diffusion of the so-called *"macro-reinforcement techniques"*, which have recourse to both different dimensions fibres and meshes inside the asphalt concrete wearing course.

So as to assess the real benefits belonging to the application of these techniques, this study is focused on the flexural analysis of traditional and reinforced asphalt concrete specimens by means of the *"Three Point Load Apparatus"*, the reinforcements used for the process varying.

Afterwards, starting from the results obtained from constant strain load tests, some specific parameters taken from the theory of steel fibre reinforced concrete, and accurately adapted for the purpose, were defined; their use allowed the Authors to clearly identify the post-crack rsistance of the reinforced asphalt concrete specimens.

In conclusion, knowing the load, the deflection and the first-crack toughness, thanks to the comparison of the "*toughness indices*" and of the "*residual strength factor*", a classification of the different typologies of reinforcement has been performed identifying, amongst them, the ones whose mechanical performances are more reliable from the viewpoint of the flexural resistance.

Keywords: *asphalt concrete pavement, fibres, steel meshes, reinforcement*

1 FOREWORD

Asphalt concrete road pavements deterioration is one of the most troublesome issues for road engineers. In particular, the causes for such degradation can be found in traffic increase and in the use of larger single tyres, along with higher axle loads, the influence of the thermal stresses being also not to be neglected.

In this research the Authors studied the behaviour of asphalt concrete road pavements reinforced with double torsion steel meshes and with innovative fibres, so as to assess the performances increase of the structural elements after the addition of such elements.

Hence, for the verification of the structural behaviour of the elements tested, some specific indices have been introduced in order to better understand the material behaviour during the post-cracking stage

2 EXPERIMENTAL INVESTIGATION

The experimental investigation provided for a series of tests on plain asphalt concrete specimens and on similar elements reinforced with steel meshes or fibres.

For each category several 20x12x6 cm specimens to be tested at 20 °C were prepared. This temperature was chosen in order to avoid, for higher values, the visco-elastic behaviour of the conglomerate, lower values being addressed as afoot of fragile comportment.

2.1 Asphalt concrete specimens

The following aggregates were employed for the manufacture of asphalt concrete:

- Basalt, with LA coefficient Equal to 13 and absolute gravity γ=2.89 g/cm^3;
- Calcareous aggregate, with LA coefficient Equal to 18 and absolute gravity γ=2.68 g/cm^3;

Figure 1 represents the particle size of such material.

Hydrated lime was adopted as filler and a soft bitumen with softening point and penetration, respectively, equal to 67°C and 46 dmm was used in the mix.

The bitumen percentage which furnished the best performances with the materials available, according to another experimentation carried out previously and also to some data available in literature, was found to be 5.5% by weight of aggregates.

In particular, the Marshall test performed according to C.N.R.- B.U. n°34/73 Standards, gave the results of Table 1.

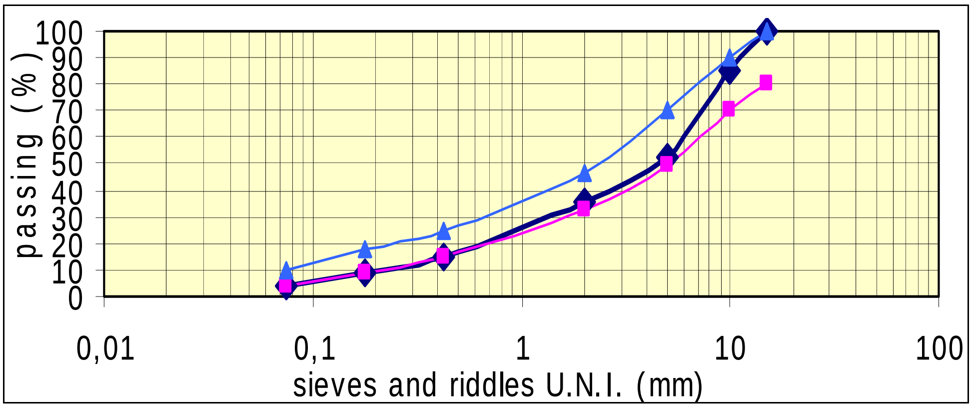

Figure 1 Grading curve of the asphalt concrete used

Table 1 Marshall test results

Mean stability	Kg	**1373**
Mean shift	mm	**2,45**
Mean stiffness	Kg/mm	**560**

Figure 2 Different stages of specimens manufacture

2.2 Apparatus used for the flexural tests execution

A compression machine with a computerised system with a limit of 40 KN was adopted for the execution of the flexural tests on asphalt concrete specimens. It can determine the first crack stress of the specimen itself and plot the corresponding stress-strain chart, thanks to a 16-channels data acquisition system.

Both loads and displacements are continuously and incrementally monitored by means of some potentiometric displacement transducers with a travel within 0 and 50 mm, based on readings close enough to reproduce the curve with the adequate accuracy. By using this apparatus, the asphalt concrete specimens were tested up to failure and, with specific solutions, toughness and residual strength were calculated in the *post-crack stage*; Figure 3 illustrates the equipment and the failure of a specimen after flexural stress.

Figure 3 Apparatus for the flexural tests and failure of a specimen

2.3 Characteristic indices definition

So as to assess the performances of the two types of reinforced asphalt concrete the toughness was measured: it is the deformation work needed to push the material up to failure, or the capacity to withstand the load also after the arise of cracks.

Toughness is identified by the area underneath the load-deflection curve belonging to the flexural test, thus determining both numerical ratios, named *Toughness Indices* and parameters derived from them, the so-called *Residual Strength Factors*.

Generally speaking, these parameters are used for fibre reinforced concrete (FRC) and their calculation is achieved by ASTM C1018-97 "Standard Method for Flexural Toughness and First-Crack Strength of Fibre Reinforced Concrete".

Actually, there are no Standards which refer to asphalt concrete reinforced with fibres, since this material is less prone to give significant results in flexure, if compared to FRC. However, the Authors decided to define some similar characteristics also for reinforced asphalt concrete, which is characterised mainly by a visco-elasto-platic behaviour.

Hence, the Toughness Indices and the Residual Strength Factors were determined also for the material used during this investigation, with the understanding that asphalt concrete, no matter if reinforced, gives limited contributions in the post-crack phase, when compared to fibre reinforced concrete.

In order to determine their value, the definition and the assessment of the *first crack deflection*, which is basically the deflection measured in correspondence of the first crack, was pivotal.

This quantity being called δ, the Authors propose the calculation of 1.5δ and 3δ as reference, for a further use in the determination of the different areas underneath the load-deflection plot.

Referring to Figure 4, the various Toughness Indices were defined as follows:

- $I_{1.5}$: ratio between the area measured under 1.5 δ and in correspondence of the first crack;
- I_3: ratio between the area measured under 3 δ and in correspondence of the first crack;

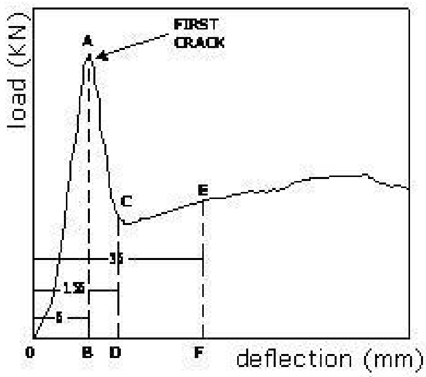

Figure 4: Chart for the determination of Toughness Indices (t=20°C)

Eventually, the Residual Strength Factor $R_{1.5,3}$ was pinpointed for the definition of the mean value of the post-crack load which can be undertaken along a specific interval (CE in Figure 4), as percentage of the first-crack load, its value being the following:

$$R_{1.5,3} = 20 \cdot (I_3 - I_{1.5}) \qquad \text{(Equation 1)}$$

2.4 Flexural results

In this section of the paper the results tests performed on the specimens under flexure are represented, with the uptake of comparing the relative values of the different kinds of reinforcement, so as to quantify the improvements, if any, with respect to traditional asphalt concrete.

2.4.1 Load – deflection relations

In order to determine the behaviour of the load-deflection charts, a 0.10 mm/min constant deformation load test was performed, continuously monitoring the quantities, by means of an X-Y plotter and checking in an incremental way the results with some transducers which could reproduce the curve with preciseness.

Once the charts of the specimens of each mix were found, the mean behaviour of each category of asphalt concrete was calculated , so as to get to the chart illustrated in Figure 5.

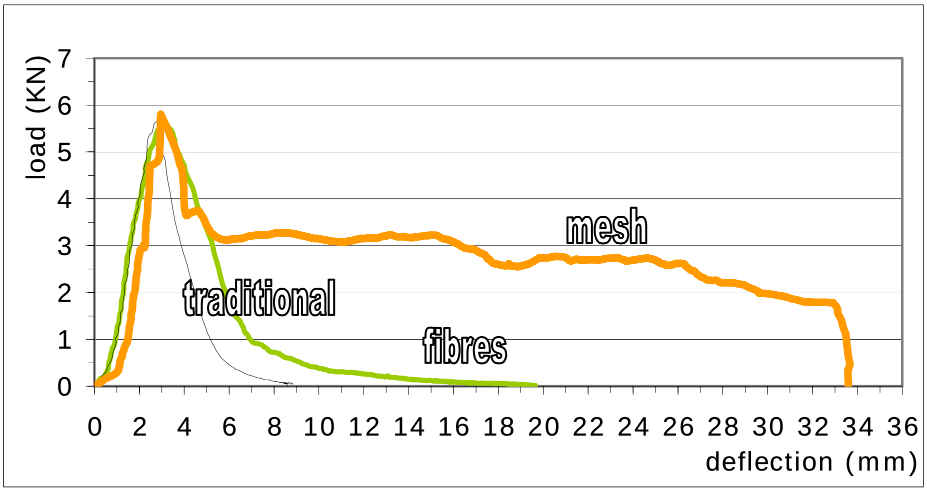

Figure 5 Results of the flexural tests for the different sets of specimens (t= 20°C)

Table 2 includes the results of such test on traditional (T) specimens and on similar elements with steel mesh (R) of fibres (F), along with the corresponding standard deviation values, while the following Figures 6-11 illustrate the charts referred to the single mixes, respectively load vs deflection and load vs time.

Such charts are very useful for the determination of the Toughness Indices and of the Residual Strength Factor, since these quantities are calculated as function of the area subtended by the charts themselves.

Table 2 Results of the flexural test on the different sets of specimens (Traditional T, with mesh R and with fibres f)

	T_{mean}	σ_T	R_{mean}	σ_R	F_{mean}	σ_F
F_{MAX} (KN)	5,70	0,61	5,81	0,46	5,68	0,49
δ (mm)	2,82	0,48	2,96	0,54	3,13	0,47
1,5δ (mm)	4,22	0,47	4,43	0,50	4,70	0,51
3δ (mm)	8,45	0,53	8,87	0,65	9,39	0,50
T (sec)	13,3	0,54	13,18	0,65	14,90	0,49
A	14,9	0,54	91,59	0,79	25,60	0,67

where: F_{max} = first crack load;
δ = first crack deflection ;
T = time corresponding to the first crack load;
A = area underneath the load-deflection curve.

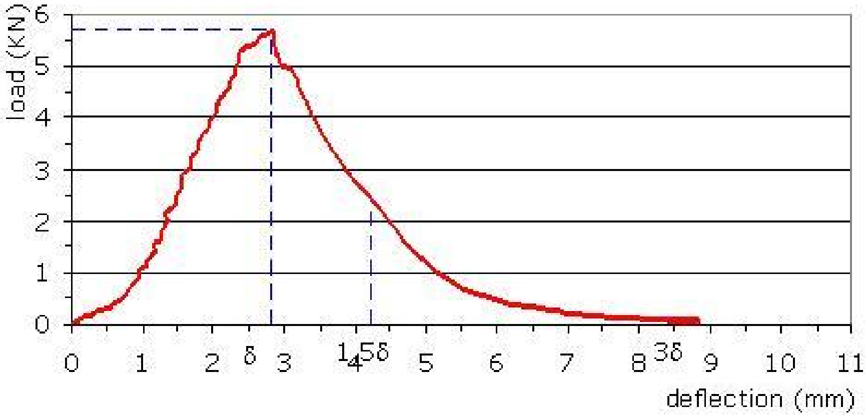

Figure 6 Mean chart load-deflection for traditional asphalt concrete specimens

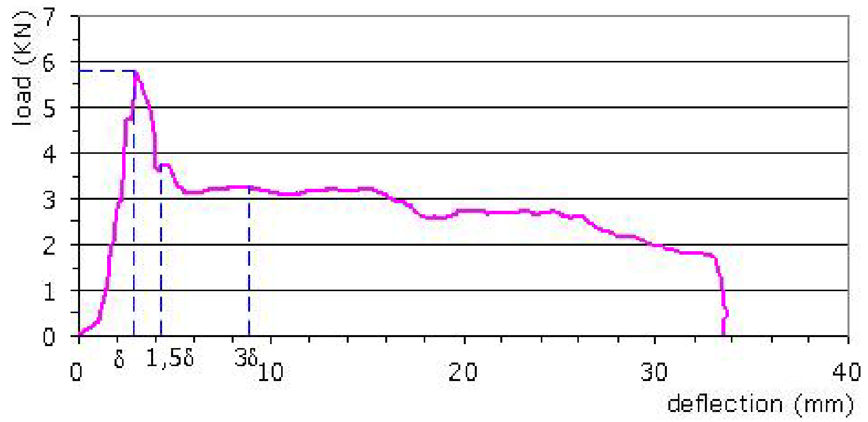

Figure 7 Mean chart load-deflection for asphalt concrete specimens with steel mesh

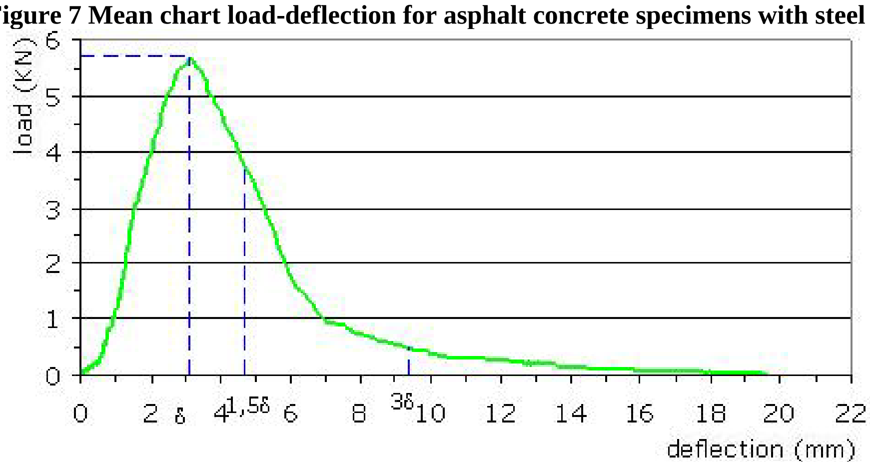

Figure 8 Mean chart load-deflection for asphalt concrete specimens with fibres

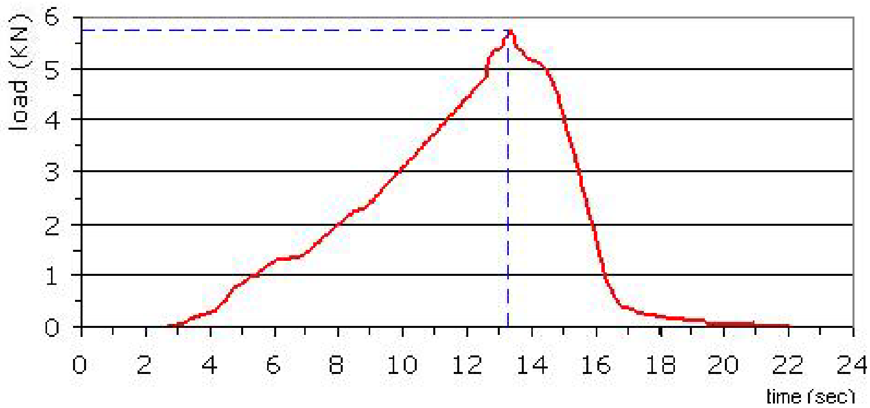

Figure 9 Mean chart load-time for traditional asphalt concrete specimens

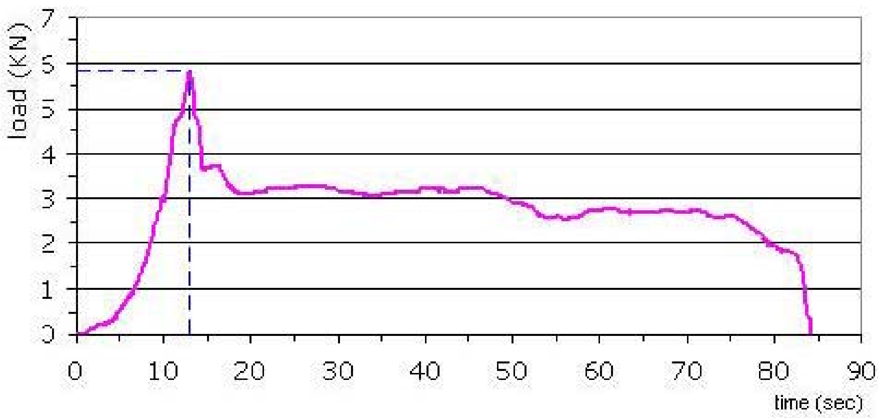

Figure 10 Mean chart load-time for asphalt concrete specimens with steel mesh

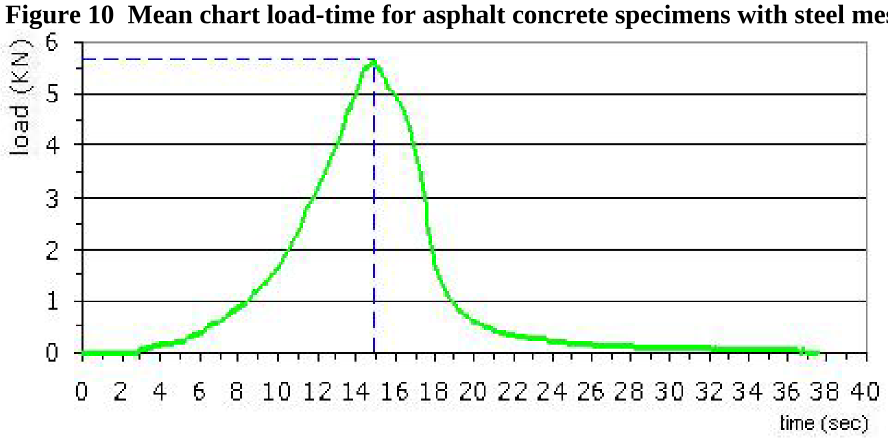

Figure 11 Mean chart load-time for asphalt concrete specimens with fibres

From the analysis of the previous Figures one can easily find out that, although the first crack load is almost equal to that of traditional asphalt concrete, the specimen reinforced with steel mesh can withstand, in the post-crack stage, stresses for a time which is 4 times greater than the traditional one, with a maximum deflection around three times greater than the corresponding traditional asphalt concrete value.

Furthermore, looking at the behaviour of the charts, it is possible to have a clear understanding of the ductility of the material and to what extent it can resist to loads applications after first crack occurs.

It the charts also the values of the first crack load, of the first crack deflection δ have been highlighted, along with the corresponding 1.5 δ and 3 δ, whose determination is needed for the calculation of the area subtended by the chart itself.

Starting from these charts, as already stated before, it was possible for the Authors to compare the characteristics of the different sets of specimens, the results being included in the following paragraphs of the paper.

2.4.2 First crack load

This is the load value for which the cracking stage starts occurring in the element subjected to flexure and, on the representative plot, it is identified by the domain where the first ascending part ends.

During the investigation the Authors evaluated the percentage variations of such value due to the addition of steel mesh or fibres, with respect to ordinary concrete, these results being included in Table 3.

Table 3 First crack load variations of the mixes compared to traditional asphalt concrete

First crack load	
Specimens	**% variation compared to traditional asphalt concrete**
With steel mesh	+1,9
With fibres	-0,4

Hence, it is evident that asphalt concrete specimens reinforced with steel mesh exhibited an increase in the first crack load, which basically means that the reinforcement can withstand higher deformations induced by cyclic loads, thus retarding the propagation of cracks in the pavement and increasing its life cycle.

As for the performances of asphalt concrete reinforced with fibres, a 0.4% reduction was observed from this standpoint: this result is the logical consequence of the fact that in such mix the bitumen percentage was 0,25% higher than the corresponding value used for traditional specimens.

2.4.3 First crack deflection

Afterwards the first crack deflection δ was measured and the corresponding 1.5 δ and 3 δ values figured out.

For the sake of brevity the percentage variations of the measured deflection in correspondence of the first crack load, with the changes of the asphalt concrete characteristics have been condensed in Table 4, from which one can easily get onto the behaviour of the different mixes.

Table 4 First crack deflection variations of the mixes compared to traditional asphalt concrete

First crack deflection	
Specimens	**% variation compared to traditional asphalt concrete**
With steel mesh	+5,0
With fibres	+11,0

2.4.4 *First crack toughness*

The following step of the investigation provided for the assessment of the first crack toughness, defined as the area underneath the first part of the chart, which is the one pointed out by the letters OAB in Figure 3; as before, these values have been compared to each other, the results having been included in Table 5.

Table 5 First crack toughness variations of the mixes compared to traditional

First crack toughness	
Specimens	**% variation compared to traditional asphalt concrete**
With steel mesh	-17,6
With fibres	+24,7

2.4.5 *Toughness Indices values*

After assessing all the quantities need for the purpose of the research, the Toughness Indices were figured out. It is important to keep in mind that such indices, referred to the two different areas underneath the chart, are useful to make a clear distinction between the different conglomerates.

Consequently, with respect to the intervals δ, 1.5 δ and 3 δ, one can understand the real plasticity rate of the asphalt concrete tested.

Figure 12 shows that the corresponding indices $I_{1.5}$ e I_3 of plain and fibre-reinforced asphalt concrete are alike, the corresponding areas being very similar, while the I_3 index of the material with steel mesh is twice as $I_{1.5}$, which basically means that the material can put up with the applied load for a larger time span, the overall deflection being thus larger.

2.4.6 *Residual strength factor values*

A further development of the research was aimed at the determination of the Residual Strength Factor value $R_{1.5,3}$, which allows to know the mean value of the post crack load along a specific interval (CE in Figure 3), as percentage of the first crack load.

Again, the best performances were achieved by the asphalt concrete reinforced with steel mesh, as reported in Figure 13.

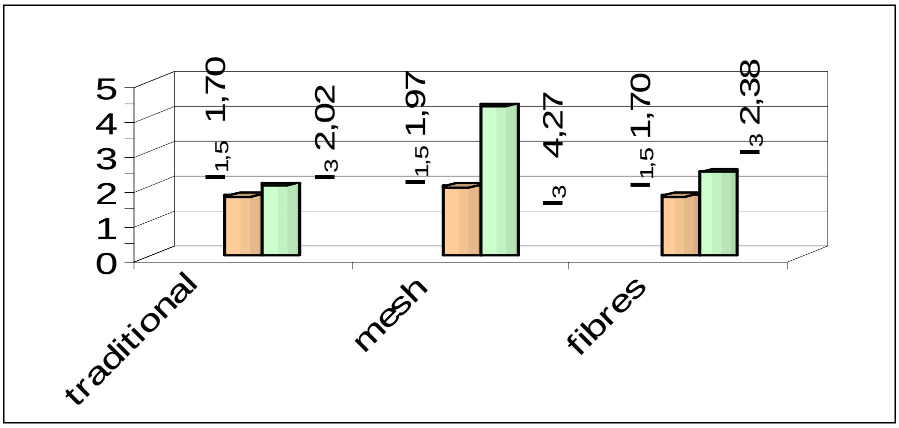

Figure 12 Toughness indices values for the different mixes

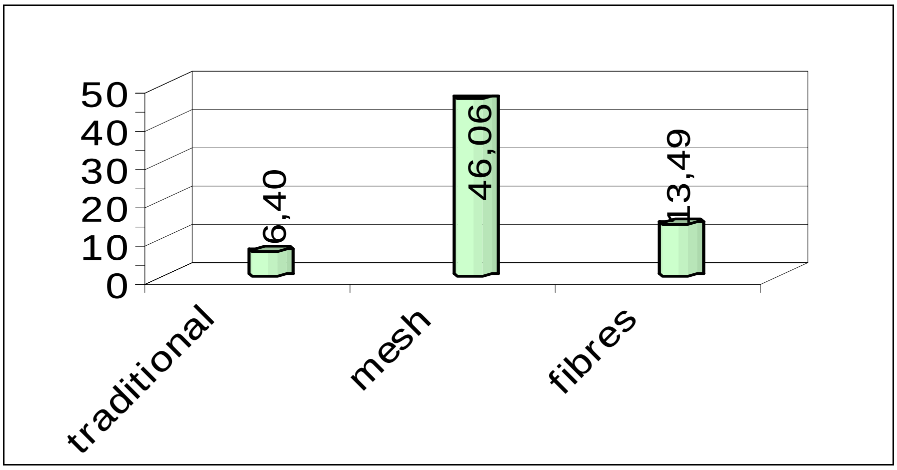

Figure 13 Residual strenght factors values for the different mixes

3 CONCLUSIONS

This research studied the post-crack behaviour of asphalt concrete road pavements reinforced with either steel mesh or fibres.

As expected from what found in literature, before cracks occur, the behaviour of the conglomerate reinforced with mesh or micro-fibres is very similar to that of traditional asphalt concrete.

Indeed, this phenomenon confirmed that the use of reinforcement into flexible pavements aims at the redistribution of cracks and at the improvement of the post crack resistance of the material, rather than at the increase of the load the structural element can withstand before the first crack occurs.

Furthermore, it was found that the first crack load of the fibre-reinforced specimens is lower than that of the traditional elements, which is mainly due to the higher bitumen percentage into the in the mix in presence of fibres.

Before the appearance of cracking the behaviour of fibre reinforced specimens is almost alike that of plain elements, the only difference residing in an increase of both the first crack deflection and the area subtended by the load-deflection curve: in addition, an increment of the first crack toughness was measured, which is consequence of the beneficial effect of fibres into the conglomerate in the post crack stage.

By using the steel mesh as reinforcement, a significant increase of the pavement bearing capacity after the first cracks occurred was experienced, the incremental factor being around four; this particular behaviour came about because the mesh took part of the tensile stress due to the bending tests.

Hence, in conclusion the Authors believe that the positive results of their investigation nourish the general idea for which reinforcements in asphalt concrete give a strong increase in the mechanical performances of the material.

However, not all reinforcements behave in the same way, since the performances depend upon the materials employed, as well to their dimension, the need for further investigations on the matter being thus pivotal.

In any case, similarly to what happens for concrete pavements, the type of reinforcement is a crucial key in the definition in the post crack performances of the structural elements.

Last but not least, apart from conditioning life cycle of pavements, this aspect has important economical implications from the point of view of road maintenance which road administrators are responsible for.

REFERENCES

AGOSTINACCHIO M., CUOMO G. (2003) - *Concrete pavements reinforced with polymer-modified and steel fibres* - CONCRETE Magazine - Volume 37 – Number 8, Crowthorne, Berkshire, Great Britain.

AGOSTINACCHIO M., OLITA S., (2005) - *The Modification of Bituminous Binders by Means of New Generation Polymers* - 3rd International SIIV Congress – People, Land, Environment and Transport Infrastructures – Reliability and Development, Bari, Italy.

AUTOVIE VENETE, FERRIERE NORD PITTINI (2002): *Rinforzo di strutture stradali flessibili con rete elettrosaldate per prolungarne la vita utile* - progetto REFLEX Marzo 1999- Agosto 2002.

CAFISO S., DI GRAZIANO A.,TAORMINA S. (2004) - *Analisi dell'efficienza in esercizio di pavimentazioni stradali rinforzate con rete metallica* - Strade e Autostrade n. 6/04, Grafica Pioltello, Milano, Italy

CUOMO G. (2005) - *Analisi del Quadro Fessurativo di Pavimentazioni Stradali Rigide Rinforzate con Microfibre* - Rassegna Economica – Rivista Internazionale di Economia e Territorio – Quaderni di Ricerca –Associazione Studi e Ricerche per il Mezzogiorno – Numero 16 - Giovani Talenti – Premio Marrama, Napoli, Italy.

MONTEPARA A. (2006) - *Road Mesh per riqualificare strade a basso volume di traffico* - Le Strade n. 3/06, Casa Editrice La Fiaccola SRL, Milano, Italy

TESORIERE G., TICALI D. (2004) - *Verifica sperimentale delle pavimentazioni stradali rinforzate con rete metallica"*, Le Strade n. 11/04, Casa Editrice La Fiaccola SRL, Milano, Italy.