CONSIDERATION OF THE SUSTAINABILITY OF FIBER REINFORCED CONCRETE WITH STEEL AND POLYMER FIBRES

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Abstract:

Concerning the sustainability of fibre reinforced concrete there are several interesting aspects. The sustainability consists of three parts including ecology, economy as well as culture and society. Regarding the application of construction materials economical and ecological aspects are in the focus of interest. For this reason this paper gives an overview of market situation, efficiency of different fibre types (steel and polymer) and limits of utilization. Considering the ecological facet some thought-provoking impulses are to be given. Examples are facts for production, health, recycling as well as disposal.

Keywords: sustainability, ecology, economy, steel fibre, polymer fibre

1 Introduction: Sustainability charge for future

The preception of sustainability has become very important during the last years. But use and construction of the sustainability item are very deceased and differ in part. The reason is that there is no general definition [1]. Consensus could only be located in the fact that sustainability should compound ecological and economical points of view as well as culture and society problems. Through this integration it will be possible to create a suitable livelihood for future generations long-rangingly. Civil engineering has a authoritative effect for sustainable development [2]. So it is necessary that all stakeholders consider the ecological effects of building activities in addition to economical aims.

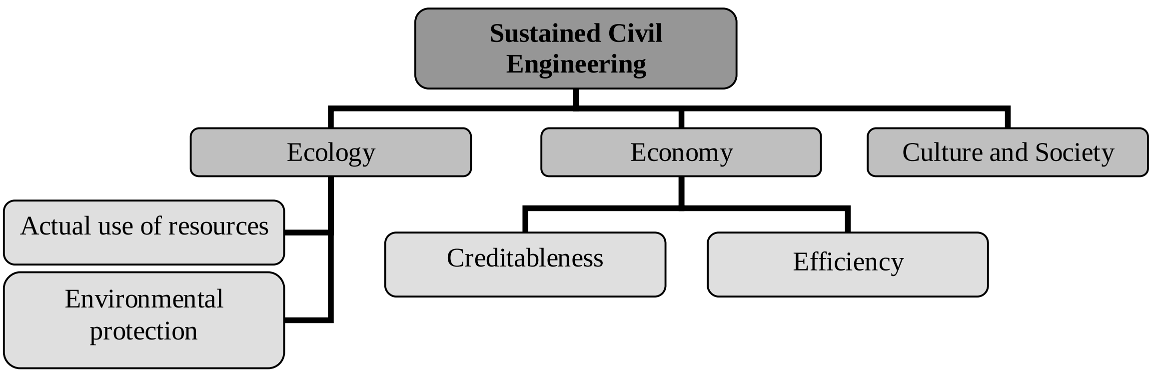

Fig.1 Sustainability in Civil Engineering [1]

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Fig. 1 presents some essential facts and aims which presuppose sustained civil engineering. Economical demands like creditableness or efficiency and economical objektives like actual use of resources as well as cover for pollution present the high significance of the used building materials. Just materials which ensure a good agreement between the mentioned aims assure real sustainability.

Fibre reinforced concrete (FRC) has been used since the 1960th for commercial uses. Only in the year 2002 the worldwide wastage of fibre was 300.000 tons buoyancy. The most scientific analysis point at the effectivneness of fibres concerning bearing strength and serviceability. Questions according to costs or to the accord between different fibre materials are often missing. Also ecological conditions like the recirculation of fibre reinforced concrete could attract a great deal of attention. For this reason this article will behold fibre reinforced concrete under sustainable stand points.

2 Economical facts

The effectiveness of fibre as an aggregate for concrete was often investigated in the past. There were two important ways. For example investigations at the level of the aggregates (fibres as a reinforcing element) or at the level of the component (FRC as a material). Thereby the direct analogy of different fibre types is often taken fright.

3.2 Market Situation

Steel, glass and polymer fibres are the most important fibre types at the moment. Typical material properties are shown in Tab. 1.

Tab. 1 Material property of different fibre types

Fibre material	Tensile strength [N/mm²]	Elastic modulus [N/mm²]	Density [g/cm³]
Polyvinyl alcohol (PVA)	800 bis 1800	25000 bis 40000	1,30
Polypropylene (PP)	600	5000	0,91
Steel (normal strengtht)	1000 bis 1200	200000	7,85
Alkali- resistant glass	2200	80000	2,78

In comparison of several producers offers it was possible to find out the costs for steel, glass and polymer fibres shown in Fig. 2. Polymer means in that case polyvinyl alcohol (PVA). PVA fibres are used for bearing capacity because of their high tensile strength (Tab. 1).

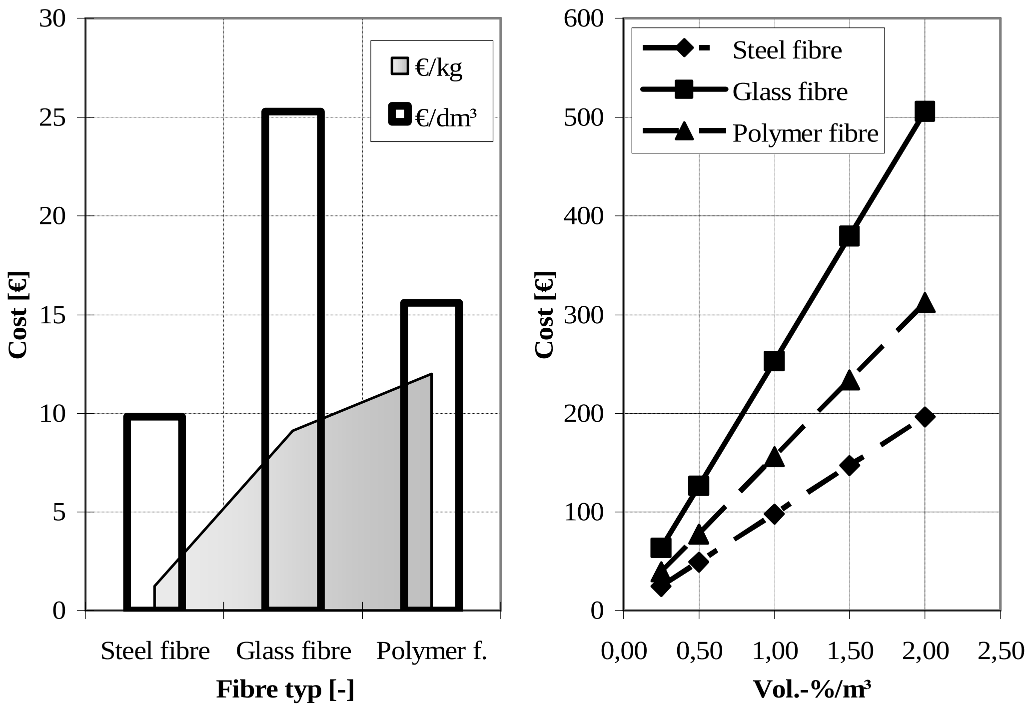

Fig. 2 Costs for different fibre materials

The price for one kilo of the fibres in the left diagram presents that the polymer fibres are most expensive. But an exchange in euro per litre shows that glass fibres are most uneconomical. In opposite, the costs for steel and polymer fibres are really less. The pointed development of the prices in the right diagram characterise the big economical advantages of steel fibres when the volume of fibres will increase.

3.2 Effectiveness of steel and polymer fibres

The comparison of costs has already shown the big varieties between the different fibre types. In the following a further economical fact will be given on the basis of load-bearing capacity. For a long time the static availability of steel and polymer fibres have been tested at the Universty of Appiened Science Leipzig. The test facility is a four point bending test with small beams (75 cm length, 15 cm width, 15 cm height). This dicplacement controlled test delivers load deflection curves by recording load (test machine) and the bending (displacement transducer). The surfaces under each load deflection curve allow a classification for a fibre class. Fig. 3 shows the load deflection curves of fibre reinforced concrete with increasing volume of steel (left diagram) and PVA fibre (right diagram). The length of the steel fibres were 50 mm with hooked ends and the diameter was 1,05 mm. The dimensions of the PVA fibres were 30 mm length and 0,6 mm diameter.

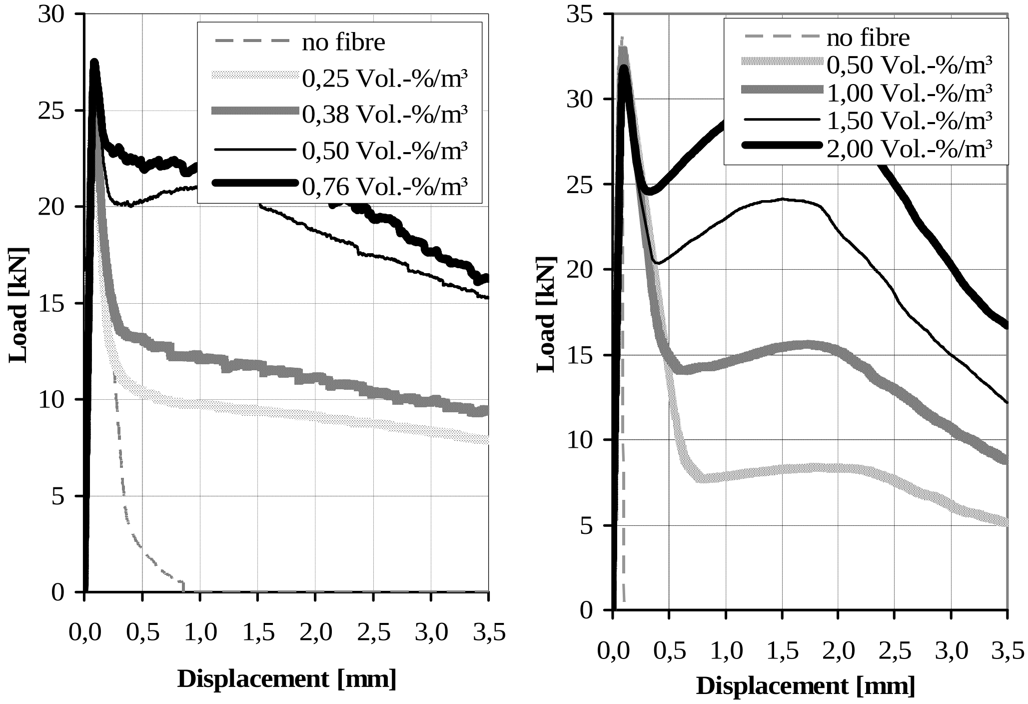

Fig. 3 Load deflection curves of steel and PVA fibre reinforced concrete

You can clearly see the increase of bearing strength depends on increasing of fibre volume. Thereby the steel fibre reinforced concrete has a consistent and ductile behaviour. At already 0,76 Vol.-%/m³ an approximate critical fibre content can be achieved. Also with the polymer fibres are articulate increases of the load bearing capacity possible, although a high volume of fibre is required. Anymore the load deflection curves are not consistent after the first crack like the curves with steel fibres. After a strong ascent of load till 1,5 mm bearing the curves go down very fast.

The diagrams show that the load at the first crack between steel and polymer fibre reinforced concrete is different. The reason lies in two different concrete compositions used for the investigations. For the steel fibre compound was aspired for a concrete C30/37 and for the polymer compound was aimed a concrete C35/45. So it was necessary to convert the achieved loads into percent for a direct comparison. The load at the first crack respectively equates 100 %. Furthermore load deflection curves of the same power setting (Fig. 3) have been compared. Fig. 4 shows the results of an deflection at 1,5 mm and beyond the costs for the required fibre volume. It can be pointed for the steel fibre reinforced concrete that it is possible to increase clearly the bearing strength after the first crack with low costs. With cost under 100 € a critical fiber content can be achieved.

This critical fiber content is also possible with polymer fibre reinforced concrete but then it's very expensive.

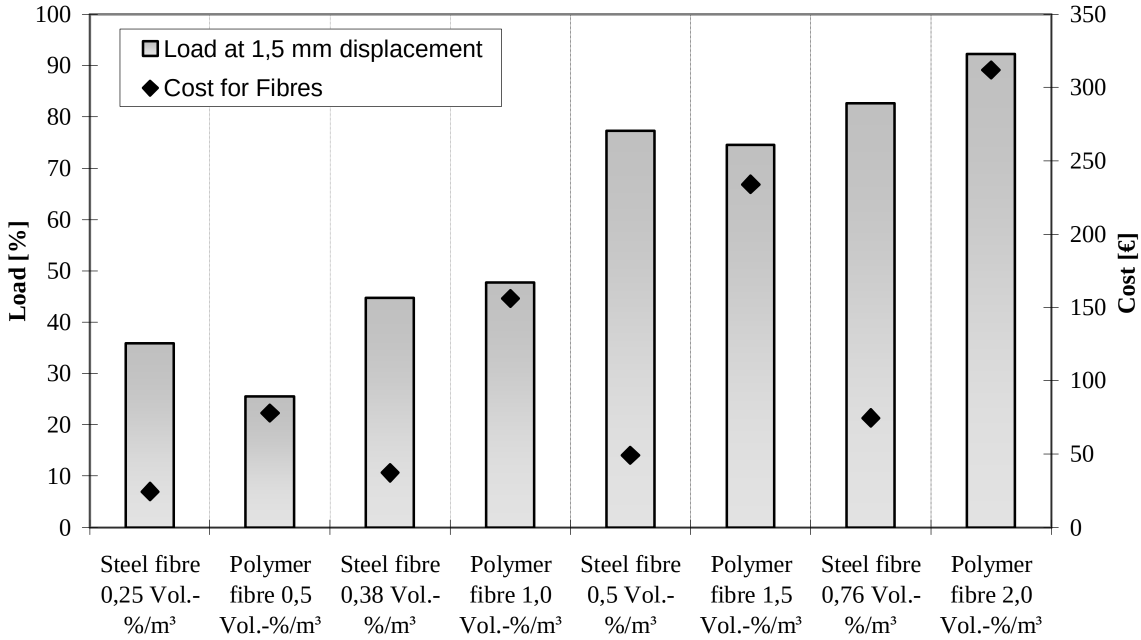

Fig. 4 The comparison between curves at 1,5 mm displacement and costs for fibres

If you want achieve an approximated critical fiber content you will have to plan costs beyond 300 € per cubic metre concrete. Furthermore the tests with the polymer (PVA) fiber compositions showed that by increasing of fibre content the processability became worse. The use of admixture could not stop this trend, too.

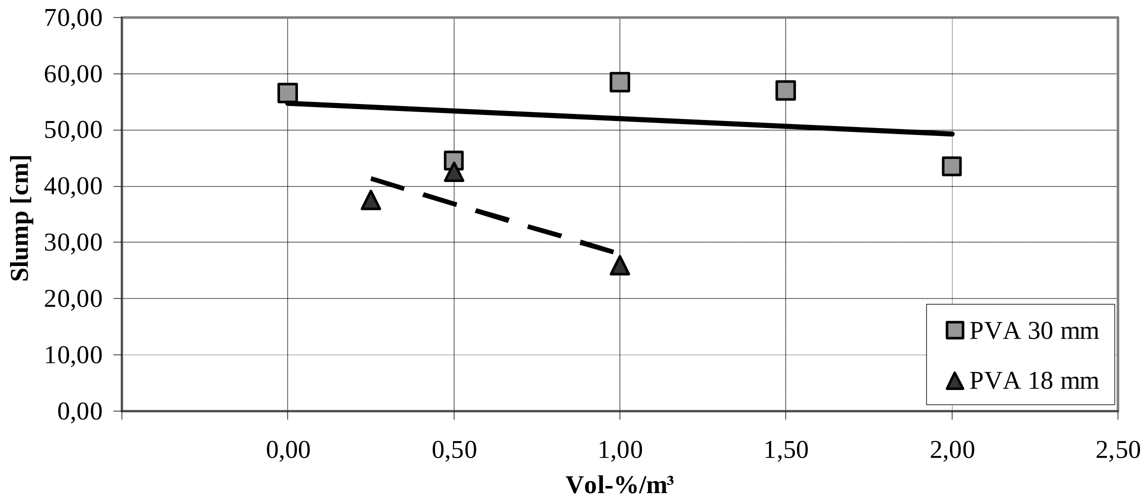

Fig. 5 Development of slump under increasing of fibre content

In Fig. 5 the slump of polymer fibre reinforced concrete with long (30 mm) and short (18 mm) PVA fibre of different content is shown. The demonstrated problems of polymer fibres clarify the importance of comparsion between different fibre materials and types. Just to look for what is doable, is not enough to declare economical facts.

3 Ecological facts

Besides economical facts the knowledge of ecological characteristics of innovative building materials is very important for sustainability [4]. Fig. 6 points at the materials cycle.

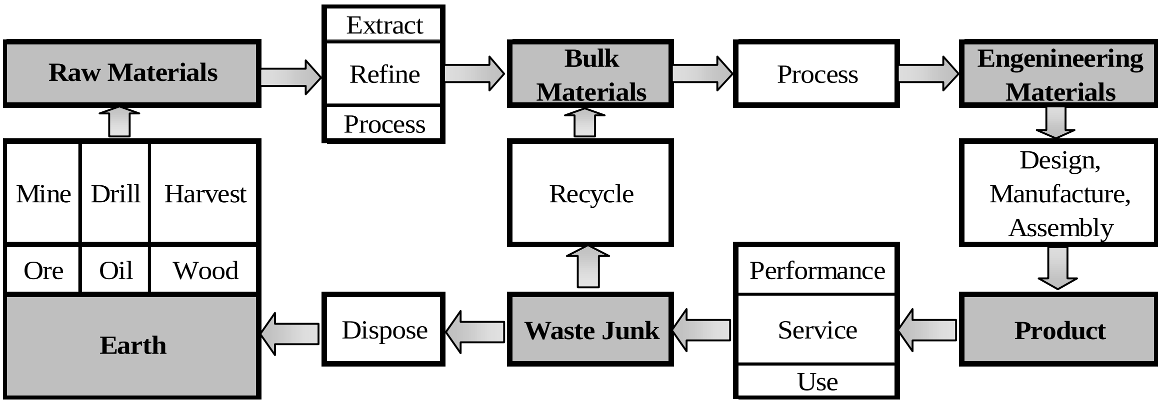

Fig. 6 Materials cycle [3]

Fig. 6 makes clear that mainly the fabrication and the recycling of a kind material are the most significant stations. Materials with a high expenditure in manufacturing and a low recyclability are critical according to ecological sustainability. On this place the nature must be the guide because natural materials cycle do not know dispose.

3.2 Production of steel and polymer fibre

The way from the raw material to the engenireering material is long for fibres and so the energy consumption is high for steel and polymer fibres. You need the CO2 emission to make ecological statements, too. Tab. 2 makes clear the energy consumption and CO2 emission for the manufacture of different bulk materials.

Tab. 2 Energy input and CO2 emission for different bulk materials

Bulk Material	Specific Energy Input [MJ/kg]	Specific CO2 Emission [kg_{CO2}/kg]
Concrete	1,20	0,15
Iron	20,00	1,40
Polymer	68,00	4,90

It can be shown that the energy input and CO2 emission for concrete is low. This is because of the quite small amount of cement and the possibility to use home produced products. Also the producing of iron and steel is relative environmentally friendly today. So the energy demand could have been decreased about 40 % for the last fifty years. But this is not right for fabrication of plastics. Already the disassembly and the transport of the raw materials are very complex and connected with many emissions. Anymore there are very difficult process steps to produce plastics. One example is the hydrolysis to get PVA.

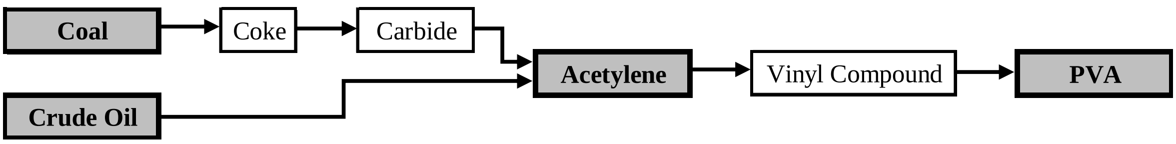

Fig. 7 Fabrication of PVA

As shown in Fig. 7 the fabrication of PVA is very difficult. It depends on fossil fuels. According to ecological demands the production of polymer fibres is not environmentally friendly.

3.2 Health and fibre materials

The sensitive point of health protection (during the period of machining and use) must be checked by fibre materials very carefully. A result of missing information were the asbestos fibres in the past. The asbest material was used until the 1990th. Today they are forbidden in the whole European Union. Two-thirds of employment diseases are connected with this fibre type.

PVA fibres can replace asbestos fibres. One big advantage of the asbestos fibres was their durability. The durability of PVA fibres could be proved, too. Health risks can be excluded because of the high-molecular compound of polymer. Furthermore PVA fibres are not respirable because of their big diameters. Another advantage of polymer fibres may be the smaller elastic modulus in opposite to steelfibres. So it is possible to use these fibres for floors in the agriculture in order to avoid injuries of productive livestock.

3.2 Recycling and disposal of fibre concrete

Fig. 6 demonstrates what will happen with wast junk after the service life of a product. Recycling should be the main aim for good suistainability. Wast junk without possibilities for recycling must be given back to earth and to future generations. Otherwise it would mean a great lost of raw materials.

The recycling of concrete and reinforced concrete is difficult and it is connected with extensive energy expenditure. At the moment the most recycling possibilities prefer crush old concrete with an impact crusher [6]. The arised aggregats can be used as recycled concrete aggregat. If concrete reinforcment steel is used it will be necessary to deposit the steel in an extra step. The effectiveness of the described methods is low and the acceptability of the arised aggregats is small. The main reason for this thing is that they have got a high porosity because of the big contingent of cement stone. The consequence of this is a smaller comprehensive strength and a higher water absorption. A well-known application is the road construction. The recycling of old concrete will get even harder if fibres as further element of the concrete are used. Also steel fibres must be deposited during the recycling. It is necessary to crush the old fibre concrete till size of the fibre diameter. Not till then it is possible to use a magnetic seperator. Now it is possible the steel fibres to give back to the steel material cycle. But a big problem is the recycled concrete aggregat. It is flour now. For these aggregates there are no possibilities for a new application in concrete compound [5]. Finally it's maybe a fact that this innovative material "fibre reinforced concrete" will get to a big ecological problem. To dipose this problem there are some efforts to include the very crushed aggregates as reactive fillers like fly ash. But this evolution has just started.

For polymer fibres there are no recycling possibilities at the moment. The list of problems is very long. There are no machines to isolate the fibres. Furthermore the fibres are often very fine and they are able to get a chemical bond with the concrete matrix. As a result a big effort is necessary to realise a seperation. Leaving the polymer fibres in the recycled concrete aggregat is unexplored.

4 Conclusions

The investigations for the sustainability of fibres as aggregat in concrete have shown how important it is to look at modern building materials all in all. The comparsion of steel and polymer fibres has described that steel fibres have many economical advantages. Examples are the low costs as well as the high load-bearing capacity. Steel fibres can also convince among ecological demands because of their low energy input and their good CO2 emissions. The use of polymer fibres should be reduced for special cases. This could be exposed concrete. An activ increasing of bearing capacity can be well-realized with steel fibres in normal cases. But the plentiful use is problematic because of the bad recycling possibilities at the moment.

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