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# Guidelines for Viscosity Modifying Admixtures For Concrete

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In co-operation with EFCA
The
European Federation of Concrete Admixture Associations
www.efca.info

## Contents

## 1. Introduction

Concrete is one of the most widely manufactured materials in the world and over recent decades technical innovations, especially in the use of admixtures have improved not only the quality but also the range of potential applications for this versatile construction product. One of the latest innovations is the development of improved Viscosity Modifying Admixtures (VMA) also referred to as Stabilisers, Viscosity Enhancing Admixtures (VEA) and Water Retaining Admixtures. Water retaining admixtures are a type of VMA already defined in EN 934-2.

Today's concrete has to fulfil a wide range of requirements in both the fresh and hardened state. In most cases the properties of fresh concrete also affect the quality of the hardened concrete and ultimately its durability. This means that concrete has to be correctly proportioned and must remain homogeneous during placing and after compaction in order to avoid effects such as bleeding, segregation, honey combing, laitance, settlement and plastic cracking over the top bar. These effects would all lead to reduced quality and durability of the hardened concrete.

Modern concrete technology produces a highly engineered material in which, by the careful selection and proportioning of its constituents, its characteristics have been designed to fulfil specific needs. Modern concrete allows faster construction, slender structures, greater durability, much higher final strength and faster strength development than was previously possible. Concrete can be pumped both vertically and horizontally over a long distance even with high flow, self compacting properties.

The more advanced the concrete becomes (self-compacting concrete, high performance concrete, underwater concrete, pumpable concrete, etc.) the more sensitive it gets to material variations and fluctuations during production and placing. Production sites are often faced with problems caused by variations in the moisture content or grading of the aggregates and with fluctuations in the fine content of the sand. Construction sites may face difficulties resulting from the location, access or from breakdowns or other stoppages during placing. Viscosity Modifying Admixtures can be used to produce concrete with better robustness against the impact of variations in the concrete constituents and in site conditions, making it easier to control and more friendly for the producer and the user.

## 2. Scope

These "Guidelines for Viscosity Modifying Admixtures for Concrete" represent a practical state-of-the-art document addressed to specifiers, designers, contractors and concrete producers who wish to enhance their expertise and use of VMA's.

The Guidelines covers information for the use of VMA's in selected applications such as SCC, pumped concrete and underwater concrete and includes sections on problem solving.

## 3. References


EN 197-1: Cement – Part 1: Composition, specification and conformity criteria for common cements

EN 206-1: Concrete – Part 1: Specification, performance, production and conformity

EN 934-2: Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures

EN 12350-2 Testing fresh concrete – Part 2: Slump test

EN 12350-8 Testing fresh concrete – Part 8: Slump flow test

EN 12350-9 Testing fresh concrete – Part 9: V – funnel test

The ‘European Guidelines for Self-Compacting Concrete, specification, production and use’.
*(Note: this is available for free download from the web sites of efnarc.org or efca.info.)*

BS 8443 Specification for establishing the suitability of special purpose concrete admixtures

CUR 18 CUR Aanbeveling 18: Colloidaal beton (Dutch recommendation)

## 4. Function of a Viscosity Modifying Admixture (VMA)

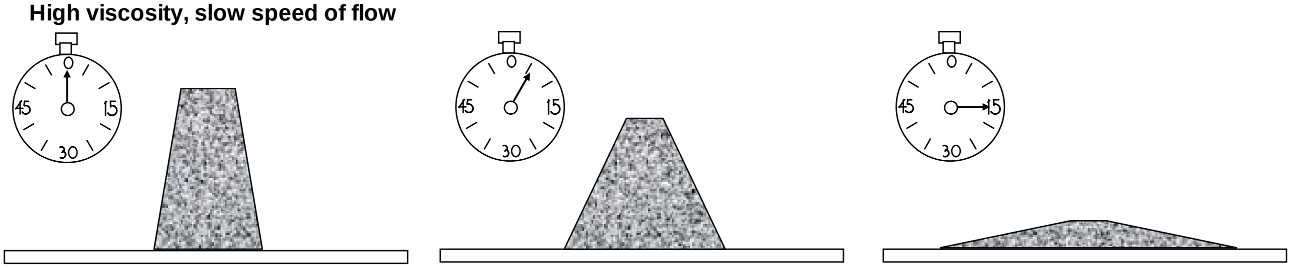
The key function of a VMA is to modify the rheological properties of the cement paste.

The rheology of fresh concrete can be mainly described by its yield point and plastic viscosity:

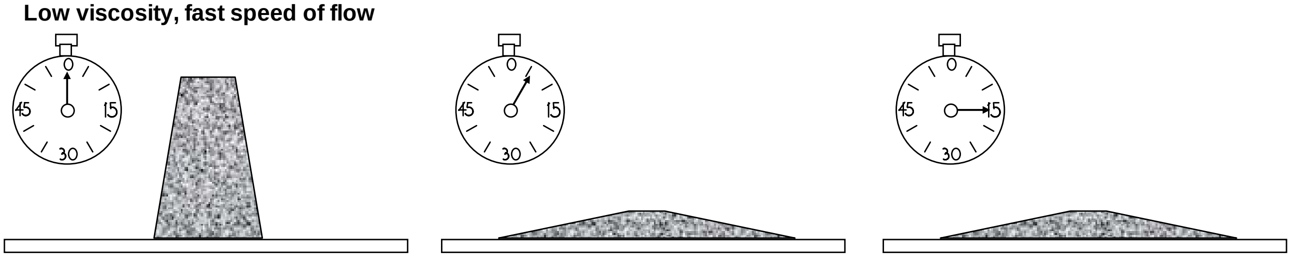
- The yield point describes the force needed to start the concrete moving. Yield point is related to the workability of the concrete and may be assessed by tests such as the slump value (EN 12350-2).

- Plastic Viscosity describes the resistance of a concrete to flow under external stress. Viscosity is caused by internal friction. The speed of flow of concrete is related to its plastic viscosity as shown in the diagram below and may be assessed by the $T_{500}$ time during a slump flow test (prEN 12350-8) or by the time to flow through a V Funnel (prEN 12350-9).

**High viscosity, slow speed of flow**




**Low viscosity, fast speed of flow**




The balance between the yield point and the plastic viscosity is key to obtaining the appropriate concrete rheology. VMA’s change the rheological properties of concrete by increasing the plastic viscosity but usually cause only a small increase in the yield point. Admixtures which decrease the yield point are called plasticizers and are often used in conjunction with a VMA to optimise the yield point.

VMA’s are a family of admixtures designed for specific applications. They are used to:
- reduce segregation in highly flowable/self compacting concrete
- reduce washout in underwater concrete
- reduce friction and pressure in pumped concrete
- compensating for poor aggregate grading, especially a lack of fines in the sand
- reducing powder content in self compacting concrete
- reduce bleeding in concrete
- improve green strength in semi-dry concrete

Most VMA's are based on high molecular weight polymers with a high affinity to water. By interaction of the functional groups of the molecules with the water and the surfaces of the fines, VMA's build up a three dimensional structure in the liquid phase of the mix to increase the viscosity and/or yield point of the paste. The strength of the three dimensional structure affects the extent to which the yield point is increased.

Some VMA's are based on inorganic materials such as colloidal silica which is amorphous with small insoluble, non-diffusible particles, larger than molecules but small enough to remain suspended in water without settling. By ionic interaction of the silica and calcium from the cement a three dimensional gel is formed which increases the viscosity and/or yield point of the paste.

This three dimensional structure/gel contributes to the control of the rheology of the mix, improving the uniform distribution and suspension of the aggregate particles and so reducing any tendency to bleeding, segregation and settlement.

Most VMA's are supplied as a powder blend or are dispersed in a liquid to make dosing easier and improve dosing accuracy. The dosage depends on the application but typically ranges from 0.1 to 1.5% by weight of cement but can be varied for specific applications.

Most VMA's have little effect on other concrete properties in either the fresh or hardened state but some if used at high dosage, can affect setting time and or the content and stability of entrained air. Users of VMA's should refer to the admixture manufacturer's data sheet for specific information on recommended dosage and the effect on other properties of the concrete.

## 5. Viscosity Modifying Admixtures for Self-Compacting Concrete (SCC)

Self-compacting concrete is a concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction.

Self-compacting concrete may be classified in three types: the powder type, viscosity agent type and the combination type:

- The powder type SCC is characterised by the large amounts of powder (all material < 0.15 mm) which is usually in the range of 550 to 650 kg/$m^3$. This provides the plastic viscosity and hence the segregation resistance. The yield point is determined by the addition of superplasticizer.
- In the viscosity type SCC the powder content is lower (350 to 450 kg/$m^3$). The segregation resistance is mainly controlled by a VMA and the yield point by the addition of superplasticizer.
- In the combination type of SCC the powder content is between 450 to 550 kg/$m^3$ but in addition the rheology is also controlled by a VMA as well as an appropriate dosage of the superplasticizer.

In a well proportioned SCC the major variation in the composition during production at the plant comes from normal changes in the moisture content of the sand and the coarse aggregates. Variations of 1.5 % moisture content are typical for aggregate will lead to a change of 10 to 15 litres/$m^3$ of free water in the concrete mix. This will lead to significant variations in the flow and cohesion properties of the concrete being observed from one batch to another on the same day or from one day to another.

Viscosity Modifying Admixtures make the concrete more tolerant to variations in the water content of the mix so that plastic viscosity is maintained and segregation prevented. The concrete has become more robust to small but normal changes in the moisture of the aggregate.

Viscosity Modifying Admixtures are not a substitute for poor quality constituents or mix design. Aggregates with a good grading curve should always be used for SCC and for high workability concrete as a lack of fines in aggregates will affect the rheology and may contribute to segregation and settlement. However, where suitable aggregates are not economically available the required rheology of the mix can often be achieved by utilizing a VMA to provide a more homogenous and cohesive concrete.

Potential benefits of a VMA in SCC may be summarised as follows:

- Less sensitive to variations in the moisture content of the aggregate
- The effects of small changes in the materials properties are minimised
- Lower powder content
- Reduces the level of production control
- Allows more fluid mixes to be used without the risk of segregation
- Improving placing rate
- Reduced risk of segregation and bleeding
- Reduced formwork pressure by thixotropic effect
- Better surface appearance

An overdose of VMA could make the fresh concrete mix too cohesive and slow the placing rate. This effect can usually be overcome by increasing the superplasticizer content.

“The European Guidelines for Self-Compacting Concrete” describes the different conformity criteria and tests methods for SCC and is available for free download on the EFNARC web site: efnarc.org.

## 6. Viscosity Modifying Admixtures for Under Water Concrete

Admixtures have a history of use in underwater concreting applications that stretches back many decades. Traditionally, concrete for underwater applications was made with a high content of fine sand and binder to increase the cohesiveness and thus decreasing the wash out. If this mix was placed by pump or tremie into still water an acceptable result could often be achieved, but as soon as there was significant water movement there would be serious washout. The stability of the mix is not helped by the fact that underwater concrete is difficult to place and compact and therefore requires a high workability. This significantly increases the chance that water will mix with the cement paste and be washed out of the mix or that it has a higher than intended water cement ratio and is therefore low in strength.

The major effect of a VMA for underwater concrete is to increase the cohesiveness of the fresh concrete to such a level that during and after placing the fresh concrete is not washed out. In this way it gives the concrete structure the required strength and durability.

Viscosity Modifying Admixtures for underwater concrete have a strong gelling effect and are often used at a relatively high dose. They are usually supplied in powder form although some are available as a water-free, liquid. Direct contact between the admixture and the mixing water can cause lump or gel formation in the weighing or dosing installation and or in the concrete. As a result, the method of dosing needs some extra attention to ensure progressive and uniform addition into the mixed concrete. Longer mixing is usually required to produce a homogeneous concrete.

Because concrete when placed underwater is very difficult or impossible to compact it requires a high workability. VMA's used for underwater concrete usually decrease the workability and for this reason are normally used in combination with a superplasticizing admixture to recover the self placing properties.

The turbulence of the water into which the concrete is placed and the method of placing determines the extent to which washout is likely to occur. The dosage of the VMA has to give an appropriate cohesiveness that is sufficient to prevent washout. However, high dosages can lead to reduced flow and unwanted secondary effects such as increased air content or retardation.

Viscosity Modifying Admixtures will reduce the problems of washout associated with placing concrete underwater but will not always eliminate them and so normal good practice in placing underwater concrete must still be followed[1].

*Note 1. Further information on placing underwater concrete can be found on the CAA web site admixtures.org.uk under Admixture Technical Sheets.*

Testing for washout in underwater concrete:

There are two washout test methods currently in use in Europe. One is described in BS 8443 and the other in the Dutch recommendations CUR Aanbeveling 18. Both test methods are based on the same principal where a known weight of concrete is placed in an open mesh basket that is dropped down a vertical pipe filled with water. The weight loss after the drops determines the effectiveness of the VMA. There are significant differences in the details of the methods which therefore give different results and have different limits.

The benefits of using a VMA include:

- Less wash-out of the fines and binder of the concrete allowing reduced binder content
- A more durable concrete
- Improved placement properties with less washout
- Reduced environmental risk caused by the wash out of cement particles
- Better visibility for the diver placing the underwater concrete

Pumping concrete with and without an underwater concrete admixture.

## 7. Viscosity Modifying Admixtures for Pumping Concrete

For both economic and technical reasons pumped concrete has gained increasing importance over recent years but as a result of developments in construction practice, the requirements on pumped concrete have become more demanding and have approached the limits of normal concrete technology. VMA is used to meet these demands and to reduce fluctuations in concrete performance.

The most common problem with pumping concrete occurs when the coarse aggregate particles start to lock together, usually at a bend or other slight constriction. The pump pressure forces the lubricating mortar fraction to separate from the mix, leaving a plug of coarse aggregate which eventually blocks the line. Traditionally this has been solved by increasing the fines content of the mix but is not always technically and economically acceptable and may not be effective in the most demanding applications. The VMA is a more effective solution, preventing this segregating effect by making the concrete more cohesive without the need to change the mix design.

The benefits of using a VMA include:

- Prevent blockages by allowing the concrete to remain fluid, homogeneous and resistant to segregation, even under high pumping pressures
- Increased output when used in combination with a superplasticizer to give optimal pumping pressure.
- Reduced wear due to lubrication effect of the admixture
- Assists pump restart by preventing segregation in static lines

The following table gives an indication of the comparable effectiveness of the VMA in pumped concrete.

| **Application / Customer requirements** | **Effectiveness** |
|---|---|
| Reduced segregation and blockages in the pump lines | **++++** |
| Overcoming lack of fines in the mix | **++++** |
| Reduced pump pressure | **+++** |
| Reduction on wear | **+** |
| Reduction in pump energy used | **+** |
| Improved pumping with crushed aggregate | **+++** |
| Long pumping distances | **+++** |
| Greater pumping heights | **+++** |
| General improvement in pumpability | **+** |
| Stabilizing entrained air during pumping | **++** |
| Pumping light weight aggregate concrete | **+++** |

+ low effectiveness ++++ high effectiveness

VMA's may be used for the following pumped concrete types:

- Standard concrete
- Self-Compacting Concrete
- Underwater concrete
- Lightweight aggregate concrete
- Sprayed concrete

Testing the pumpability of a concrete mix in the laboratory is difficult as there are no internationally recognized and accepted test methods for evaluating the performance of the concrete. Even pre-testing on site creates problems of scale. To maximize the effect of a VMA, the optimal dosage may have to be established at site during the pumping process.

## 8. Other VMA applications

### 8.1 Sprayed concrete and repair mortar

Sprayed concrete and sprayed repair mortar have gained increasing importance over recent years for civil engineering applications, but for economic and environmental reasons, rebound should be minimised. The enhanced cohesion achieved by use of a VMA will significantly reduce rebound.

Thick layers of non-accelerated sprayed repair mortar may suffer from sagging on vertical surfaces. This problem can be reduced by the use of micro fibres but is further improved by use of a VMA.

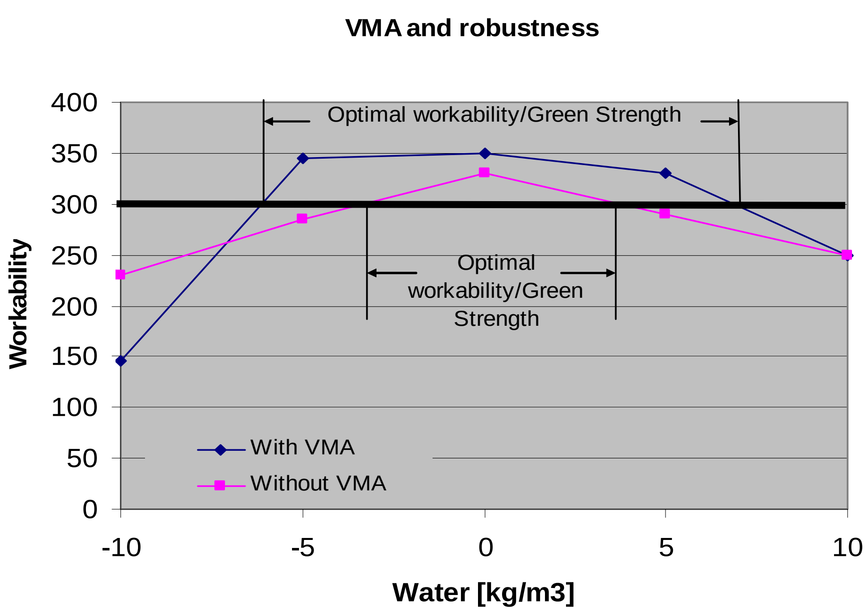
### 8.2 Lightweight concrete

Most lightweight aggregates are porous with water absorption much higher than normal aggregates. They can readily absorb water causing the mix to dry out and lose workability. Pumping lightweight aggregate concretes presents additional problems if the aggregates are not pre-soaked and fully saturated. The pump pressure drives water into the aggregate causing the mix to dry out and block the lines. VMA's can reduce the amount of water which gets absorbed, allowing partially saturated aggregate to be used.

The low density of lightweight aggregates can also causes flotation problems in high workability concretes, VMA will increase the paste viscosity helping to prevent flotation and keeping the mix homogeneous.

### 8.3 Manufactured Concrete Products

Concrete products manufactured from semi-dry concrete require sufficient water for compaction and hydration, however there is also a maximum level if the desired green strength is to be obtained. This balance is difficult to achieve. The use of a VMA broadens the range of optimal water content.



### 8.4 Screeds and renders

The control of moisture loss from screeds and renders is very important because of problems related to curling and plastic cracking. Moisture loss can occur as a result of suction of water into the substrate, leading to desiccation and bond failure or by moisture loss from the surface leading to curling and plastic cracking. VMA find wide application in screeds and renders to minimize these problems.

## 9. Conclusion

The purpose of the addition of a VMA is to replace or limit the addition of fines, thus making a fresh concrete more cohesive. This principle is valid for all applications that have been described. Depending on the application or required effect, the addition of a VMA might need an adjustment of the mix composition to obtain the optimum effect.
Different types of fines (cement types, fillers, fly ash, micro silica etc. etc.) have different effects on the rheology of the fresh mix, for this reason there are several types of VMA that influence the rheology of the mix in a different ways. The choice for a certain type of VMA therefore depends on both the application that it is used for and the concrete mix constituents.
As for all admixtures, trials should be carried out using all the concrete constituents involved in order to optimize the mix. Failure to do so may result in unwanted problems on the job site.

## 10. Annex - Trouble shooting

This trouble shooting guide only considers problems that may be related to the use of a VMA and not to other concrete mix design issues.

- When problems occur with concrete on the job site the overall mix design and quality of constituents should be examined first to ensure that they are appropriate for the application
- Most VMA's are application specific so correct choice as well as optimised dosage is important
- Most VMA's are used at low dose and have little effect on other concrete properties; however overdosing may result in a cohesive mix or increased air entrainment. The manufacturer's data sheet should give guidance on other secondary effects

The following points should be taken into account when using VMA in applications:

Overdosing can result in:

- Loss of initial workability
- Retardation
- Increase of coarse air bubbles
- Difficult cleaning of equipment

Under dosing can result in:

- Too much wash out in underwater applications
- Continued problems with bleed and segregation
- Low viscosity, not enough cohesion

Addition of a superplasticizer might be necessary to overcome the reduction on workability due to the use of the VMA.

The following table summarises the benefits derived from the use of a VMA with respect to specific problems commonly found during production, delivery and placing of concrete.

## Problem solving table

| Problem | SCC | Pumped concrete | Underwater concrete | Reason for improvement when using a VMA |
|---|---|---|---|---|
| Bleeding | X | X | (X) | Bleeding is reduced by increasing the cohesion particularly in high flowable concrete. |
| Blockages in pumping lines | (X) | X | | Prevents separation and reduces settlement in the pumping line. |
| Cohesion is not enough | X | X | (X) | VMA will increase the cohesion |
| Fluctuations in production | X | X | X | Reduces sensitivity to fluctuations in production, making the concrete more robust. |
| Formwork pressure is to high | X | | | The pressure on formwork can be reduced by increase of the cohesion |
| Increase of coarse air bubbles | X | | | The flow from the pump is improved so reducing the entrapment of coarse air bubbles. |
| Lack of fines | X | X | X | Replaces the missing fineness content and prevents separation and bleeding |
| Loss of workability | X | X | | Stabilises the mix and improves workability retention |
| Poor aggregate grading | X | X | X | Improves the fresh concrete quality by the compensating for fluctuations in aggregate grading. |
| Pumping pressure is too high | (X) | X | | In combination with a superplasticizer the internal friction is reduced and the pumpability is improved. |
| Pumping rate is insufficient | (X) | X | | In combination with a superplasticizer the internal friction is reduced and the pumpability thereby is improved. |
| Segregation | X | X | X | Segregation is reduced by improvement of the cohesion particularly in high flow concrete |
| Variations in aggregate supply | X | X | X | Adjusts the fluctuations in the aggregates, in particular within the fines range. |
| Washout in Underwater Concrete | | | X | Washout is improved by increasing the Cohesion. |
| Wear in the pump is too high | (X) | X | | In connection with superplasticizer the internal friction is reduced and the pumpability is improved. |