Surface delamination in slab on ground construction

A report based upon site experience & observation in the Auckland region
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This technical report is jointly published by the Cement & Concrete Association of New Zealand and the Auckland Branch of the New Zealand Ready-Mix Concrete Association.

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Readers please note:
This document has been issued in the interests of actively promoting industry understanding of the influences, both good and bad, that impact on slab on ground construction and in particular, with respect to the delamination of slab surfaces.

As such, it is seen by the promoting organisations as a 'living' document and constructive comments are invited from individuals or organisations.

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Introduction

There is a perception, especially in Auckland, that recent industrial floor slab installations are more prone to delamination of the top surface layer than they were in the past. Although the incident level is not great, there is a high cost of remedial work to ready mix suppliers and contractors. There is also the risk of the general dissatisfaction of clients. All of these considerations have prompted the preparation of this document.

This document is the culmination of nine meetings between a group of readymix personnel, all of whom have significant experience in the concrete construction industry. The points made in this report are a combination of perceptions based upon the groups experience, and literature searches.

Delamination defined

The delamination, or blistering, of concrete floors is physically represented by the separation of a thin layer of mortar at the top surface of the concrete from the rest of the underlying concrete. The thickness of this layer can vary from paper thin up to 8mm thick, depending on the mechanism involved. The size of the delaminated area can vary from a couple of square centimetres to several square metres.

The actual delamination can occur between one and two weeks after the placing and finishing process is completed.

The delamination mechanism

Authoritative literature sources, such as the American Concrete Institute explain the causes of delamination as being due to the formation of a closed surface layer of paste that seals the concrete prior to the completion of bleeding. The surface layer is normally closed when it is steel trowelled. If this trowelling occurs too early, air and water in the underlying concrete may continue to rise until it becomes trapped beneath the layer of dense surface paste. The trapped water or air can create a plane of weakness that may cause the top to delaminate due to subsequent drying shrinkage or disturbance by traffic.

It is perceived that most cases of delamination are caused by trapping bleed water below the surface of the finished slab, brought about by early finishing. Another possible cause of delamination occurs when the finishing process is started too late in some areas. In these instances, the finisher may attempt move the paste around the surface to achieve the desired finish. In isolated spots where the surface has already set, this paste may simply sit on the surface rather than form a monolithic mass.

Examples of delamination

A localised “drummy” area which will eventually separate from the base concrete, due to wear and tear from warehouse traffic.

Examples of “drummy” areas distributed within areas of “crazed” surface cracking. The crazed areas, by contrast, can provide acceptable long-term surface durability. Note: The thickness of these surface delaminations ranges between 1 to 2mm.

Example of a delamination repair. Although the repair may have acceptable durability, surface discolouration due to repair work can be an issue with warehouse owners, and is an avoidable cost if good practice guidelines are followed.
Scope
The prevalence of delamination seems to have increased in recent years. The reasons behind the formation of a localized and weakened top surface are many and varied. This report endeavors to provide guidance to help reduce the risk of delamination occurring and covers such things as:
• materials;
• mix design;
• placing and finishing techniques;
• specification and supervision; and
• environmental factors.
This document identifies risk factors thought to be associated with delamination rather than identifying absolute causes, as these can be job-specific. The report is concerned with the management of these risk factors through the recommendations contained herein.
Although this technical report deals specifically with delamination, there are a variety of other surface defects associated with fresh concrete characteristics and the finishing process. Many of the causes identified as being implicated in the formation of the delamination phenomenon for slabs can also be implicated in other issues, such as:
• crazed cracking;
• plastic shrinkage cracking; and
• dusting.

Document layout
The intention of the report is to provide information and guidance to interested industry parties in order to minimise the incidence of delamination. Commentaries and/or Discussion points have been added to facilitate better understanding between industry parties.

Disclaimer
This publication is not intended to replace existing New Zealand Codes, but to be used in addition to these documents and to be accepted as part of the resource used to promote industry best practice. It is a compilation of information from several recognized sources, but is not intended to be used as a design or specification document, or as a tool to absolve responsibility for the various parties involved in the commercial process of designing, and contracting to supply, place and cure a slab-on-ground.

Materials
Concrete is a material that is sometimes misused and abused though over-familiarity and a perception that it is a relatively simple material. There have also been significant changes to the expectations people have of the desirable properties of fresh and hardened concrete. These expectations are often driven by economic considerations. Many of the lessons learnt in the past can also be overlooked or forgotten in the rush to embrace new technologies.
In this section, the constituent materials that make up concrete (cement, aggregate, admixtures) are discussed with reference to delamination. The following section, Mix Design and Production, explores how the combination of these materials (the mix design) may impact on the probability of a surface delaminating.

Cement
Modern concrete now, almost invariably, consists of the traditional components (cement and coarse and fine aggregates) together with admixtures and sometimes, mineral additives (used in conjunction with cement and often referred to as ‘blended cements’. The cement chemistry of the two Type GP Portland Cement brands manufactured in N.Z. are not perceived to contribute to the risk of delamination. However, admixtures can influence rates of bleeding and cement setting times. If a problem exists, compare the setting times of different cement/admixture type combinations with trial mixes.
New Zealand cement producers manufacture a GP grade cement product that targets a relatively high level of C3S in the cement. The C3S content drives the early age strength that is demanded by the industry. Additionally, an increase in the C2S content would require a higher firing temperature in the kiln, thus increasing production costs and more significantly, increasing the CO2 emissions per tonne of cement manufactured.
Specific issues associated with cement that may lead to a delamination problem include:
• Concrete which uses blended cements that display little or no bleed water and have extended setting may have an increased risk of premature finishing.
  Corrective measure: Be aware of the mix or environmental conditions, which might extend setting times or affect the amount of bleed water on the concrete surface. High Early Strength (H.E.) cement, silica fume, Ground Granulated Blast Furnace Slag (GGBS) based cement and Huntly flyash tend to retard setting times. For concrete with little or no bleed water, protect the surface from rapid drying by spraying an aliphatic alcohol film, known in the industry as ‘antivap’ (see also Environment, page 6).
• Mix designs with higher cement contents (for high strength floors) may produce a sticky or tacky mix,
which may have a tendency to crust prematurely, therefore increasing the risk of delamination (due to the finishing operations commencing too early) or plastic cracking.

Corrective measure: Protect concrete from the adverse effects of sun and wind. Consideration should be given to programming pours for early or late in the day to avoid temperature extremes. Ensure that the concrete has stiffened uniformly and not just at the surface.

Aggregates

The use of good quality, well-graded, clean aggregates is perceived to reduce the risk of delamination occurrence. This approach ensures that the total water added to the concrete mix is optimized to the absolute minimum, commensurate with optimum handling and placing requirements. Lower water content in the mix means that there is less chance of the mix segregating or settling, which in turn leads to the migration of water to the surface and then becoming trapped by early finishing operations.

Specific issues associated with aggregate type and quality that may lead to a delamination problem include:

- Poorly graded and/or dirty aggregates may create some risk through a higher void content, higher water demand and potential settlement as a result of higher overall water and void content.
  Corrective measures include: Always use well-graded coarse aggregates, without large gaps between size fractions (uniform gradation). This strategy does not apply to mixes designed for the vacuum dewatering process. For fine aggregates, monitor sand equivalent on a regular basis to assure compliance with NZS 3121:1986. Specification for water and aggregate for concrete.

- Aggregates which are too fine (maximum size 13mm or less) and sands which have an excessive amount of ‘fine fines’, ie, too much material passing 300 and 150 micron sieves, can produce concrete with excessive paste (sand/cement/water). This paste may come to the surface during placing and finishing. It is perceived that this increases the risk of delamination.
  Corrective measure: Avoid using aggregates smaller than 19mm (Max. size). Use mix designs with relatively low sand percentages. Monitor sand equivalent on a regular basis to assure compliance with NZS 3121:1986.

Admixtures

Admixtures are now used extensively in most concretes that are used for slabs on grade. The most commonly used admixtures are water reducers, retarders (for summer use) and air entrainers. Specifications derived from the USA strictly limit the use of air entraining admixtures to slabs prone to frost attack. There is evidence to suggest that this restriction minimizes the incidence of delamination failures in the USA. This view is contested by some associated with the concrete industry in New Zealand and is to be the subject of ongoing research driven by CCANZ.

Issues and corrective measures

Specific issues associated with admixtures that may lead to a delamination problem include:

- Chemical factors that retard concrete setting times, or impede the progress of bleed water to the surface can contribute to conditions that cause delaminations by making it appear that the concrete is ready to finish. Lower w/c ratios achieved with water reducers and superplasticisers will have less total free water and thus exhibit altered bleed and set characteristics.
  Corrective measures: Be aware of how the admixtures used in the mix will affect its bleed and set characteristics. Only use retarders where environmental conditions make it necessary.

- Certain admixtures that can create excessive air entrainment. Examples are retarders, water reducers and superplasticisers. It is a recommendation of this report, that air entrainment not be used in mixes 30MPa and above, where hard trowelling is required. High strength mixes will naturally have more paste, which provides for workability. Hence, there is no need for artificial air entrainment. Be aware that 25MPa (and below) mixes without air entrainment may make the mix too harsh for satisfactory placing and finishing to be achieved.
  Corrective measures: Admixture companies may overcome the problem of excessive air entrainment problem by adding de-foaming agents, or the mix design engineer may compensate by reducing the dose of air entraining agent. However, care in using these products is required, and air contents should be checked regularly both at the concrete batch plant and on-site, (unless risk of unintentional air entrainment is known to be negligible).

- High amounts of entrained air may reduce the bleed.
  Corrective measures: Take extra care when entrained air is necessary, eg, freezer/cold rooms etc.

- Admixtures do not in themselves cause delaminations but can sometimes deceive concrete placers into commencing finishing too soon, thereby trapping escaping air and bleed water below the surface.
  Corrective measures: Site-dosing and mixing of Mid-Range Water Reducers and High-Range Water Reducers (superplasticisers), are best avoided because the initial and final set times may vary from load to load. Avoid using retarders unless there are long traveling times between the concrete batch plant and the construction site.
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Mix design & production

Mix design (or the properties the mix design imparts to the concrete) and production processes can have a strong influence on the tendency for a concrete mix to be susceptible to the delamination phenomenon. Careful selection of well graded aggregates, admixtures, and the avoidance of over-sanded mixes and small aggregate sizes is believed to lower the risk of delamination occurring.

Specific issues associated with mix design and production processes that may lead to a delamination problem include:

- **The effect a combination of admixtures may have on air entrainment and bleed characteristics.**
  
  *Corrective measure:* Be aware of how the admixtures used in the mix will affect the air content, and on how this can affect bleed characteristics. Entrained air has a marked effect on bleeding. Small air bubbles, deliberately introduced into the mortar by an admixture have the effect of reducing water demand; and settlement is also reduced. When bleeding is substantially reduced, concrete can be prone to premature drying and stiffening effects. This is due to surface evaporation (when the rate of evaporation exceeds the bleed rate) whilst the body of concrete below the surface behaves normally, stiffening gradually due to chemical reaction of the cement. Bleeding and surface setting are therefore inter-related.

- **Highly sanded/small aggregate sizes have higher fine aggregate content.**
  
  *Corrective measure:* Avoid over-sanded mixes and small aggregate sizes, eg, designed for ease of wide area freehand screeding. Sand content should only be high enough to just provide a consistent, non-segregating mix, at target slumps.

- **Match mix design to the method of placing and to finishing equipment.**
  
  *Corrective measure:* (see Placing and Finishing)

- **Quality/consistency of concrete delivered to site.**
  
  *Corrective measure:* Ensure the concrete is thoroughly mixed, with close control over the workability/consistency of successive loads as these affect bleed and setting characteristics, particularly when more than one batching plant is used to supply the site. Avoid over-wet mixes.

Environment

The environment can have a significant affect on correct timing of the finishing operations of a slab. The timing issue for finishing operations to commence is recognised as the key to providing a durable and long lasting surface. Correct timing is critical to avoid delamination problems arising, particularly when bleed water evaporation is to be considered. Traditionally, the loss of sheen to the surface of the slab has been the accepted criteria to determine the commencement of the finishing operation – this is no longer necessarily correct.

The most common problem encountered by finishers is that the surface sheen has disappeared from the slab surface, possibly due to it ‘crusting’ while the concrete below the surface is still plastic and not yet sufficiently stiff to support a power float — referred to by some as the ‘jelly effect’. To avoid the possibility of premature finishing operations commencing, consider the use of a walk behind power float for the first pass.

Specific issues associated with climatic conditions that may lead to a delamination problem include:

- **Low relative humidity, high air temperatures with high concrete temperature, or any combination of these factors, may cause the rate of evaporation at the surface to be greater than the bleed rate and cause crusting of the surface.**
  
  *Corrective measures:* Graphs are available that indicate the relationship between wind speed, relative humidity and air temperature and how these factors influence the rate of evaporation. Some manufactures of aliphatic alcohol sprays suggest that a rate of surface evaporation higher than 0.5kg/m² to 1kg/m² per hour causes excessive drying stiffening of the surface (*New Zealand Guide to Concrete Construction*, 1999, fig 10.6). In the absence of bleed water on the surface of the slab, precautions should be taken immediately.

  - Protect the surface particularly from high winds by erecting windscreens and using aliphatic alcohol sprays, to minimise surface drying. It is important to follow the application instructions from the suppliers in order for these products to be effective.

- **Highly sanded/small aggregate sizes have higher fine aggregate content.**
  
  *Corrective measure:* Avoid over-sanded mixes and small aggregate sizes, eg, designed for ease of wide area freehand screeding. Sand content should only be high enough to just provide a consistent, non-segregating mix, at target slumps.

- **Match mix design to the method of placing and to finishing equipment.**
  
  *Corrective measure:* (see Placing and Finishing)

- **Quality/consistency of concrete delivered to site.**
  
  *Corrective measure:* Ensure the concrete is thoroughly mixed, with close control over the workability/consistency of successive loads as these affect bleed and setting characteristics, particularly when more than one batching plant is used to supply the site. Avoid over-wet mixes.

- **Direct sunlight increases surface temperature and contributes to stiffening of the surface.**
  
  *Corrective measure:* An internal environment is always preferred, so schedule slab placing to occur once the roof and walls of the building are erected when ever possible

- **Cold subgrades and vapour barriers contribute to differential setting between the slab surface and the underlying concrete.**
  
  *Corrective measure:* Be aware that the concrete below the surface will take longer to stiffen. Take precautions as above to prevent premature finishing and to protect the surface from drying out.
Placing

Correct placing techniques, used by experienced placing sub contractors, has the potential to overcome many of the problems seen in the industry today. The benefits of a pre-pour meeting cannot be overemphasized. At this meeting, all parties associated with the contract can meet to highlight any client expectations of the contractor and sub-contractors, and resolve any concrete supply and technical points. Issues such as placing/supply rates, the number of plants that may be batching concrete for the pour, commencement times etc can all be addressed, with problems subsequently avoided in the process.

Specific issues associated with placing that may lead to a delamination problem include:

- **Insufficient concrete placers/finishers relative to the size/area of the pour**
  
  *Corrective measure:* The engineer, main contractor and placer should establish the minimum labour resource to be present for the whole pour. The number of placers and the minimum equipment needed will be relative to the area of pour and in accordance with industry best practice or NZMCPA recommendations.

- **Lack of experience of concrete placers**
  
  *Corrective measure:* The engineer and main contractor should choose from a list of suitably qualified concrete placers with a good record of producing quality slabs and finishes for similar conditions – contact the NZMCPA.

- **Selecting the correct screeding process.**
  
  Several processes are available, namely free screeding techniques and those using vibrating screed or beam systems, on rails or with control by laser. The relationship between the screeding method and delamination is unclear though it is believed that methods and concrete mixes that create a thicker surface paste maybe more prone to delamination. The method of screeding will impact on the mix design:
  
  - **Free screeded floors** – require more labour to achieve flatness and levelness, so the concrete placer will prefer a more workable mix. Concrete placers preferences should be balanced with factors that increase paste, retard mix, or slow bleed (see Mix design, page 5)
  
  - **Floors placed with a vibrating screed** – can accommodate more coarse aggregate because using a mechanical screed as well as a poker vibrator can consolidate more effectively than using a poker vibrator on its own will do. Design and supply mixes appropriate to the placing and finishing techniques.
  
  - **Vibrating screed/beam vibrators** – can ensure a high degree of flatness and levelness before the finishing operations begin. Therefore there is less reliance on putting so much work into achieving this with ride-on machines. Use a vibrating screed/beam vibrator to achieve strict flatness tolerances rather than free-screeding and ride-on finishing.

The human element

Performance-based contracts, commonly specified, unless properly supervised by the contractor/specifier, leave the sub-contractor to ‘get on with the job’. This project management approach combined with lowest cost driven sub-contract price means that if a dispute arises over issues of materials/quality of work, the cause of the dispute is difficult to determine after the event.

Specific issues associated with quality of work that may lead to a delamination problem:

- **Concrete workers as subcontractors can influence the nature of the mix used.**
  
  *Corrective measure:* To control this, advise and provide training for all parties about the risks of higher sand contents and higher admixture doses.

- **Some concrete placers prefer very workable concrete, such as are found in some pump mixes, because they have a higher sand content and are often provided at a higher slump.**
  
  *Corrective measure:* Balance any request for highly workable mixes with the other risks involved (see Mix Design).

- **Higher slumps are achieved in part by using more superplasticiser or water reducer which may affect bleed rate and retardation, which in turn increase the likelihood of the placer misreading the timing to begin power-floating and trowelling**
  
  *Corrective measure:* (see Finishing)

- **Proper supervision of all aspects of placing and finishing is often missing.**
  
  *Corrective measure:* Adequate control/supervision of the pour and all sub-contract personnel by the main contractor. It is important that a nominated principal placer remain on site for the entire operation.
Finishing processes

As has already been stated, the simple rule has always been: Do not start finishing until the bleedwater sheen has gone from the surface and a footprint leaves an indentation no greater than 3-6mm in the surface. This depth will vary depending on whether a walk behind or ride-on power float is used. The window of finish-ability varies for each concrete mix and can even vary from batch to batch on the same project. Therefore, there is no strict rule as to when to begin the different finishing steps.

The concrete, the environment and the equipment influence the window of finishability.

Specific issues associated with the finishing process that may lead to a delamination problem include:

• The type of finishing equipment has an effect on closing the concrete surface.
  Corrective measure: Delay the floating and trowelling as long as possible to avoid closing the surface – this is the key to avoiding the formation of blisters and surface delamination.

• Be aware of the timing of the finishing operations in relation to the rise of air and water through the concrete.
  Corrective measure: There is a potential for delamination where the bleed takes longer than the placer expects and or the amount of bleed is masked by reduced water content as in the case of a superplasticised mix.

• Placers should have an evidential system to show they did not get onto slabs too early.
  Corrective measure: See Appendix 2 for suggested QA Systems to avoid this happening.

• Bull floating done incorrectly seals the surface to some extent.
  Corrective measure: Bull floating should be completed prior to any bleedwater appearing. Care should be taken to avoid overworking the surface. Too much paste can lead to sealing.

• Floating. Floats can be full circular pans or blades, and ride-on or walk-behind. When large areas of slab are to be finished this will often require the use of ride-on floats and trowels.
  Corrective measure: Be wary of pan floating paste depths greater than 6mm. These depths are likely to be caused by vibrating ‘soft’ mixes or shifting paste around to fill low spots.

The use of ride-on machines requires considerable experience from the operator. There needs to be a system for determining which sections of a floor are ready to finish. Ensure the boot test is carried out prior to finishing operations beginning on any slab. This requires a regular walk over the floor to determine how far along the pour a ride-on machine can operate.

If the floating operation is throwing paste wait until the surface has stiffened before resuming power floating. Alternatively, a walk behind machine may be used for the first pass of the finishing operation, followed by a ride-on machine.

• Trowelling. Trowelling is done at some time after floating with the delay to allow some stiffening of the surface.
  Corrective measure: The first pass is done with the blades as flat as possible. Additional trowelling may be used to improve the density, smoothness or wear resistance of the surface. Successive trowelling should be done with the blades tilted at an increasing angle to the surface. If blisters form behind the trowel then the angle of the trowel is too great. These blisters should be immediately pushed down with a magnesium float or a flat trowel and the angle of the blades reduced. Some time should be allowed between each pass to allow the water to evaporate that has been squeezed to the surface.

• Trowelling does seal the surface so must only occur when all bleeding has stopped.
  Corrective measure: Ensure the concrete is ready to finish. It is essential that the finishing process is to ‘hit the gap’. Working concrete that is ready to finish will result in reduced effort by the finisher to achieve the same end result.

• Machine trowelling an air entrained slab can also cause air to be squeezed out under the surface causing delamination.
  Corrective measure: For mixes 30 MPa and greater avoid air entrainment in the mix when machine trowelling.
Conclusions & recommendations

The issue of the delamination of the wearing surface of concrete slabs and their causes, is a complex and at times contentious topic. This document is the result of industry consultation and is to be viewed as a discussion document that represents the industry consensus view at the time of publishing. Thus, it is subject to ongoing industry review.

The conclusions and recommendations which follow are the key points from many that have been covered in this publication. Due to the at-times unpredictable nature of slab delamination failures, readers are urged to consider all of the points covered in this report rather than to rely on the main points listed. These are listed to give readers an overview of the main issues only and are not presented in any particular order of importance.

Air entrainment
All American literature references air content as a contributing factor in delamination. Because of this, it is sensible to suggest removing air from the mixes of 30MPa and above. It is practical to retain air entrainment in the lower strength mixes up to and including 25MPa as an aid to the cohesion of those mixes, to improve their workability and to reduce their water content.

Use of admixtures
Ensure that there are no unintended air entrainment affects when two or more admixtures are used in the same mix. Be prepared to use ‘antivap’ surface films to control the premature stiffening of the surface of the concrete.

Finishing operations
Finishing operations should be undertaken using experienced placers and finishers, who are familiar with recognised best trade practice. (Placers who are members of the NZMCPA are encouraged to keep up with latest trade practice.) Exercise caution in the decision to commence finishing operations when using pan and ride-on machines.

Concrete mix properties
Be aware that high cement content mixes and mixes containing mineral additives such as fly ash or silica fume will be sticky to handle and may crust at the surface, leading to premature finishing. Site observations indicate that high sand content mixes may increase the occurrence of delamination in slabs.

Site QA systems
Carry out on-site tests on the concrete to determine the bleed rate of the concrete. This will give a good indication of the correct time to commence machine finishing operations.
Consider obtaining sign-off from the main contractor, stating that all operations were undertaken in accordance with good trade practice, to ensure that the sub-contractor is not pressured into actions which may, at a later date, rebound on him.
Glossary

Admixture: A material other than water, aggregate and Portland Cement (including blended cement) that is used as an ingredient of concrete and is added to the batch in controlled amounts immediately before or during its mixing, (unless stated otherwise by the manufacturer), to produce some desired modification of the properties of concrete. Common admixtures used are: air-entraining water reducing (see below), set retarding, set accelerating, combinations and high range water reducing (superplasticiser).

Admixture, water reducing: A water reducer can be defined as an admixture that reduces the amount of mixing water in concrete for a given workability. It improves the properties of hardened concrete, and in particular, increases strength and durability.

Low range: The reduction in mixing water is a minimum of 5% (NZS, ASTM, CAN) at the manufacturer’s recommended dosages, usually 0.2-0.3% by weight of cement.

Mid range: The reduction in mixing water is about 10% at the manufacturer’s recommended dosages, usually 0.45-0.60% by weight of cement. Higher water reduction can be achieved with higher dosages (up to 1.0-1.2%).

High range (superplasticisers): The reduction in mixing water is about 15% (but can be up to 30%) at the manufacturer’s recommended dosages, usually 0.8-1.0% by weight of cement. High range water reducers (HRWRs) are used to produce concrete with a high workability for easy placement, and high strength concrete with normal workability but with lower water content. There are many HRWRs with different properties – selecting the most suitable for a specific application requires a thorough engineering process from mix design to lab trials to field tests.

Aggregate, coarse: An aggregate predominantly retained on a 4.75mm test sieve.

Aggregate, fine: An aggregate predominantly passing a 4.75mm test sieve (sand).

Air in concrete: There are two kinds: entrained air – fine spherical voids, of size less than 1mm; and entrapped air – coarse voids of irregular shape, size greater than 1mm, which should be dissipated through correct placement, vibration and consolidation of the freshly placed concrete.

Blistering: The formation of blisters in the concrete surface during trowelling can be the result of entrained air or excessive fines in the mix, of early trowelling or of an excessive angle of the trowel blades. If the air content is known to lie within an acceptable range, then blister formation is an immediate indication that the angle of the trowel blade is too great for the surface in that area at that particular time for the concrete and current job conditions.


Concrete placers: Concrete workers who receive the fresh concrete from barrow, skip, pump, chute or conveyor and place the concrete into position so that it is properly consolidated and the slab surface is left prepared to receive the finishing process. Consolidation is achieved using (pencil) vibrators and various forms of vibrating screed.

Concrete finishers: Concrete workers who apply the finishing process to the slab concrete surface. Work is begun after the bleed phase of the concrete setting process is complete. The finishing process consists of floating followed by trowelling, and may be executed using walk behind or ride-on power trowel machines.

GGBS: Ground granulated blastfurnace slag.

NZMCPA: New Zealand Master Concrete Placers Association.

Paste: A thick mortar of sand, cement and water, of creamy consistency.

SCMs: Supplementary cementitious materials such as pozzolans.
Appendix 1:  
Recommendations for adding/dosing superplasticers at the site

Due to the mix specific nature of admixture modified concrete mixes, site batching of admixtures should only be undertaken after preliminary site trials, undertaken by experienced operatives. In the following discussion it is assumed that the initial slump (before addition of superplasticiser) is within the tolerances specified by NZS 3109: Concrete Construction.

Consultants and or specifications requiring superplasticiser addition on site usually want the concrete to be a uniform slump after superplasticising. However, the concrete arriving on site will always vary in slump to some degree. The concrete is assumed to have been correctly batched but, for whatever reason, the batcher has not been able to correctly estimate the sand moisture content. A number of possibilities for dosing successive loads of concrete arise. These are:

- **Adding superplasticiser on site, varying the dose between loads:** A ‘dry’ load (i.e., drier than the specified initial slump) will have less total bleed water available. In an attempt to achieve the same final slump, it will be given a higher dose of superplasticiser than the wetter load placed next to it. This means that in comparison to the load next to it, the dry load may bleed less, bleed slower and set slower due to the increased dose. If finishing operations occur at the same time for both loads (almost inevitable with ride-on power floats), then one or both loads will be finished at the wrong time. This greatly increases the risk of surface defects such as delamination.

- **Add superplasticiser on site, using exactly the same dose of superplasticiser for each load:** To achieve the specified initial slump on site for dry loads, measured quantities of water are added, and recorded, to bring the load to the required slump. A measured quantity of superplasticiser is then added to achieve the increased slump for placing. This quantity should be the same for every load, regardless of their relative slumps. The added water is simply correcting the initial error in estimating the aggregate moisture contents, so better uniformity of workability, bleed and set characteristics should result.

For ‘wet’ loads, no additional water needs to be added, simply add an identical quantity of superplasticiser as for all the other loads. As long as the slump falls within the required tolerances, the strength and durability of the concrete should be acceptable.

- **Dosing with superplasticiser at the plant:** In many situations, adding superplasticiser at the plant can be a better option. In any case, this is the usual method of dosing; and it is certainly faster and more efficient than site dosing. Better quality and consistency of concrete can be expected because the same person is usually involved in batching, dosing and mixing every load. For central-mix plants in particular, the superplasticiser will receive better mixing through the concrete than if it is truck-mixed on site. In addition, every load will automatically receive the same dose of superplasticiser when the concrete is plant-dosed.

**A cautionary note for specifiers**
Specifiers should recognise that ready mix concrete suppliers work with only one brand of admixture on a plant-by-plant basis. As a consequence, the plant operators, being batcher, production testing technician and mix design engineer become very familiar with the characteristics of a particular brand of admixture and its performance when combined with local raw materials supply, and further, with other same brand admixtures within the same mix.

Concrete suppliers trial new admixtures extensively from lab to field trial and, for a given set of plant supply characteristics, will ask for adjustments to be made by admixture suppliers to get the desired characteristics whether this is for (excessive) air entrainment, setting time, etc. Thus a long history of performance is established.

**Reference**
For a discussion on admixtures for concrete see Chapter 5 in *New Zealand Guide to Concrete Construction* (1999), published by the Cement and Concrete Association of New Zealand.
**On-site tests to determine the ‘window of finishability’**

**Photographic records and main contractor sign-off**

Photographic documentation, or sign-off by the contractor’s supervisor stating that the bleed water sheen had gone and that the footprint test gave an indentation of no greater than:

- 3mm indentation for a ride-on-float, or
- 6mm indentation for a walk-behind-float,

is a method that can be used to acknowledge that best industry practice has been followed.

This approach is the simplest means that could be used on site. It does not attempt to quantify the condition of the slab (other than by measuring slab indentation) and depends upon the knowledge and co-operation of the parties involved for it to be successful as a QA tool.

Acceptance of this approach, and its contractual standing would need to be agreed by all parties involved in the contract before the work commences on site.

**Bleed water measurement**

This test is a method that attempts to duplicate the conditions of the freshly placed slab. The proposed method is a variation on the Suprenant and Malisch test (1998, p. 170).

The test procedure is suggested as follows:

Samples of the wet slab concrete are placed in buckets at a depth equal to the finished slab depth using consolidation similar to that achieved on the job. The buckets are then covered with a clear lid and slightly tilted in order to observe and to facilitate bleedwater collection. The clear cover provides protection for the sample against any prevailing environmental conditions. The accumulating bleedwater is drawn off at intervals until the operator is satisfied that bleed has effectively stopped and this test may be combined with an top of actual slab impression test as further verification that a particular area of the slab is ready for the finishing procedure to proceed.

As with all sampling procedures care is required to replicate sample selection and actual placing and concrete consolidation procedures. Where large slab pours are to be undertaken the concrete may be supplied from several plants and the placing and finishing can occur over a period of many hours. This means that the potential for variations in the consistency of delivered concrete is high. In these circumstances the number of samples would need to be increased accordingly.

This QA system would provide the concrete placers and suppliers with some protection if a slab delaminates. From the construction company or head contractor’s point of view getting the timing right for slab finishing operations is so important that they should require evidence that not only was the timing correct but that testing was continued throughout the duration of the concrete pour.
Appendix 3:
A discussion on the use of pan floats and ride-on floats

There is some disagreement within the industry on the correct use of pan and ride-on floats. The two most disputed issues are discussed below.

1. Do pan floats seal or not?
Pan floats and subsequent power trowelling impart more energy to the concrete surface at an earlier time than do traditional walk behind or ride-on machines equipped with clip-on float shoes. Pan floats form a dark layer of dense, almost air free, low w/c ratio paste at the surface of the slab. If the concrete below the finished top surface (to a depth of 5-10mm) is still somewhat plastic, any voids containing air or excess water are squeezed and elongated in the near surface zone before the concrete achieves final set.

The horizontal shearing action from the early use of pan floats causes near surface voids to come together. Under the influence of drying shrinkage and floor traffic, the elongated voids interconnect and become subsurface fractures that eventually delaminate.

An alternative view argues that the shearing action of pan floats breaks open the surface much better than do float blades. Pan floats actually reduce the amount of trapped bleedwater and air as long as they can break open the previously formed, densified top surface layer.

2. Ride-on machines exert less pressure on the slab, and thus encourage finishing operations to commence prematurely.
It must be emphasised that huge areas of floor slabs have been finished with ride-on machines without delamination of the top of the slab occurring. However, there is an argument that was reinforced by the investigations for Project Slab undertaken by CCANZ, that the use of ride-on machines are contributing to an increase in the incidence of delamination

Ride-on machines exert less pressure than that of the traditional boot test. This enables the finisher to be floating the slab earlier, which if the views expressed in issue 1 above is true, can then lead to delamination of the surface of the slab.

The contact area of a pan float is greater than that of clip-on or combination float blade. Therefore the finisher can apply less pressure to float the slab and thus tends to get on to the slab sooner, especially if the ambient conditions or the setting characteristics of the concrete indicate that its starting to set or the surface paste is crusting.

Walk behind and ride-on machines exert surface pressures of 2.5 to 6.5kPa when equipped with blades. Pan floats decrease the pressure to 1.1 to 2.9kPa. A concrete finisher, walking on the slab, can apply 20 to 40kPa depending on the individuals boot size and weight. Thus, it is much later in the window of finishability when a slab could support a finisher walking behind a power machine as opposed to when it could support the mass and the surface pressure of a ride-on machine with pan floats.

Users of ride-on machines state that the ride characteristics alter dramatically when the finisher encounters wetter concrete. Therefore, an experienced operator will not press on to finish areas that are not ready.

References

Scali, Mauro., & Suprenant, Bruce. (2000, December). 'Do Pan Floats cause blisters or delaminations?', Concrete Construction [World of Concrete], 45 (12): 51-54.

Surface delamination in slab on ground construction

A report based upon site experience & observation in the Auckland region