



Reologia em Concretos

“uma necessidade em um
mundo sustentável em
construção”

Dr. Rafael G. Pileggi



1

O que é
reologia ???

2

“Ciência que estuda a relação entre os esforços e a deformação da matéria”



http://st2.depositphotos.com/3369547/11630/v/950/depositphotos_116304520-stock-illustration-question-mark-icon-doubt-design.jpg

3

“como as coisas escoam”



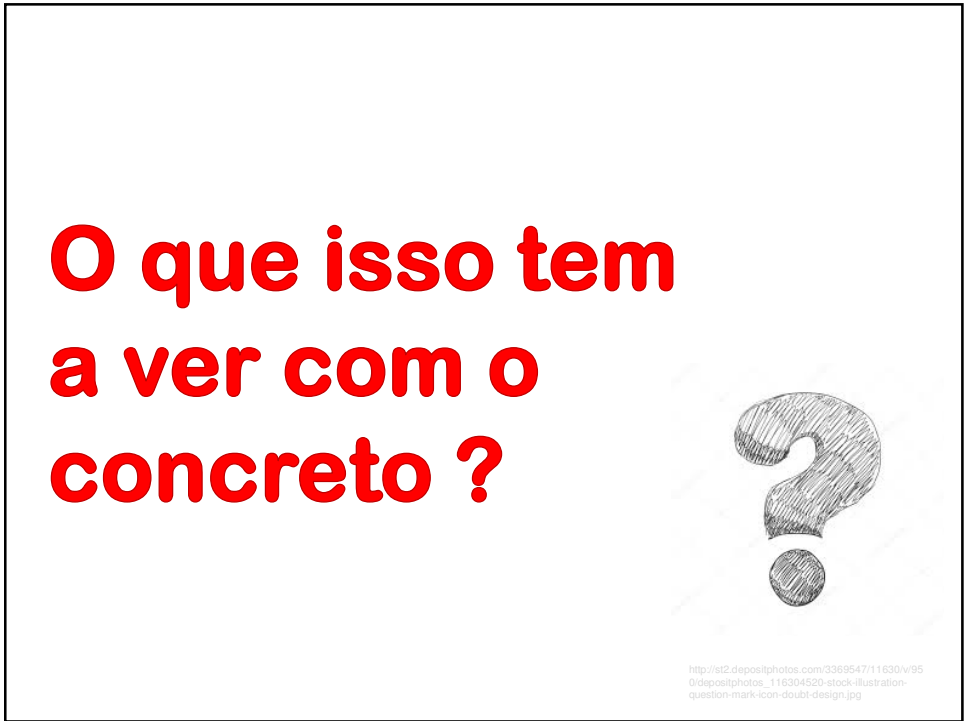
http://www.stc-clips.org/wp-content/uploads/2013/11/infused_honey.jpg

[https://www.azom.com/images/Article_1/images/ImageForArticle_13176\(1\).jpg](https://www.azom.com/images/Article_1/images/ImageForArticle_13176(1).jpg)

4



5



6



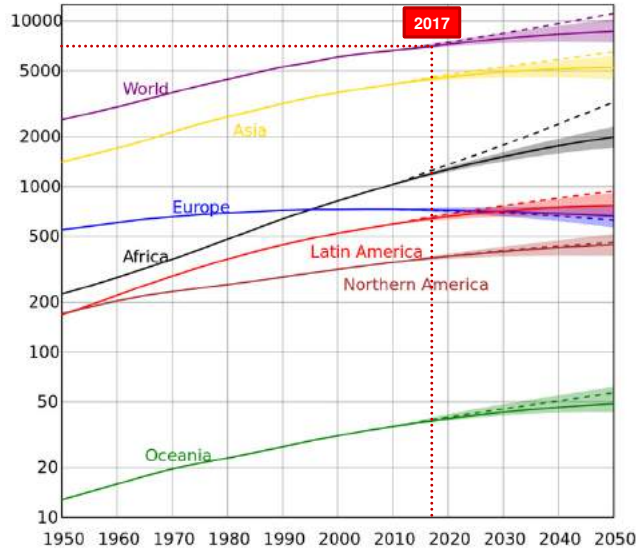
7



8

O Planeta Humano

Curva de crescimento populacional



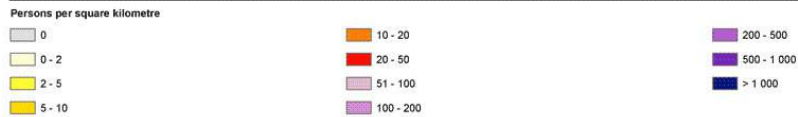
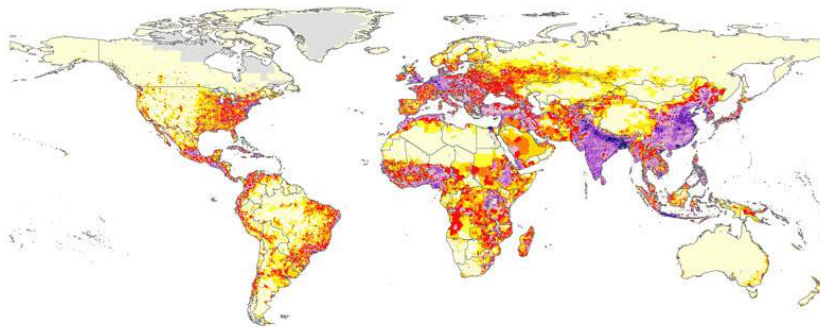
https://upload.wikimedia.org/wikipedia/commons/thumb/1/11/World_population_328UN9529.svg/1024px-World_population_328UN9529.svg.png

9

O Planeta Humano



Map 2.3: Global population density estimates, 2015
FGD Module 2: Population



Reference: FAO, 2005. "Mapping global urban and rural population distributions", by M. Salvatore, F. Pizzi, E. Ataman, B. Huddleston & M. Bikke. Environmental and Natural Resources Working Paper No. 24. Rome.
This map was printed from the DVD included in "Food Insecurity, Poverty and Environment Global GIS Database: DVD and Atlas for the Year 2007", Environmental and Natural Resources Working Paper No. 26. FAO, Rome 2006.
The geographic representations employed on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, or of its authorities, or concerning the delimitation of its boundaries. Please, see the full FAO disclaimer in the above documents.
© FAO & CIESIN.

<http://www.populationdata.net/images/cartes/articles/monde-densite-2015.jpg>

10

O Planeta Humano



Um mundo urbano em construção

http://www.nasa.gov/sites/default/files/images/712130main_8246931247_e603c09fb_o.jpg

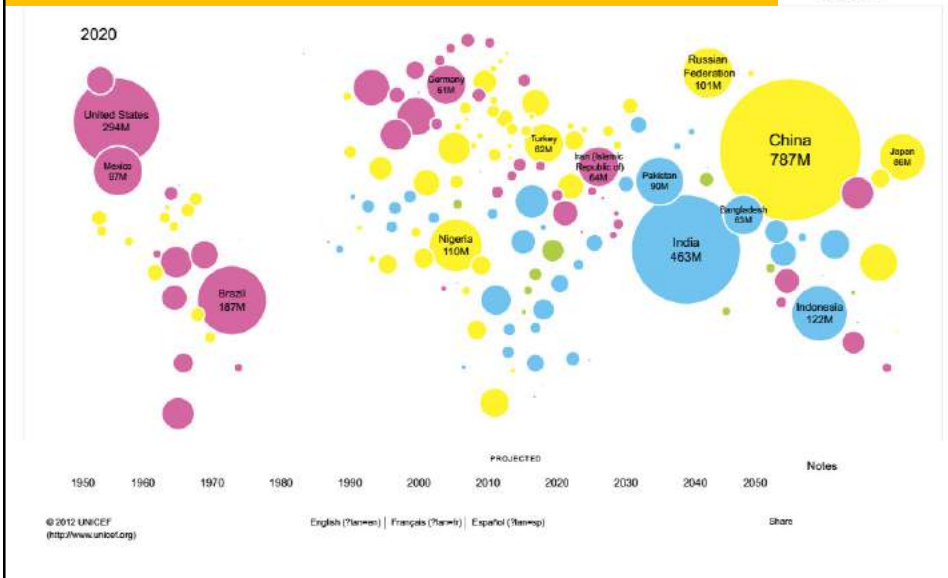
11

Um mundo urbano em construção



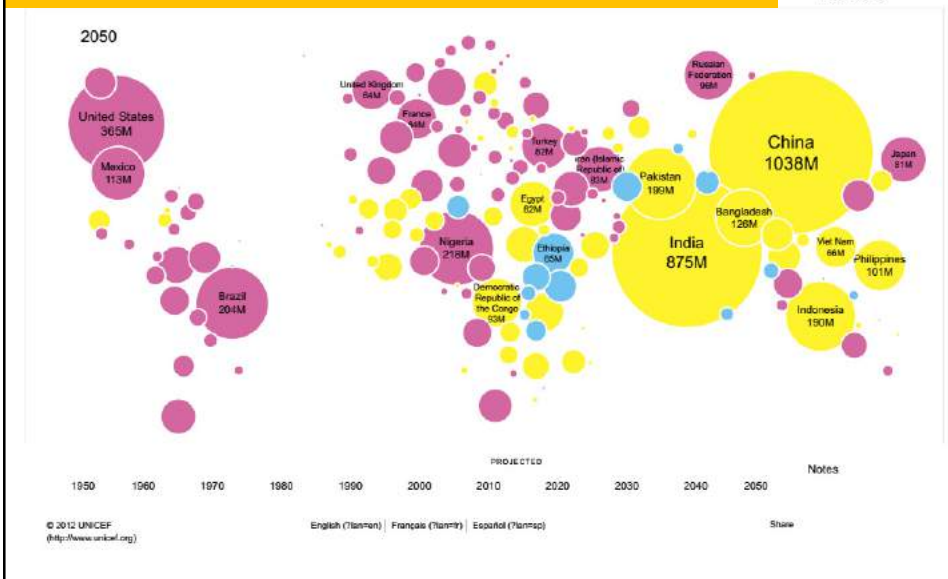
12

Um mundo urbano em construção



13

Um mundo urbano em construção



14

É necessário construir para toda a sociedade

https://u.realgeeks.media/tophmsfor-saleco/fort_collins_homes1.jpg

www.visualphotos.com

<http://www.chinadaily.com.cn/m/chengdu/images/attachment1/jpg/site1/20140817/286ed488c7b1155412a804.jpg>

<http://www.visualphotos.com/photo/2x7557196/aerial-view-of-worli-slum-bombay-mumbai-maharashtra-india.png>

15

É necessário construir mais e mais rapidamente

Tecnologia atual

World population (billions)

Category	2010	2030	2050
global	> 7	> 8	> 9
urban	< 3	> 5	> 7
world urban total	> 1	> 2	> 4
in slums	< 3	< 3	< 2
rural	- 1 in 3	- 1 in 2	- 2 in 1

people living in slums

http://4.bp.blogspot.com/_inl23kVAK/TPN23UpVknI/AAAAAAAAADA/ScORpsyksuU/s1600/Nova-brasilia+rio.jpg

<http://images.huffingtonpost.com/2010-02-26-Slumsurbanpopulationopt.jpg>

16

O Planeta Humano

Déficit habitacional brasileiro é maior que 6 milhões de moradias CBIC / IBGE

<http://www.cbicdados.com.br/menu/deficit-habitacional/deficit-habitacional-no-brasil>

17

Déficit em INFRAESTRUTURA é real

http://www.pmc.br/wp-content/uploads/DSC_0170.jpg



<http://www.revistaseguradorbrasil.com.br/wp-content/uploads/2017/03/Obras.jpg>

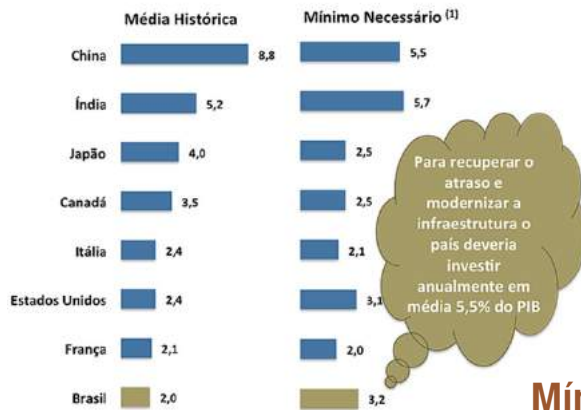
<http://fiosvivos.org.br/wp-content/uploads/2016/02/ferrovia-norte-sul-inaugura%C3%A7ao.jpg>

18

Déficit em INFRAESTRURA brasileiro

Investimentos em Infraestrutura

(em % do PIB)



Para recuperar o atraso e modernizar a infraestrutura o país deveria investir anualmente em média 5,5% do PIB

Mínimo R\$ 500 bilhões

(1) Valor necessário só para a manutenção da infraestrutura já existente.
Fonte: Neoway Criative, McKinsey e InterB.Consultoria.

<http://www.sindicosp.com.br/opportunidades-de-investimento-em-infraestrutura/>

https://static.wistatic.com/media/a444ad_c606d4c2df4a42dca34114e61d70424f?mv2.png/v1/crop/x_10_y_0_w_1113_h_1019/fill/w_533_h_488_al_c_usm_0_66_1_00_01/a444ad_c606d4c2df4a42dca34114e61d70424f?mv2.png

19

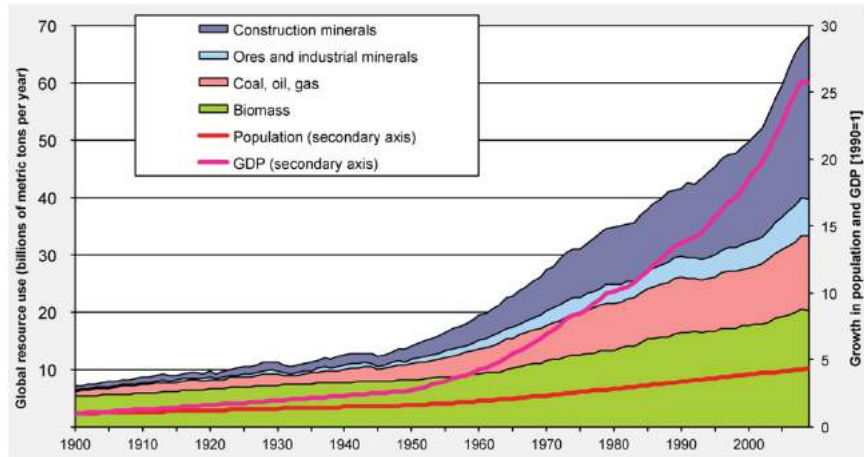
O *“Worldwide Fund for Nature”* calcula que, em **2050**, a humanidade precisará **100%** a mais de biocapacidade total do planeta (silvicultura, pesca, terras agrícolas).

Quais são as perspectivas de encontrar outro planeta para os seres humanos explorarem em **2050**?

<http://www.abc.net.au/radionational/image/4984820-3x2-700x467.jpg>

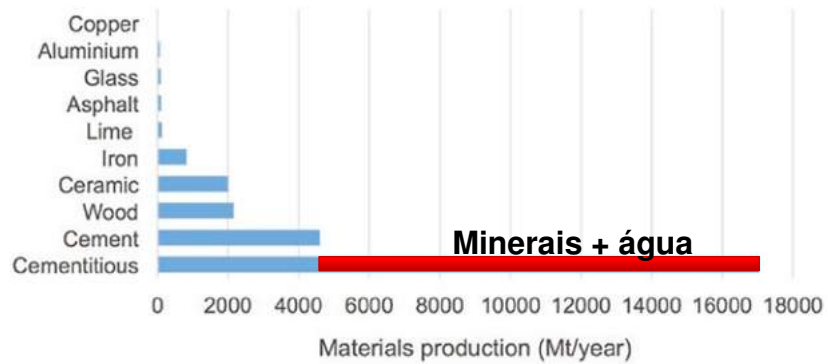
20

Consumption of natural resources



21

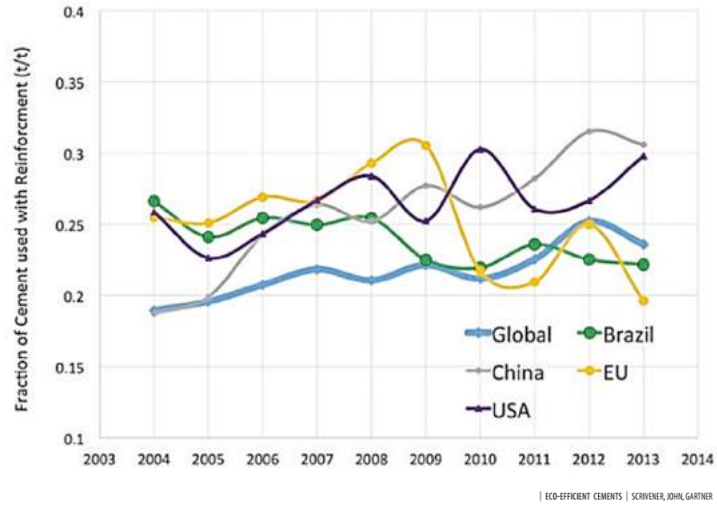
Consumo Estimado de Materiais Comuns



| ECO-EFFICIENT CEMENTS | SCRIVENER, JOHN, GARTNER

22

Cimento em concreto reforçado



23

Demanda Crescente

Eco-efficient cements: Potential, economically viable solutions for a low-CO₂ cement-based materials industry

Karen L. Schvener, Vandolay M. John, Ellis M. Gartner

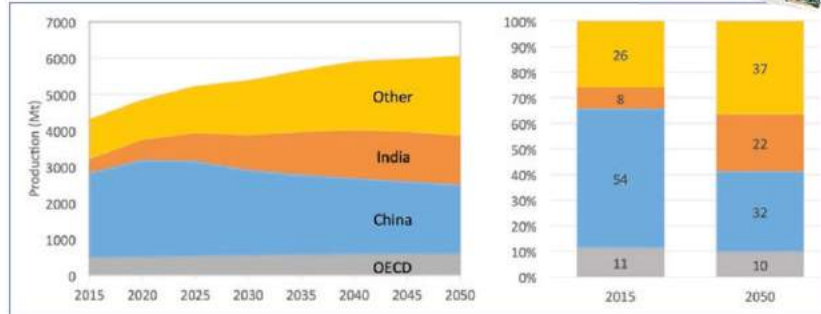
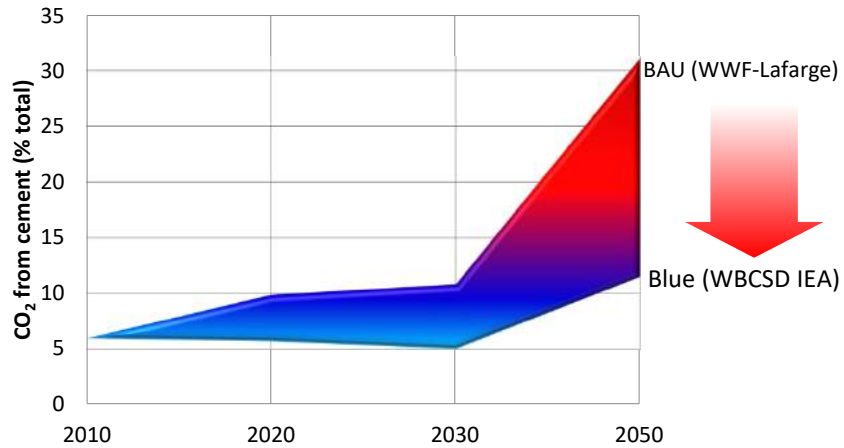


Figure 3. IEA high-consumption scenario for future cement consumption by region [13]. The lower section shows the evolution of cement production distribution among different regions.

24

Projeção de Emissões CO₂



WBCSD & IEA Cement Technology Roadmap 2009
A blueprint for a climate friendly cement industry. WWF-Lafarge 2008

25

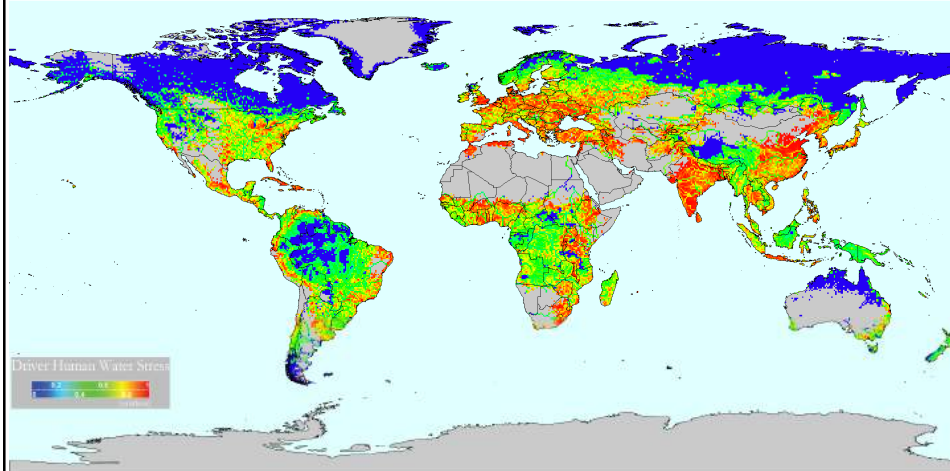


<https://4.bp.blogspot.com/-Cxye0kNIM/Vxhc4k38bsI/AAAAAAAAAAQo/elthF5U5Vd4dS3op2Mr2AK1ETcSYjgCLcB/s1600/imgin5.png>

Misturada com água

26

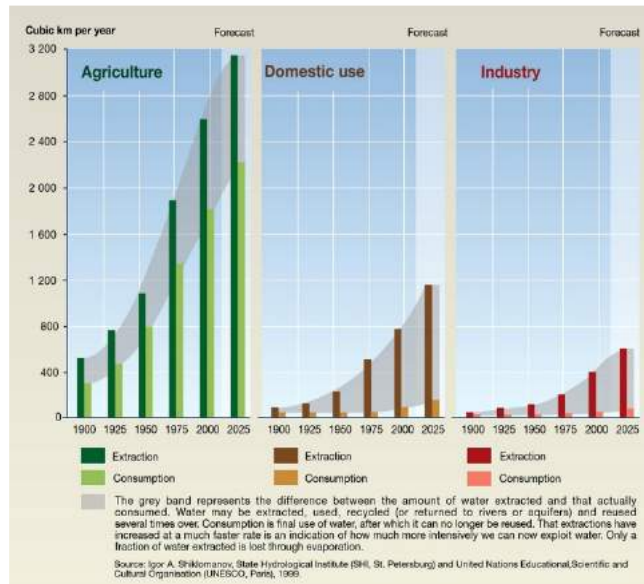
Stress hídrico



http://riverthreat.net/data/image_files/Human_Water_Stress.png

27

Competição pela água



http://www.unep.org/dewa/vitalwater/jpg/0211-withdrawcons-sector-EN.jpg

28

É necessário construir melhor



<http://frsbar.es/wp-content/uploads/2014/05/frsbar-eficiencia-energetica-slide2.jpg>

Desempenho / Análise ciclo de vida

31

**Em um planeta finito,
sustentabilidade não é
uma opção, mas uma
questão de como
alcançá-la**

www.abc.net.au/radionational/image/4964829-342-700x467.jpg

32

Emprego x condição de trabalho

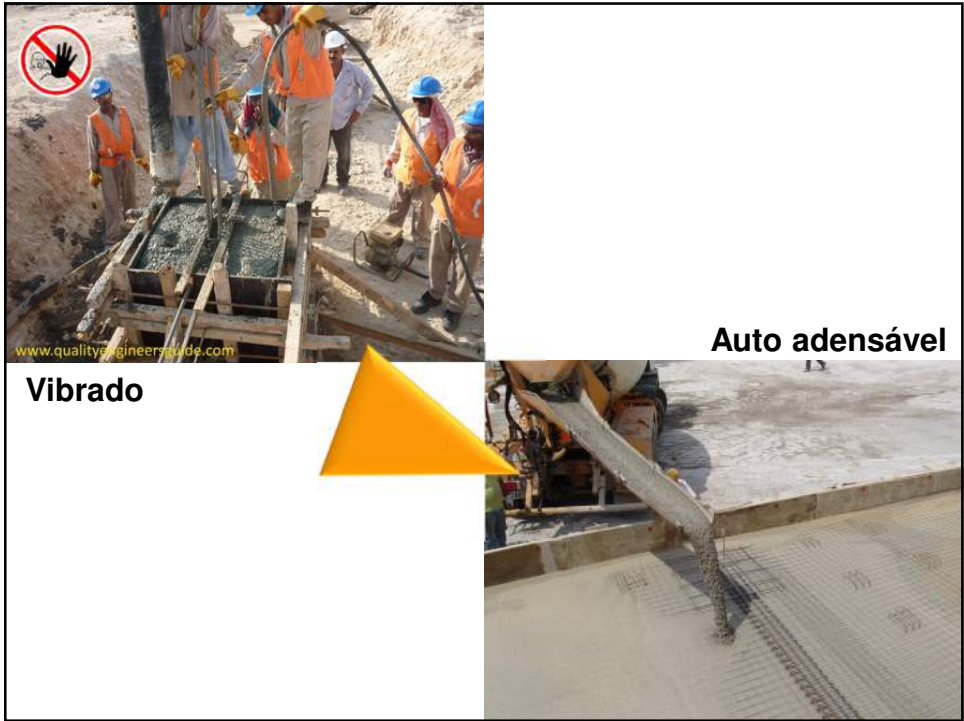


Aceitável??

33



34



35



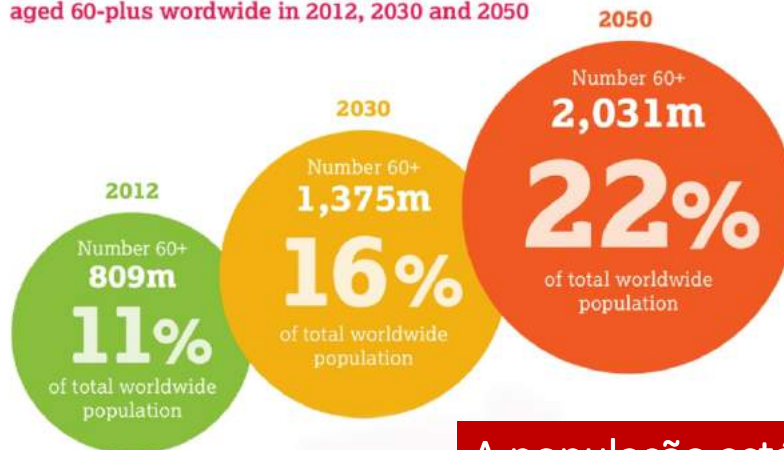
36

Shotcrete



37

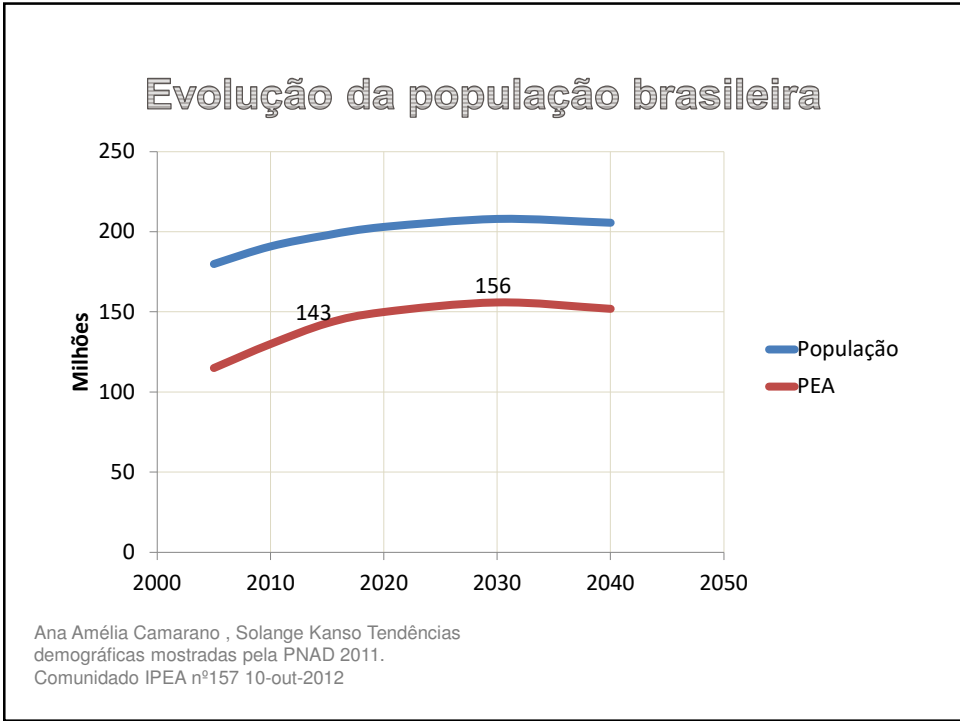
Figure 1: Number and proportion of people aged 60-plus worldwide in 2012, 2030 and 2050



A população está envelhecendo

http://timebanks.org/wp-content/uploads/2015/06/image_adapt_990_high_gl_obal_summary_092713.13806533132661.jpg

38



39



40

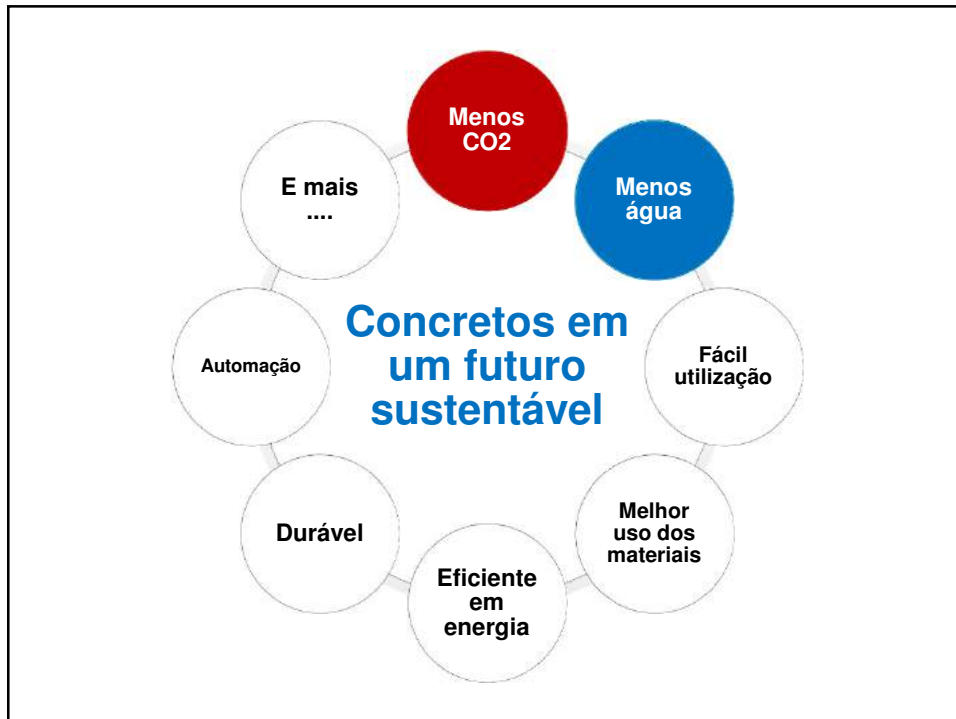
Automação na Construção



<https://cnet4.cbsistatic.com/hub/i/2015/08/19/da869c9c-338c-4931-9db9-3593c140018b/4e4dfcf40adfc749808d6be7c963c70/pic10-branch-robot-arm.jpg>

+ Velocidade
+ Valorização do ser humano
- Desperdício

41



42



Como caracterização
reológica se relaciona com a
sustentabilidade dos
materiais cimentícios?

43

CONCEITO DE "EFICIÊNCIA"

Quanto **menor** for o teor
volumétrico de **água**, menos
poros e melhores as
propriedades no estado
endurecido

44

PROBLEMA

Quanto menor for o teor de água, mais difícil a **Trabalhabilidade**

45

Trabalhabilidade

- American Concrete Institute (ACI)
 - facilidade e homogeneidade do material na mistura, lançamento, adensamento e acabamento
- Association of Concrete Engineers (Japão)
 - facilidade com a qual o material pode ser misturado, lançado e adensado devido à sua consistência
 - homogeneidade do concreto e grau de resistência à separação de materiais

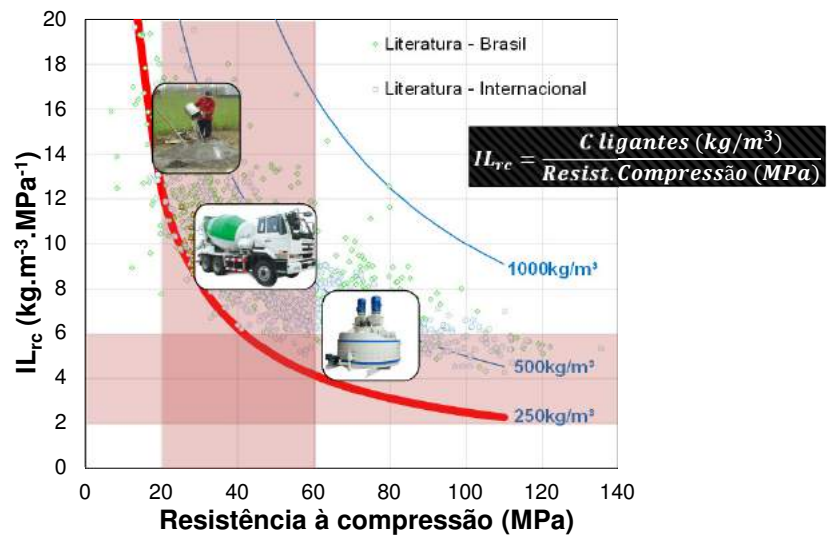
46

MOMENTOS REOLÓGICOS



47

Eficiência no uso de **ligantes** (*reativos industrializados*)



48



+ ÁGUA
trabalhabilidade
=
+ Cimento
=
> Impacto Ambiental

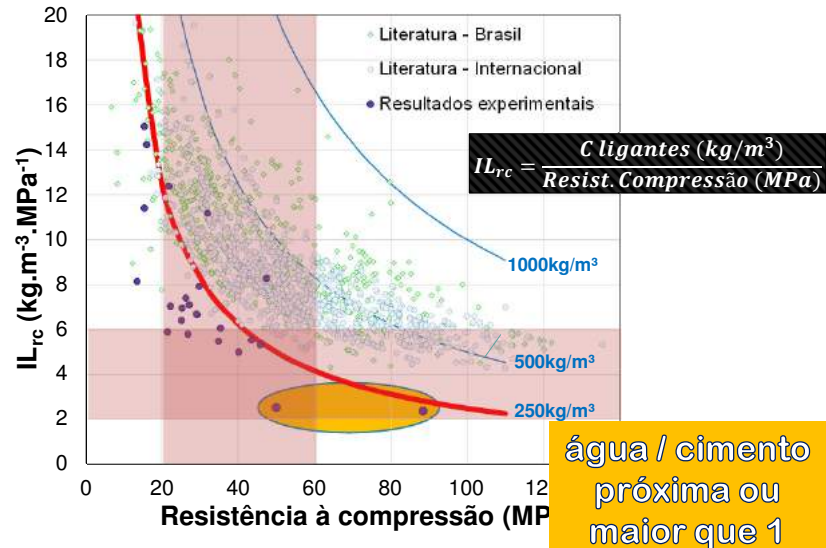
49



- ÁGUA
trabalhabilidade
=
-- Cimento
=
< Impacto Ambiental

50

Eficiência no uso de **ligantes** (*reativos industrializados*)



51

PORTANTO

Domínio do comportamento reológico nos diversos **momentos reológicos** (conceito inovador) é caminho crítico para a tecnologia

52

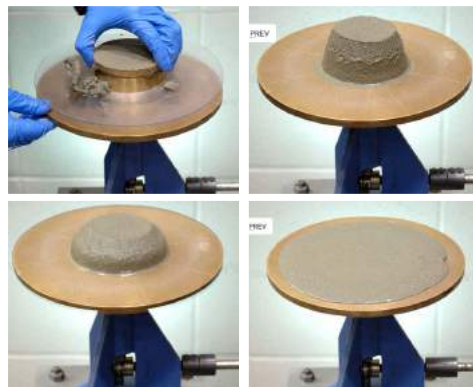
Como medir TRABALHABILIDADE?

53

Ensaio Monoponto



Abatimento
tronco de cone

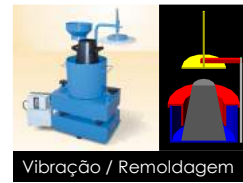


Flow table
(mesa de consistência)

<http://www.testingequipment.com/images/product/1484380100flowtable.jpg>

54

Ensaio Monoponto



55

Porque ensaios
Monoponto
NÃO são
suficientes ?

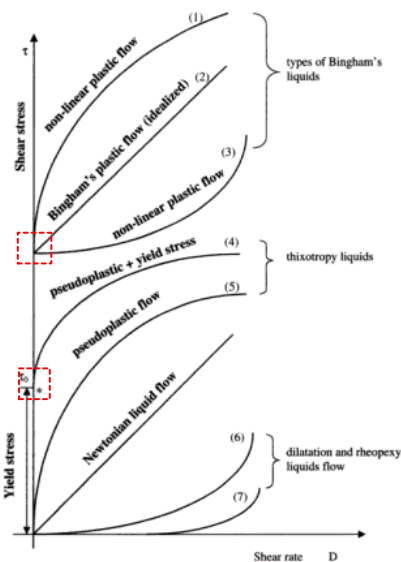
56

CONCRETOS NÃO SÃO FLUIDOS NEWTONIANOS

57

≠ tipos de comportamento reológico

Tensão de escoamento



http://soft-matter.seas.harvard.edu/images/thumb/e/e1/Relationship_bt看_stress_and_rate.jpg/325px-Relationship_bt看_stress_and_rate.jpg.png

58

Ensaaios Multiponto

Reômetros Concretos e Argamassas



Two-Point rheometer



IBB rheometer



Rheocad

.....



ConTec Rheometer



BTRHEOM

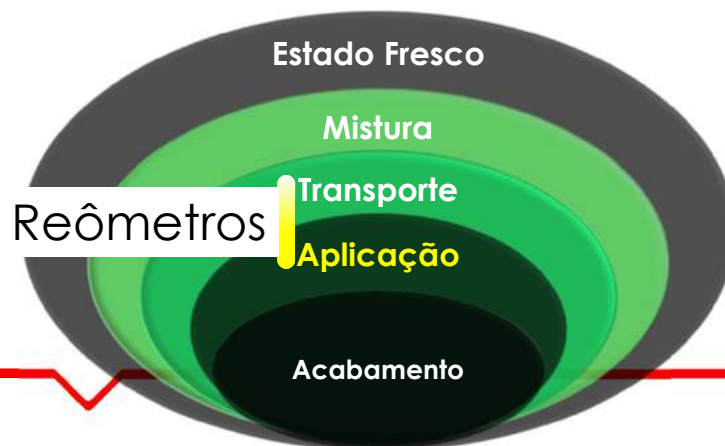


Viskomat NT

.....

59

MOMENTOS REOLÓGICOS



Avaliação incompleta

60

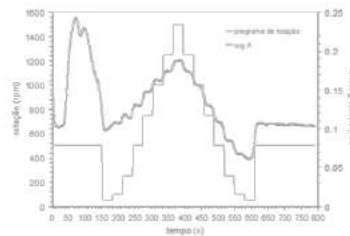
MOMENTOS REOLÓGICOS



61

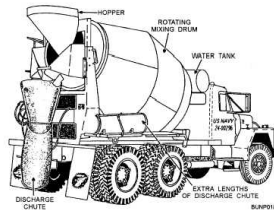
Reômetros misturadores multifuncionais

INOVAÇÃO EM REOMETRIA



62

Misturadores



63

INOVAÇÃO

Testes

Mistura
Ciclos cisalhamento
Longa duração
Planetário - central

Suspensões

- ✓ *Pasta – argamassa – concreto*
- ✓ *Fluidez elevada - baixa*
- ✓ *Materiais secos*
- ✓ *Suspensões fibrosas*
- ✓ *....*



PHEO

Patented
BR 10 2014 015604
6

64

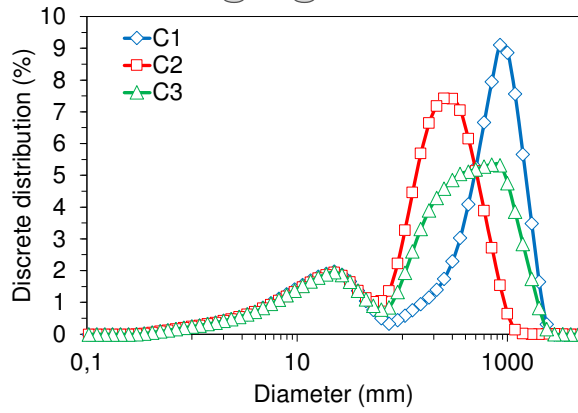
Resultados de
reometria de
mistura
exemplos

65

**≠ distribuição
granulométrica dos
agregados
≠ incorporador de ar**

66

≠ distribuição granulométrica dos agregados



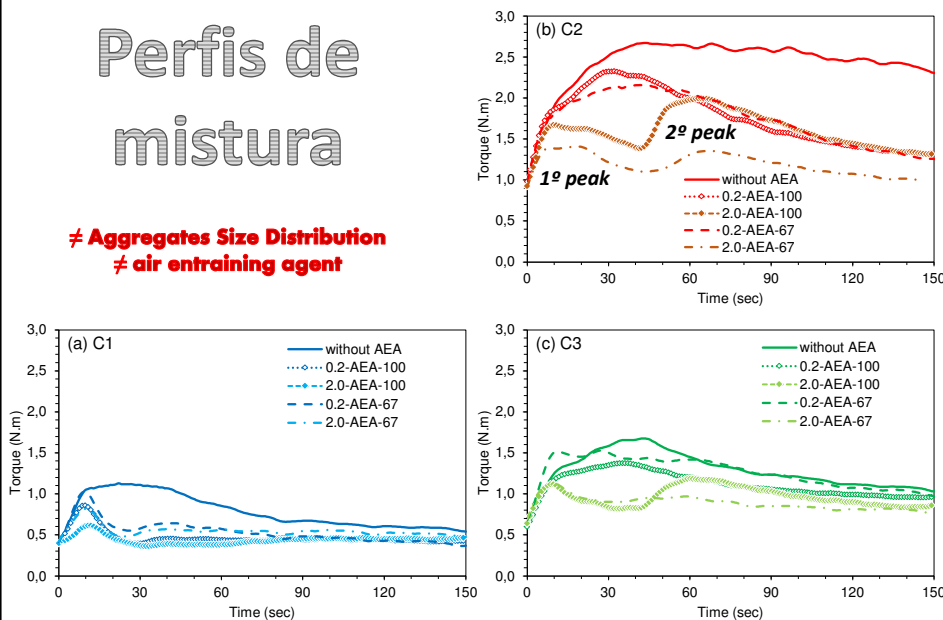
C1 – 75% of Medium sand + 25% of cement
 C2 – 75% of Fine sand + 25% of cement
 C3 – 50% of Fine sand + 25% of Medium sand + 25% of cement

≠ Aggregates Size Distribution
≠ air entraining agent

67

Perfis de mistura

≠ Aggregates Size Distribution
≠ air entraining agent



68

Auto-adsensável

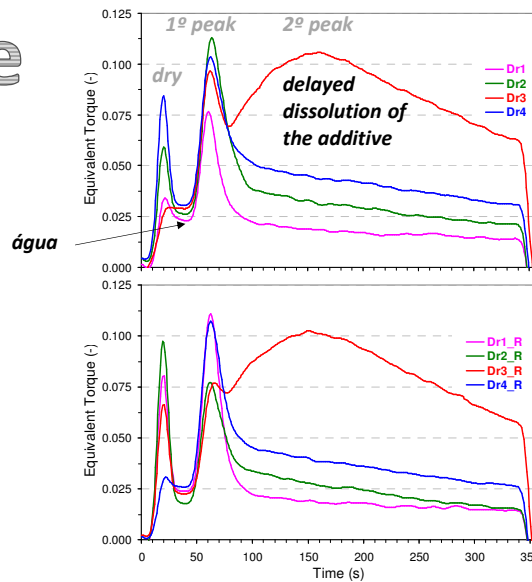
≠

Aditivos



69

Perfis de mistura

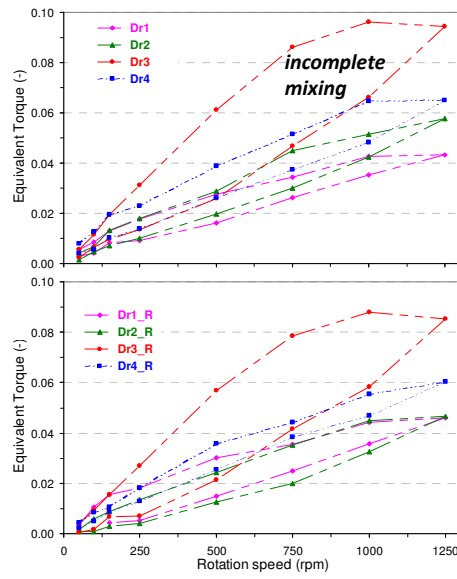


Self-leveling
≠
Admixtures

70

Perfis de cisalhamento

**Self-leveling
≠
Admixtures**

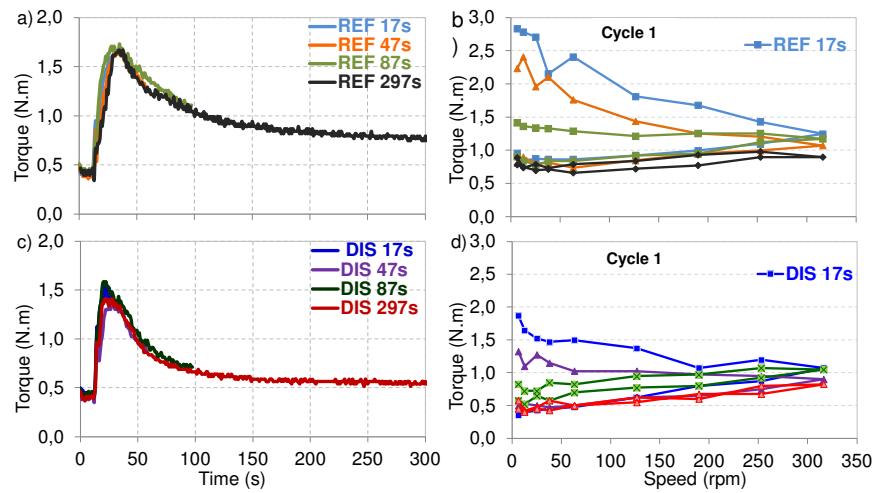


71

**≠
Tempo de mistura**

72

Tempo de mistura

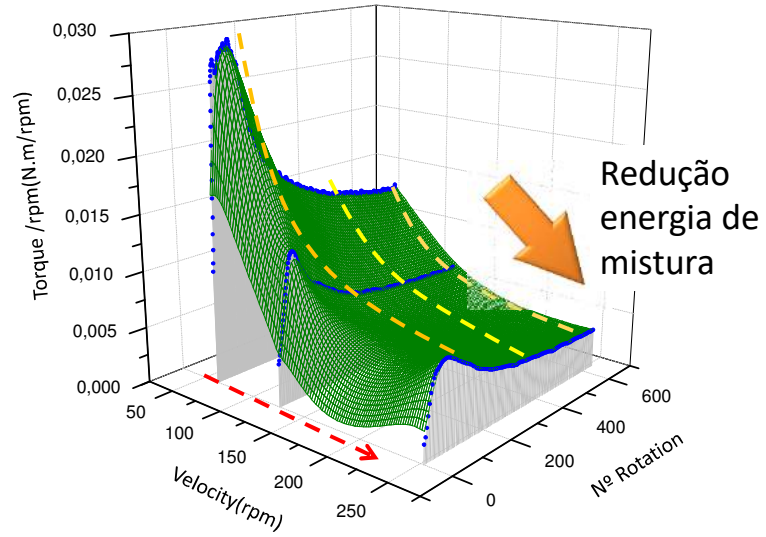


73

≠
Velocidade mistura

74

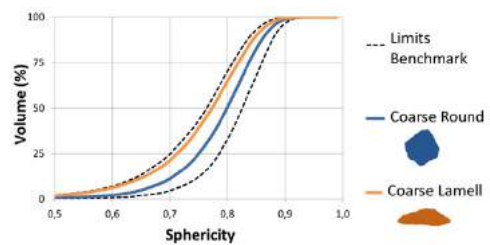
Velocidade de rotação



75

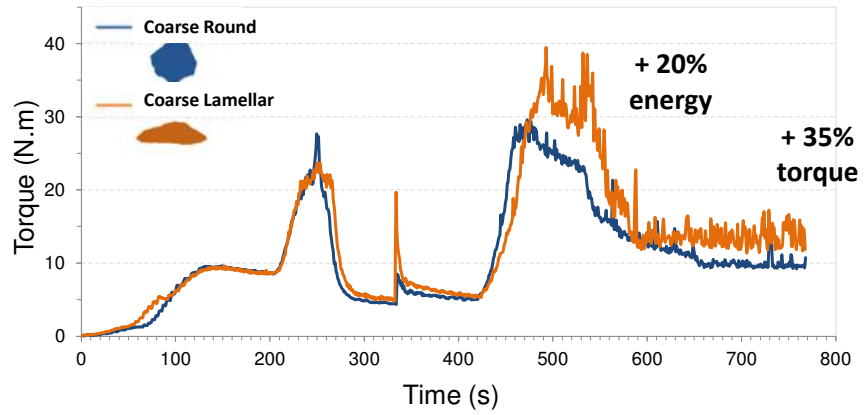
≠

Morfologia agregado



76

≠ Morfologia agregado



77

Concreto na usina

78

Caracterização reológica na concreteira



79

Caracterização reológica na concreteira



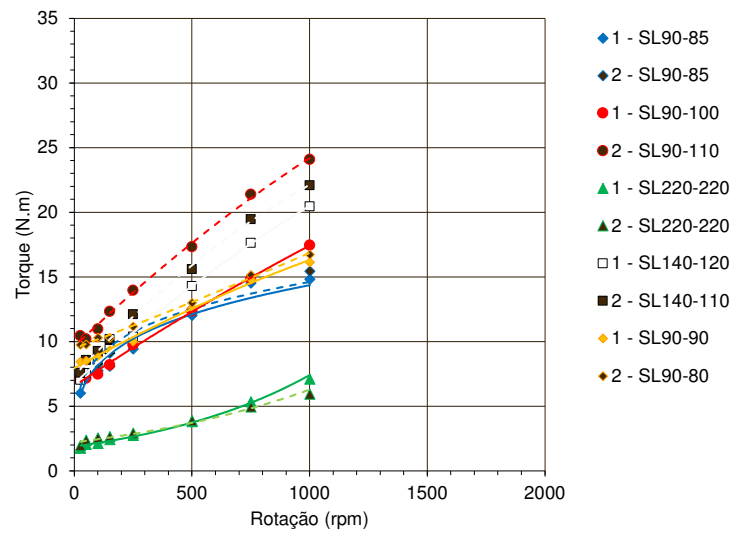
80

Caracterização reológica na concreteira



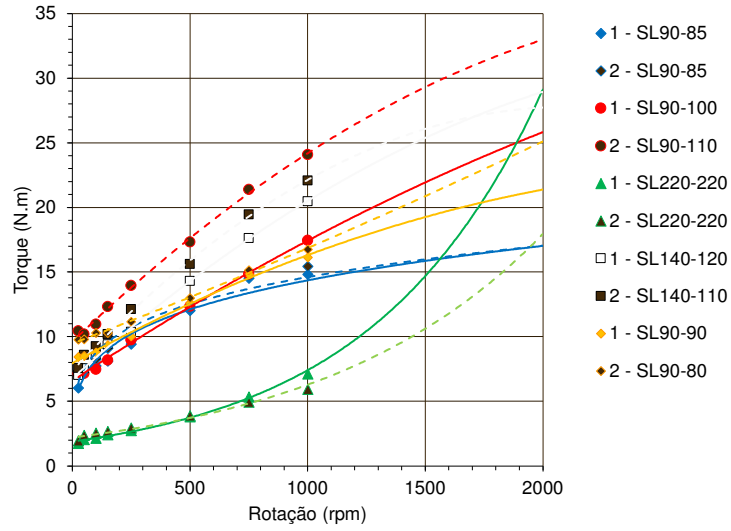
81

Caracterização reológica na concreteira



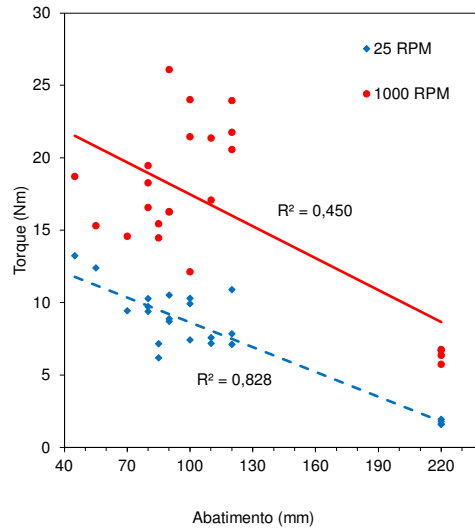
82

Caracterização reológica na concreteira



83

Caracterização reológica na concreteira



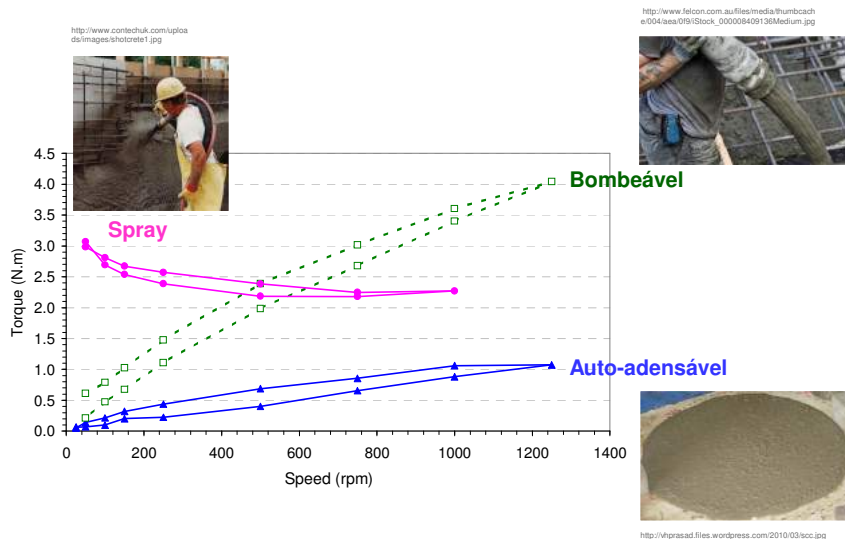
84

Caracterização reológica na concreteira

O mundo das altas taxas de cisalhamento
(bombeamento, projeção, injeção...) é invisível ao controle

85

Classes reológicas



86

Acabamento superficial

REÔMETROS

*não avaliam
espalhamento
sobre superfícies*

87

Acabamento superfície concreto



http://blog.exilva.com/hs-fs/hubfs/Exilva_Blog/Blog_pictures/2016-07/workers-807577_1280-240751-edited.jpg?t=1502093359585&width=625&name=workers-807577_1280-240751-edited.jpg

88

Acabamento superfície concreto



http://www.milestonelp.com/_images/toppers/Concrete-Paving.jpg

89

SQUEEZE FLOW



90

SQUEEZE FLOW

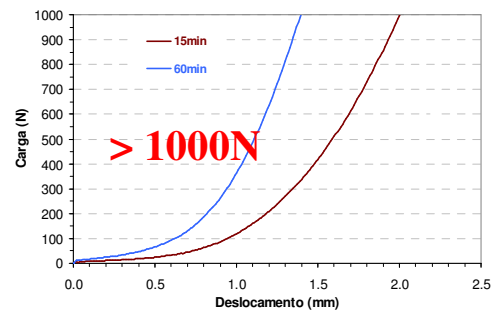


91

SQUEEZE FLOW

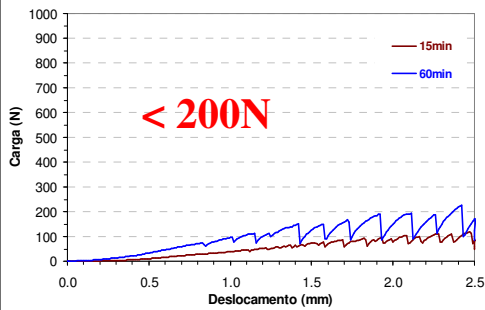


flow > 340mm



92

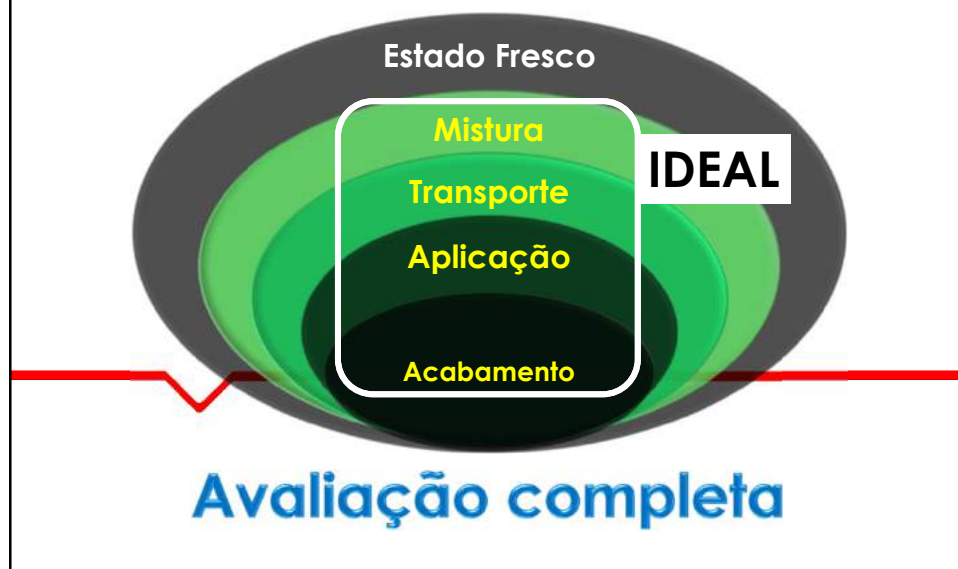
SQUEEZE FLOW



flow = 279mm

93

MOMENTOS REOLÓGICOS



94

**Exemplo:
concreto bombeável**

**▶ ADIÇÃO TARDIA DE
SUPERPLASTIFICANTE EM
CONCRETOS AUTO-ADENSÁVEIS ◀**

95

**Superplastificante
adicionado 15, 30, 60 min
depois da mistura**

96

ADITIVO APLICADO NA OBRA

**Correções (água / *aditivo*) decididas
pelo motorista baseando-se na fluidez**

97

**Fluidez é
suficiente??**

98

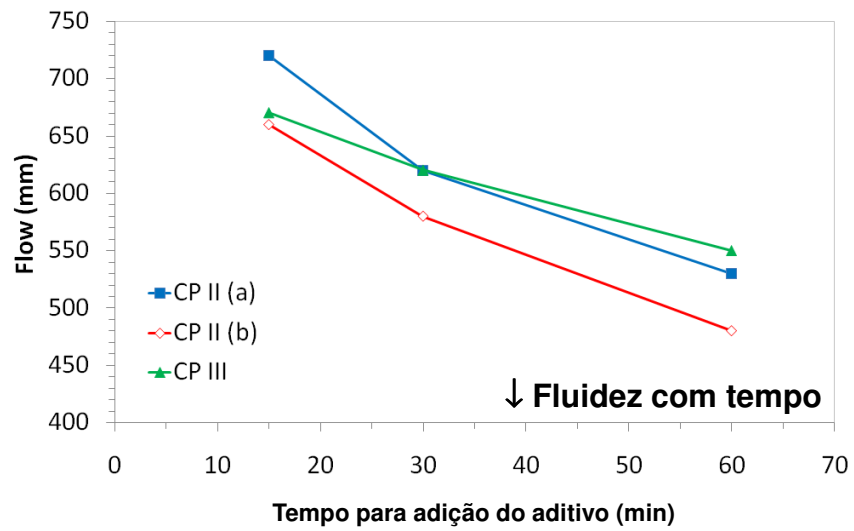
3 cimentos

CPII (a) – escória AF (6-34%)

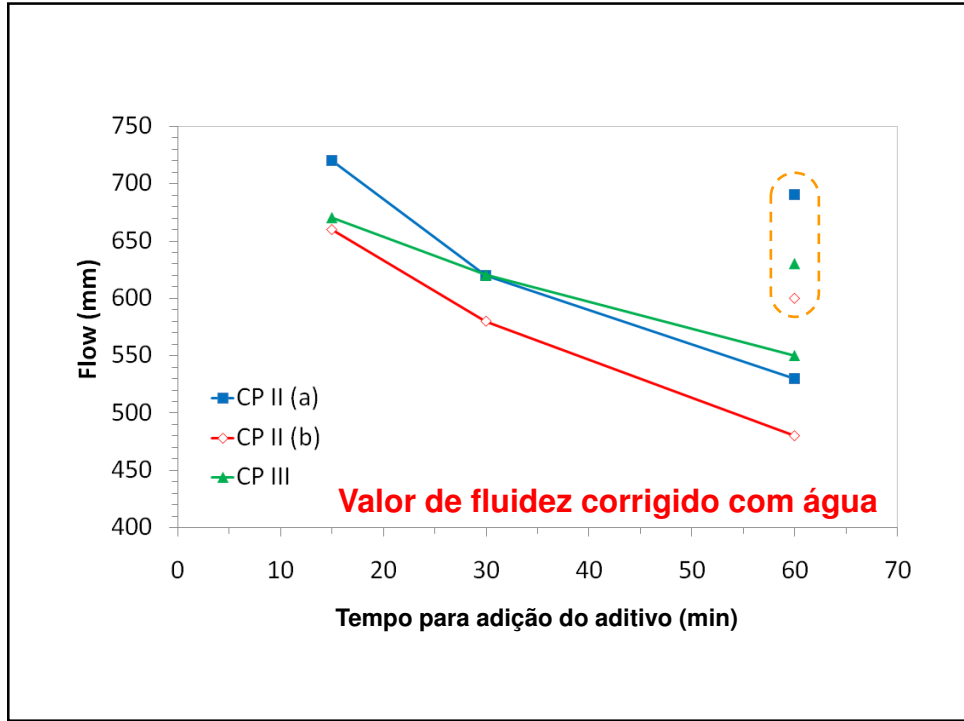
CPII (b) – escória AF (6-34%)

CPIII – escória AF (65-70%)

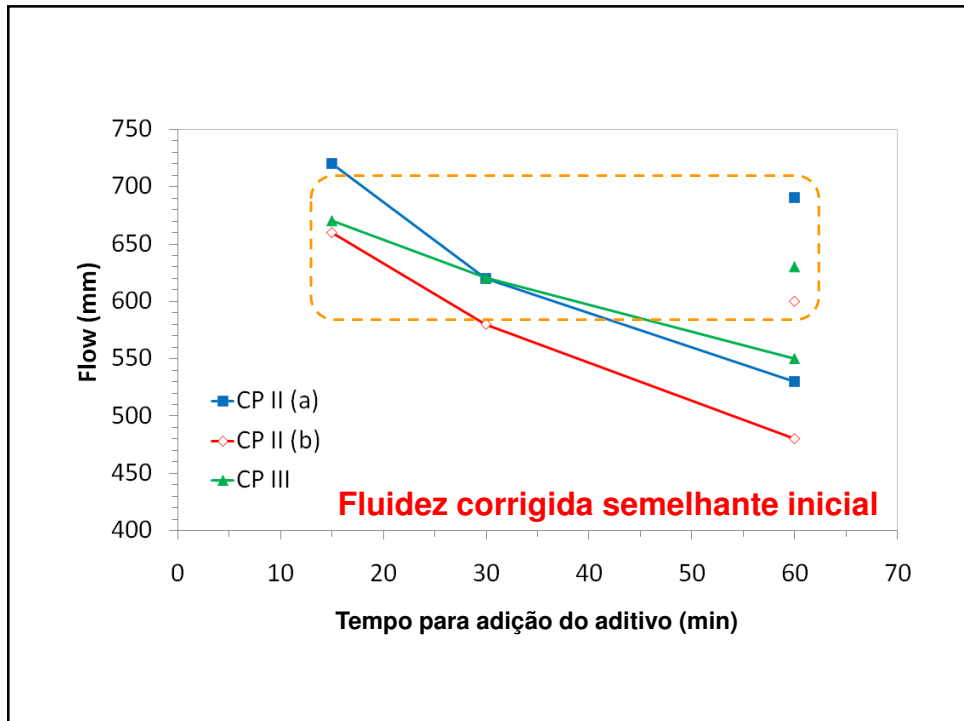
99



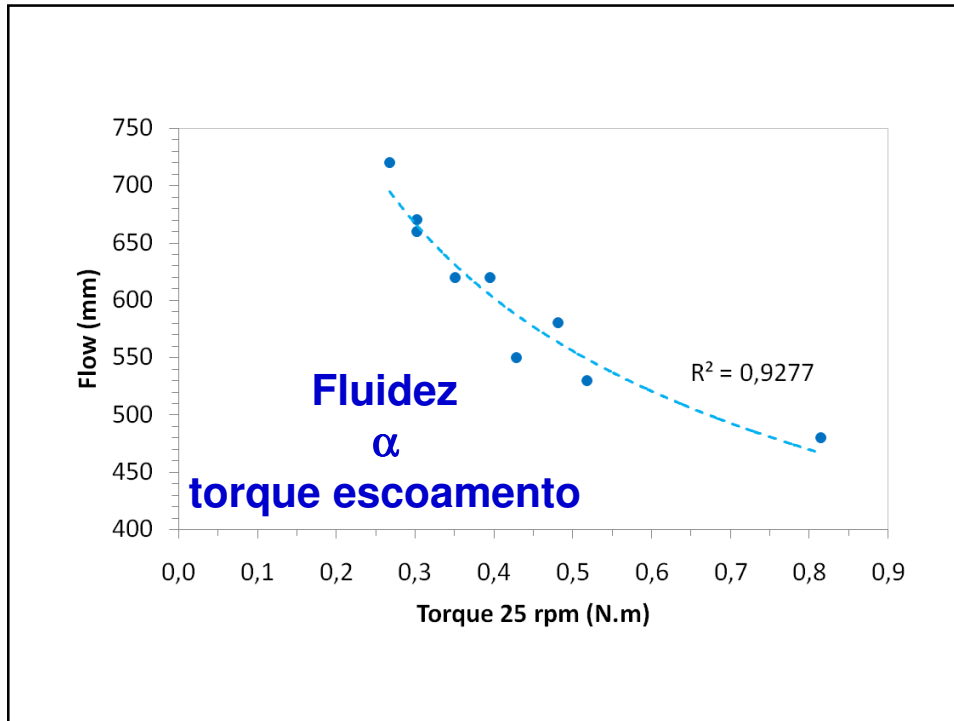
100



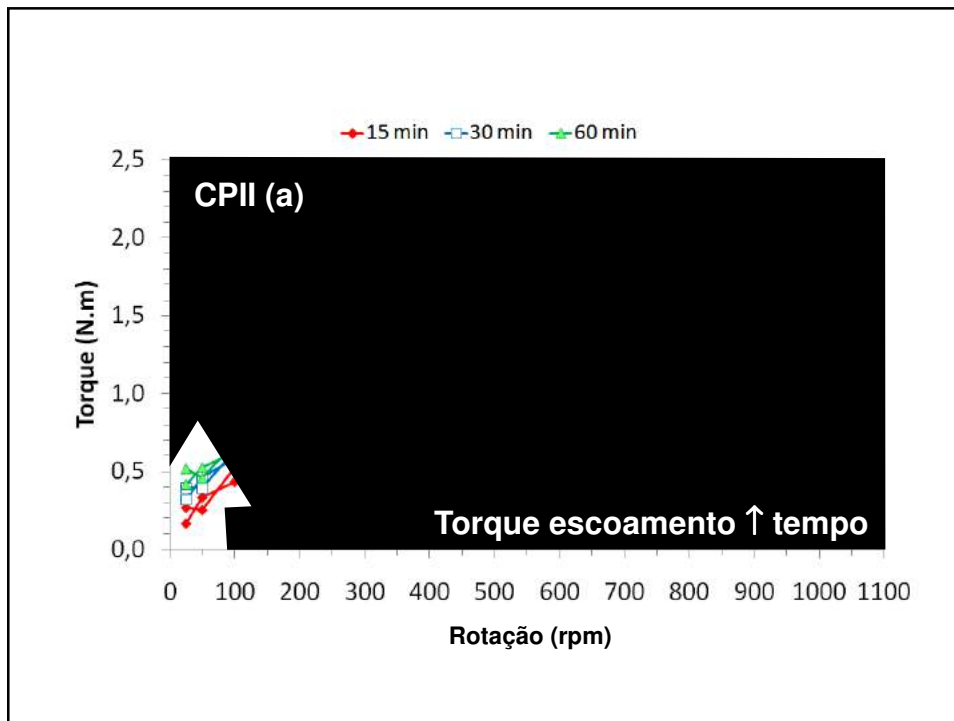
101



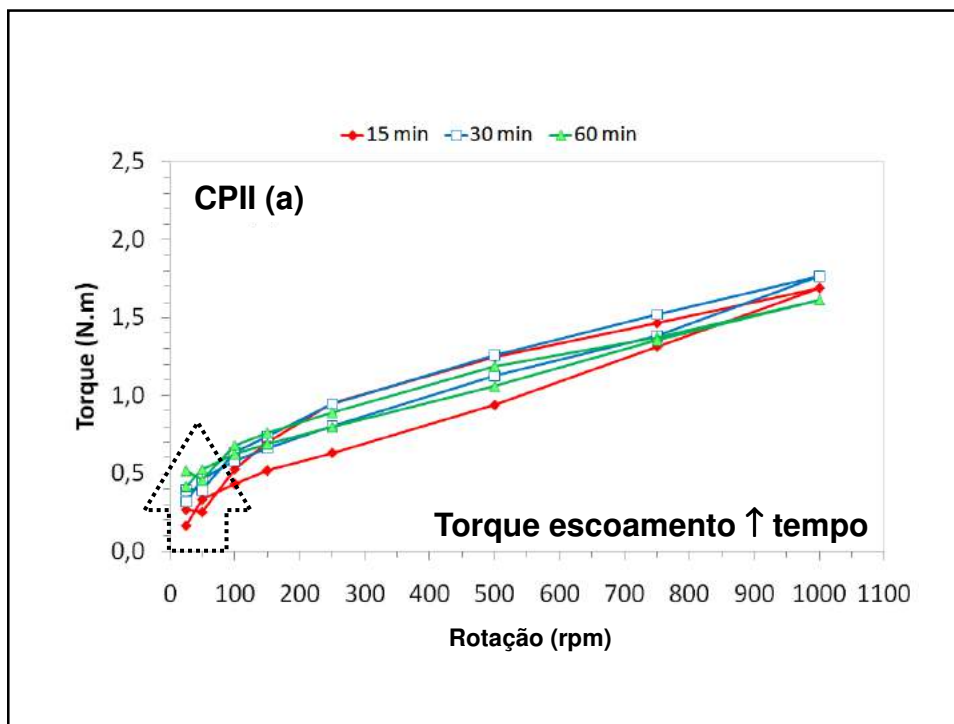
102



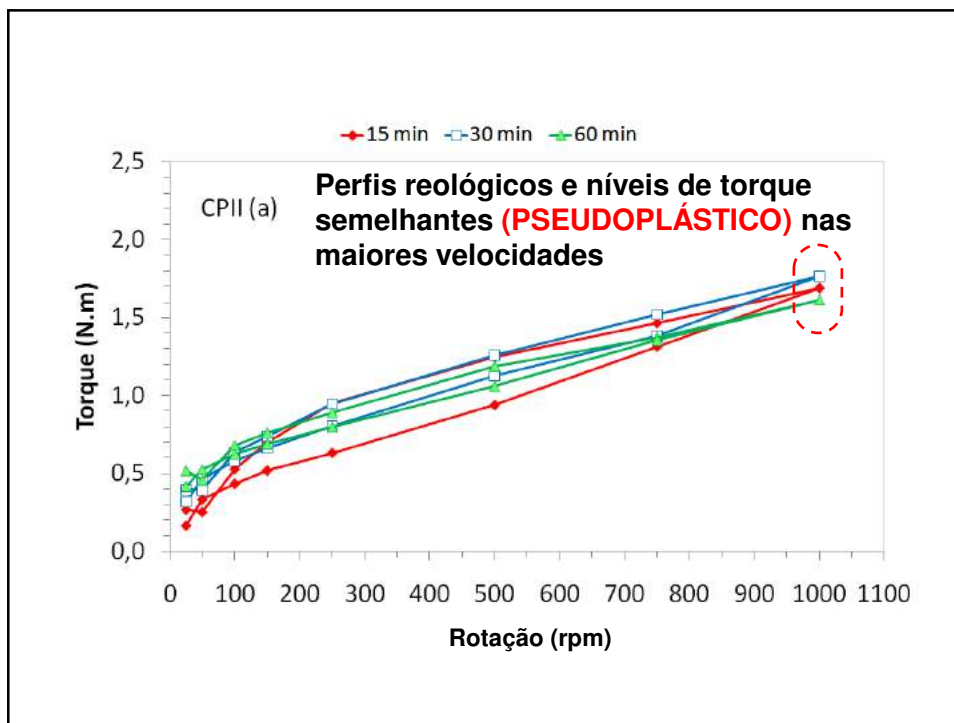
103



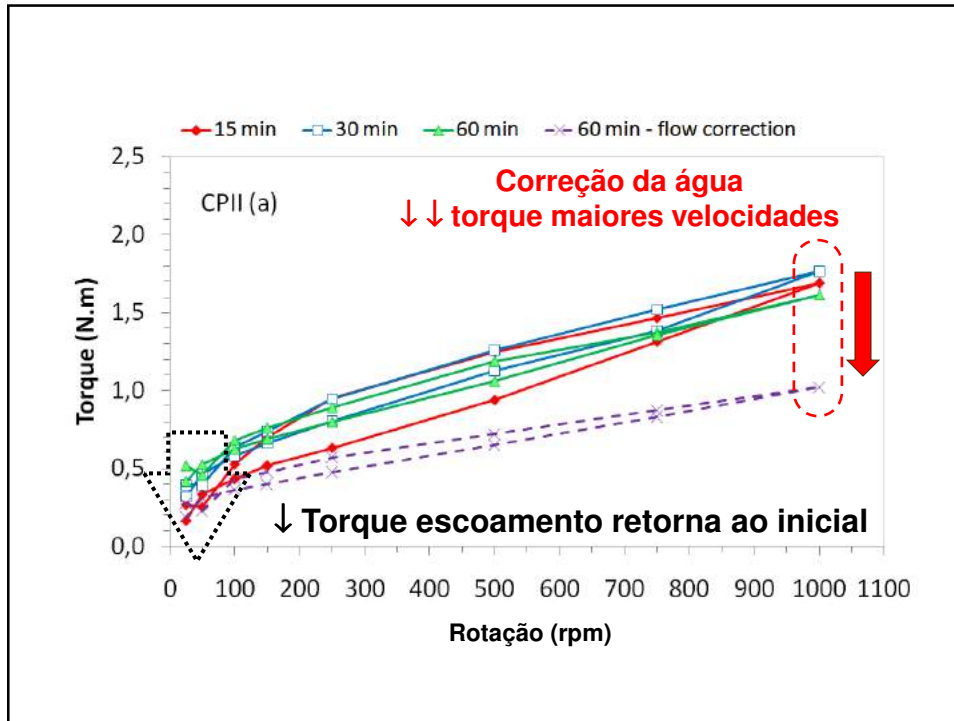
104



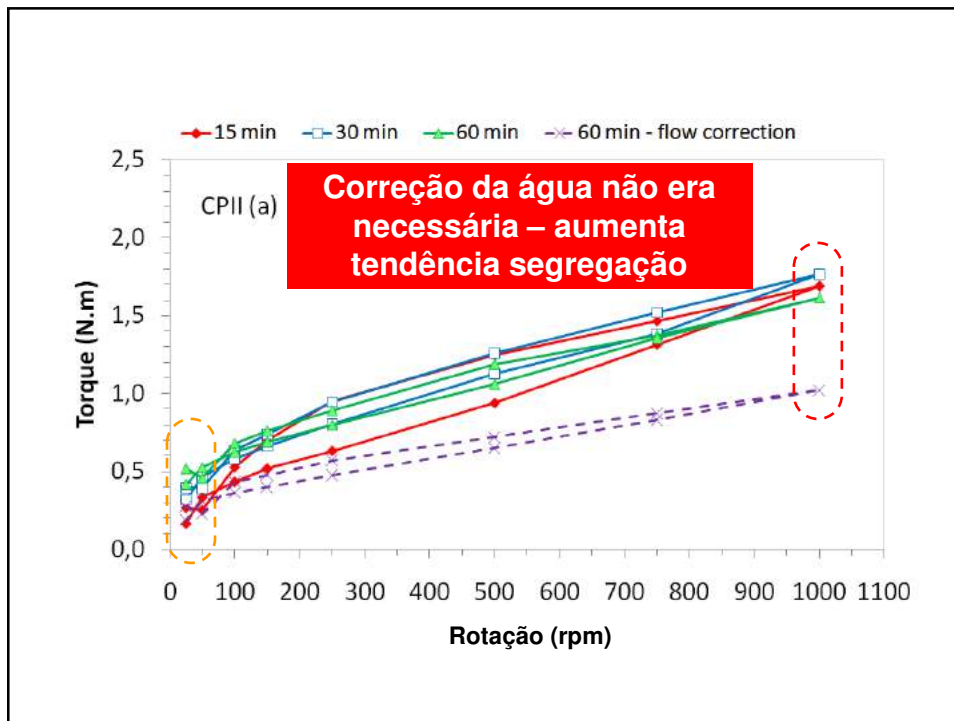
105



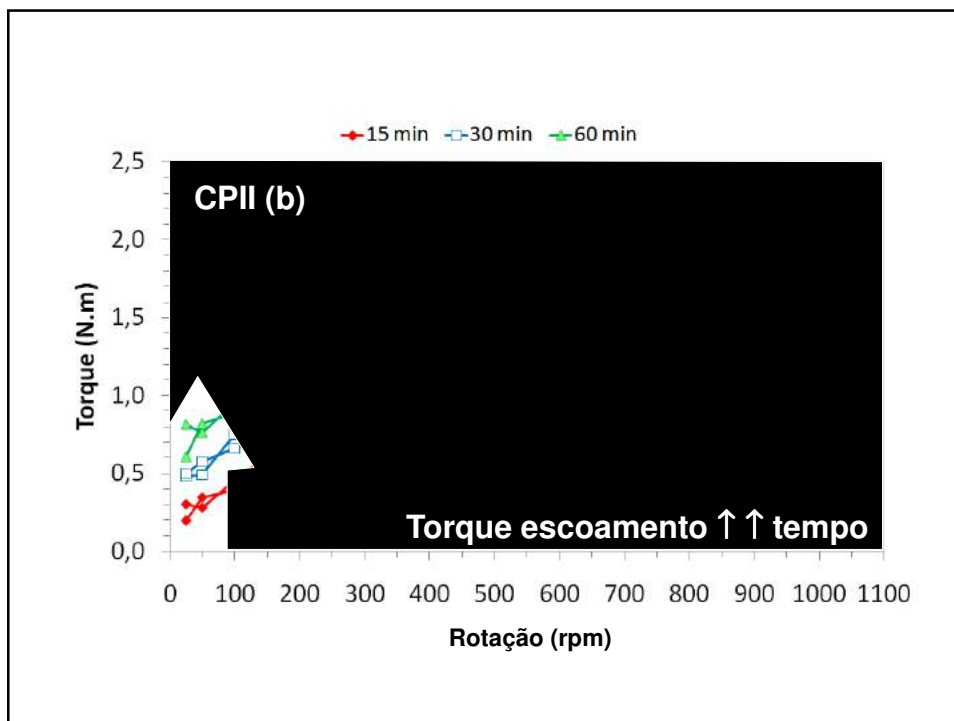
106



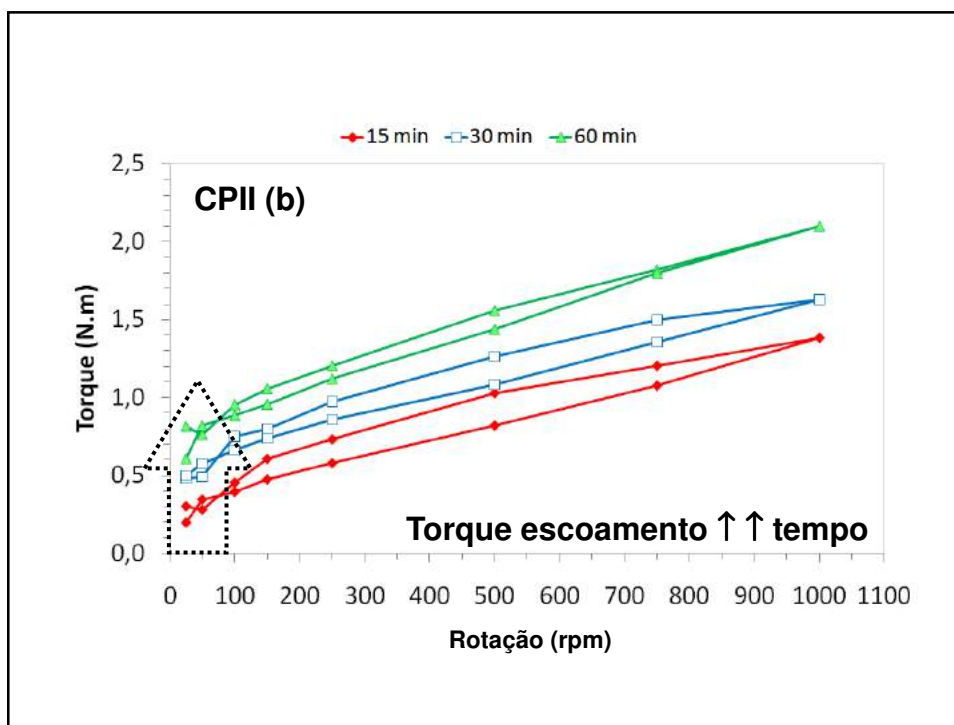
107



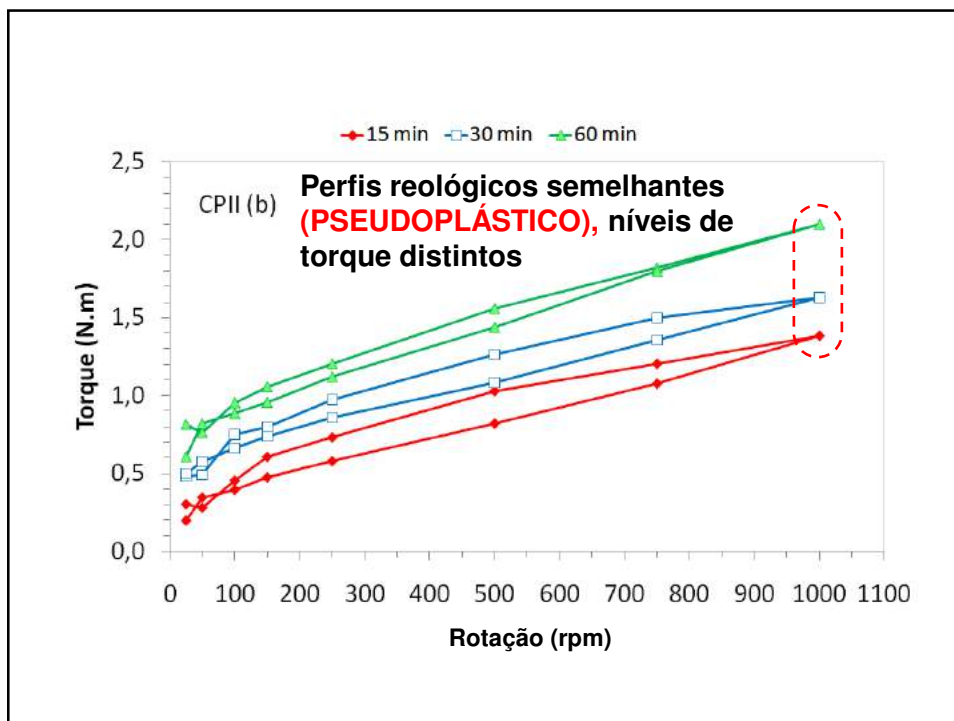
108



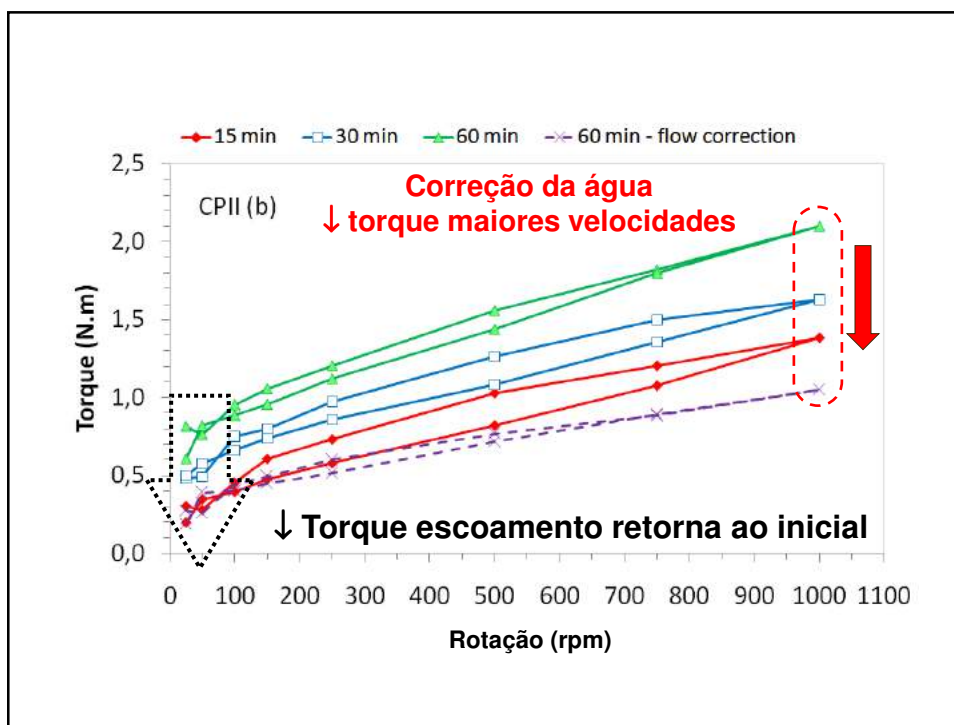
109



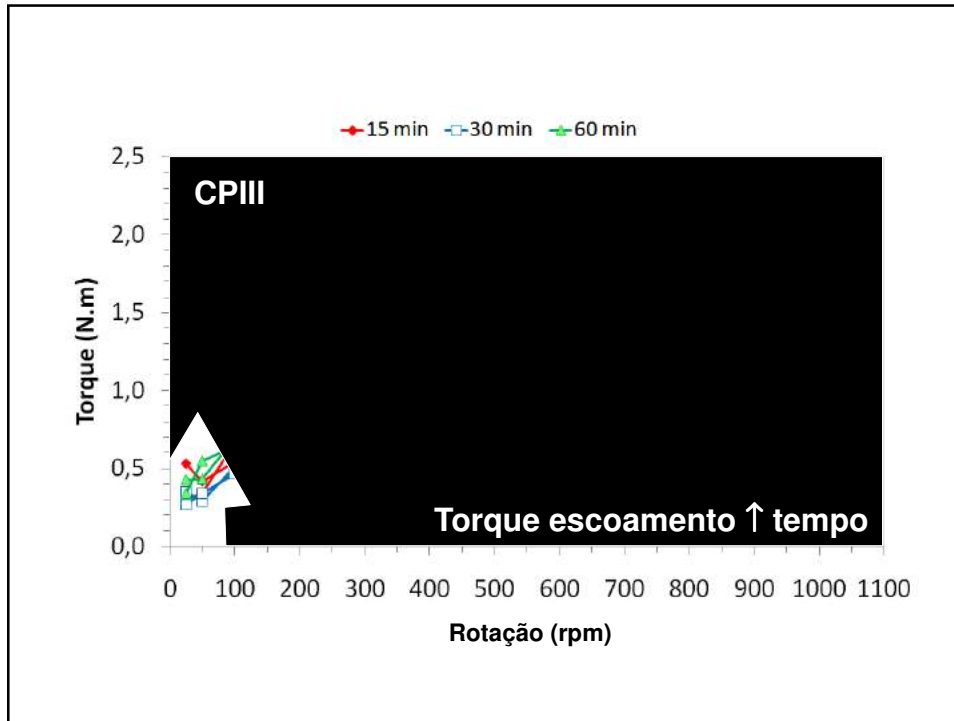
110



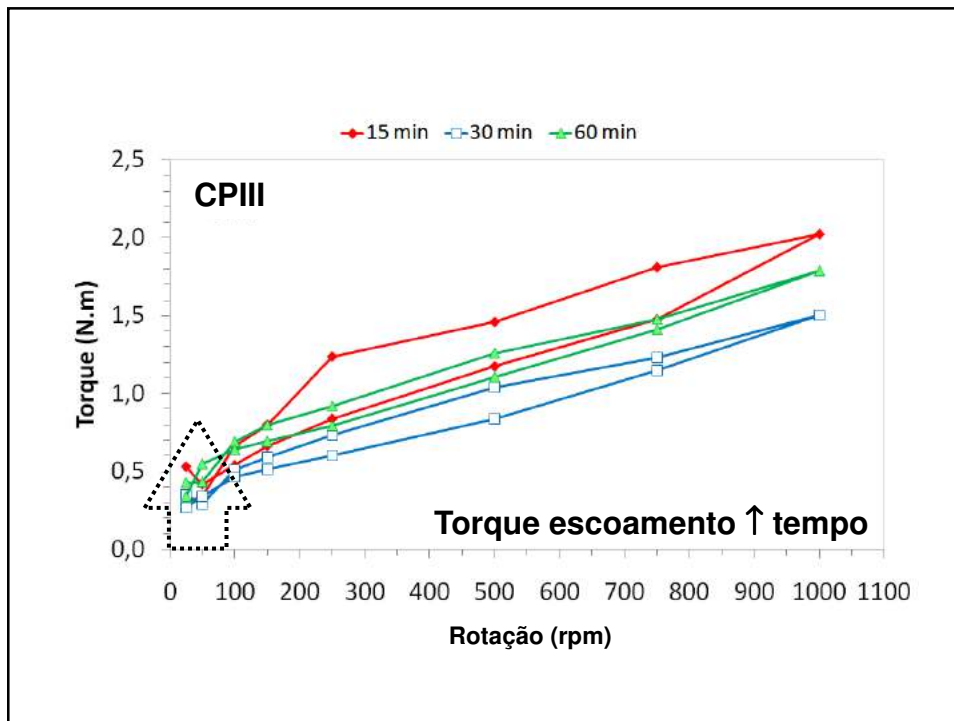
111



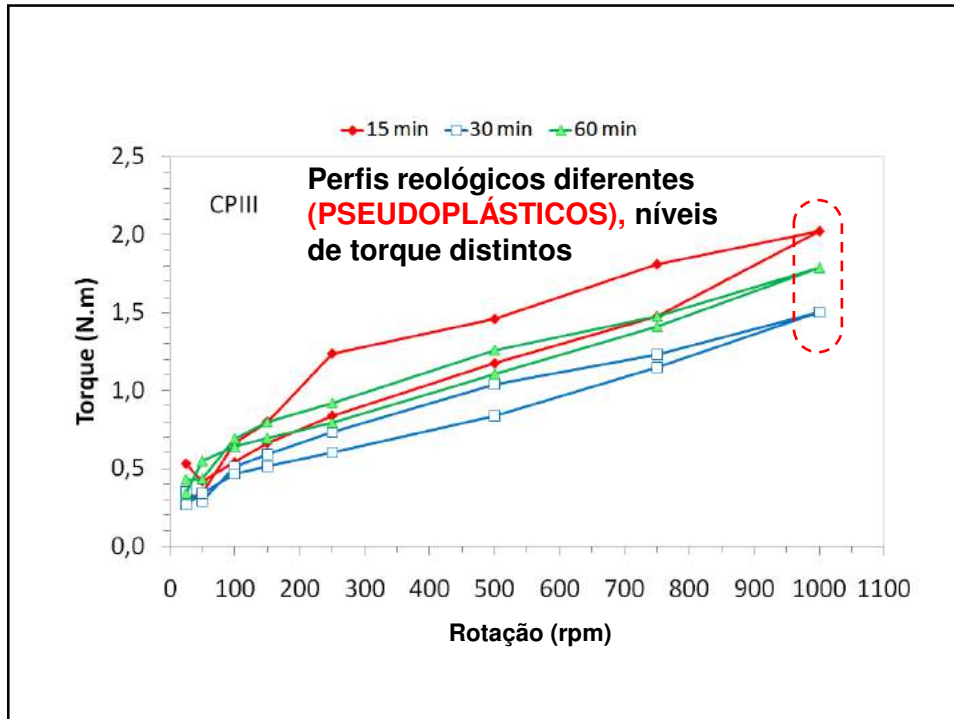
112



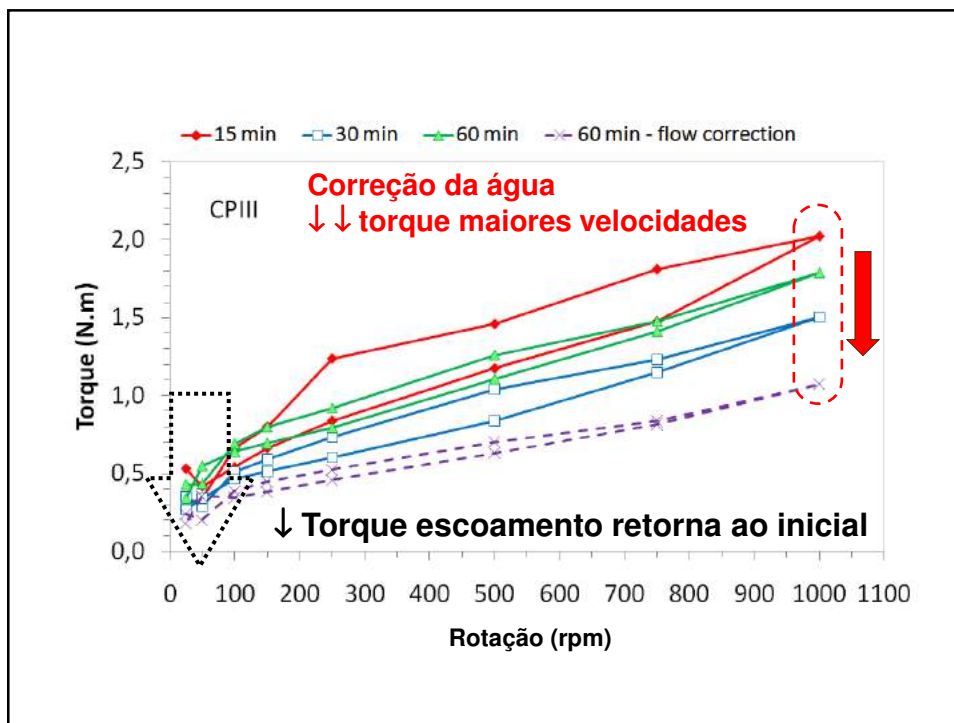
113



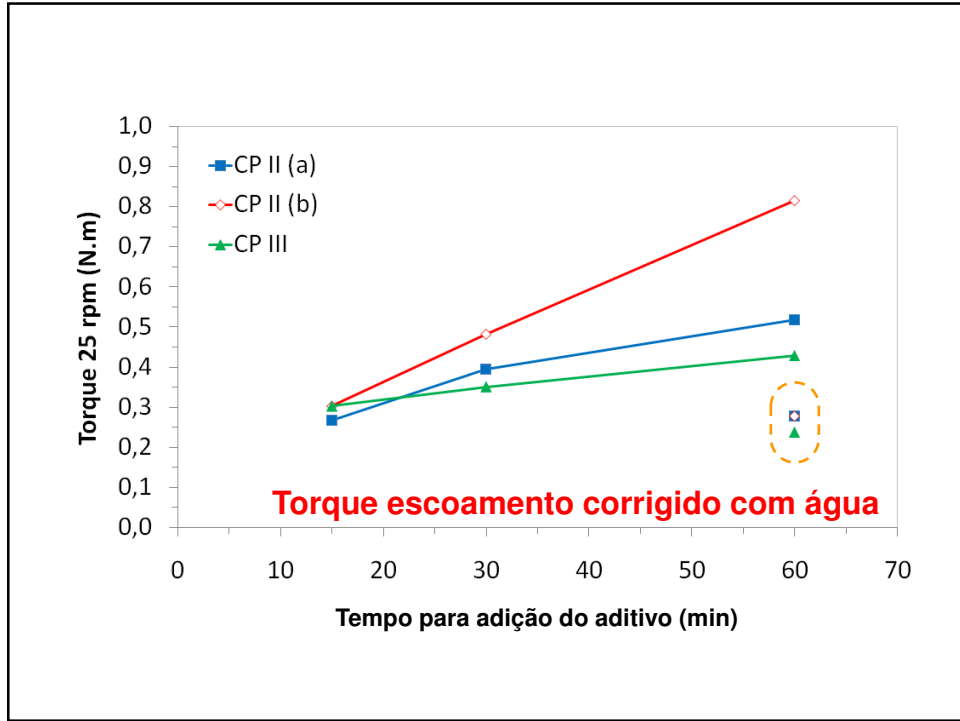
114



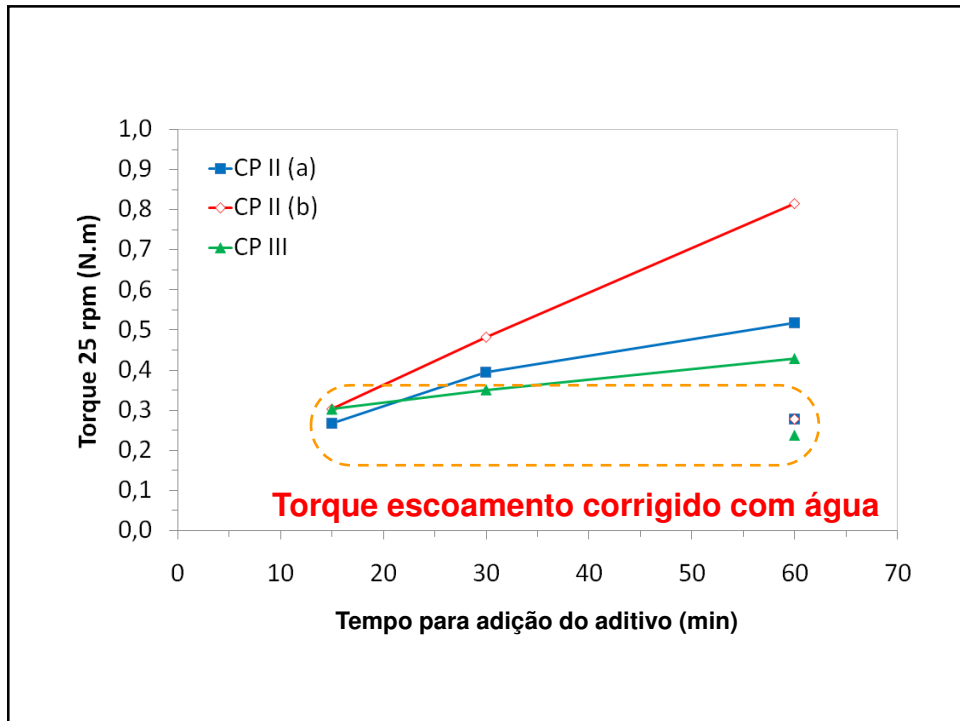
115



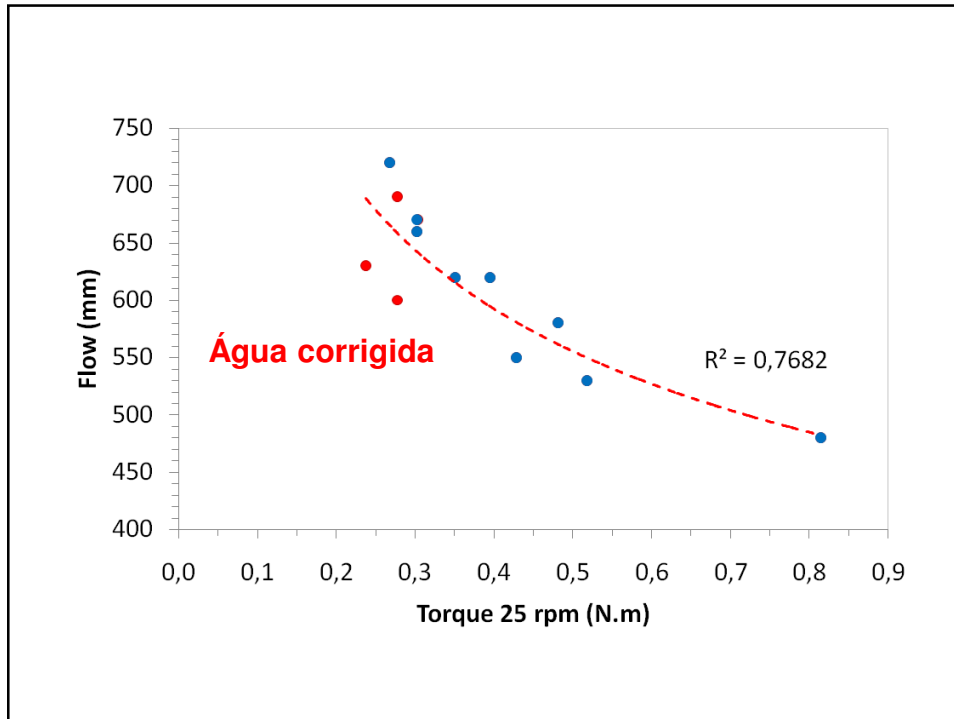
116



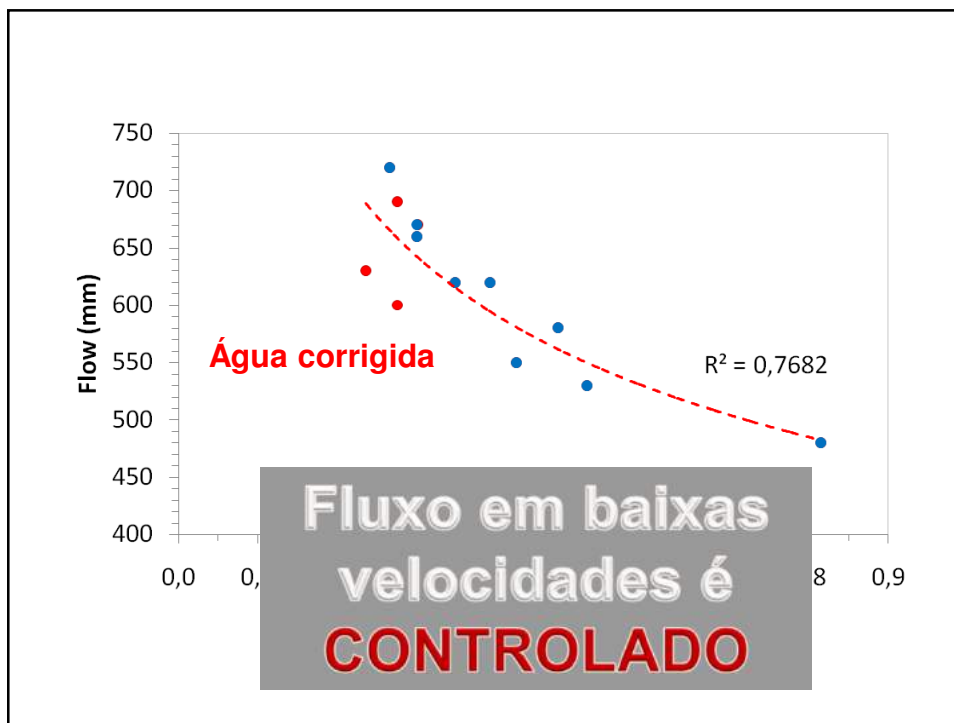
117



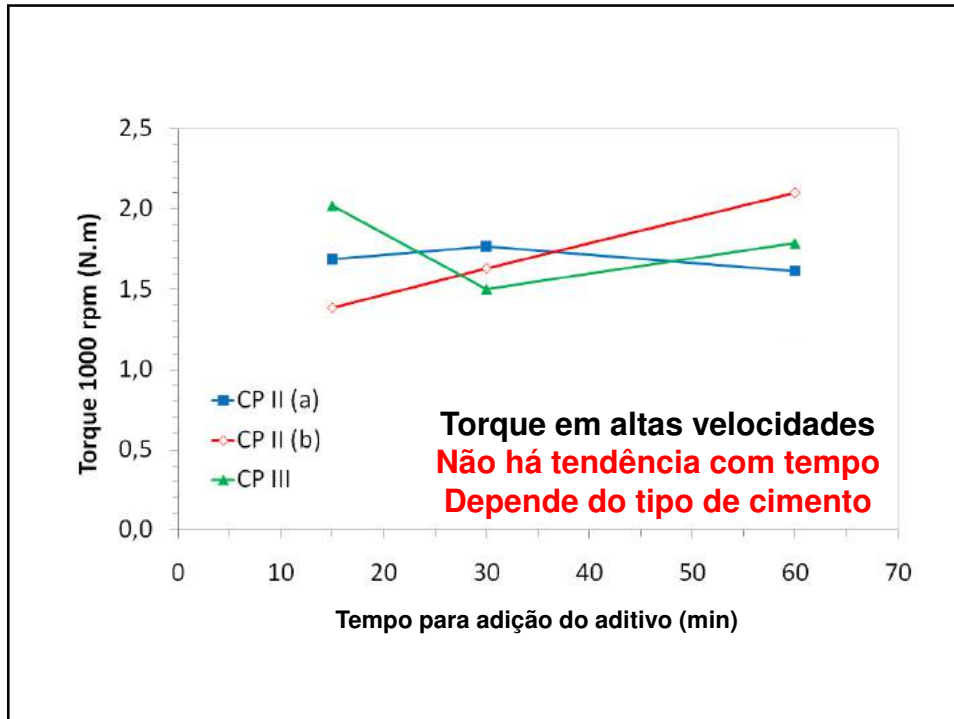
118



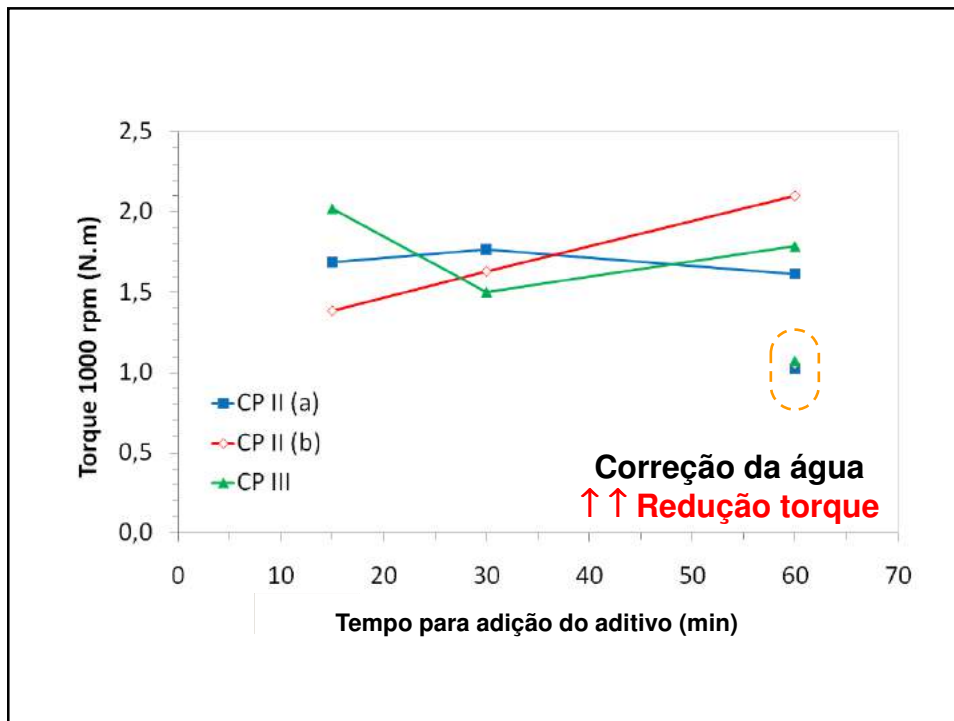
119



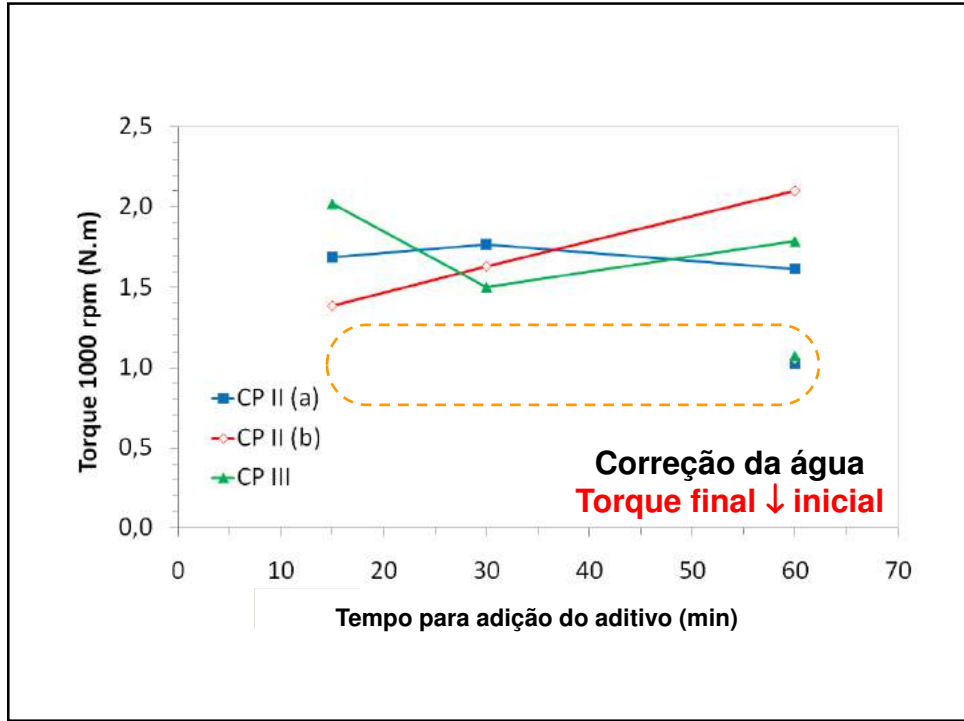
120



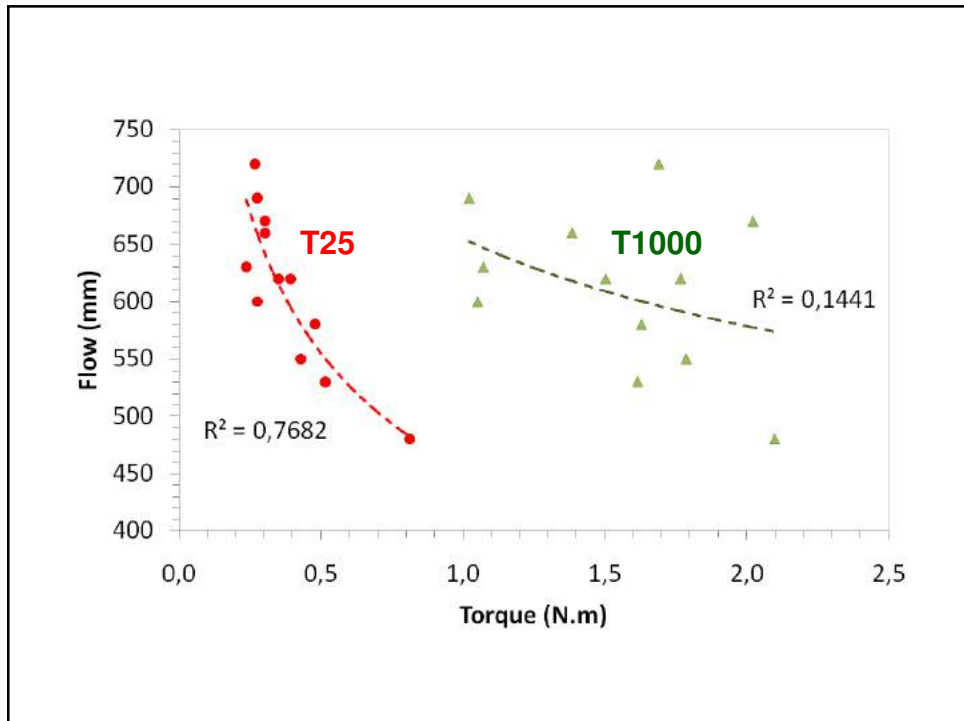
121



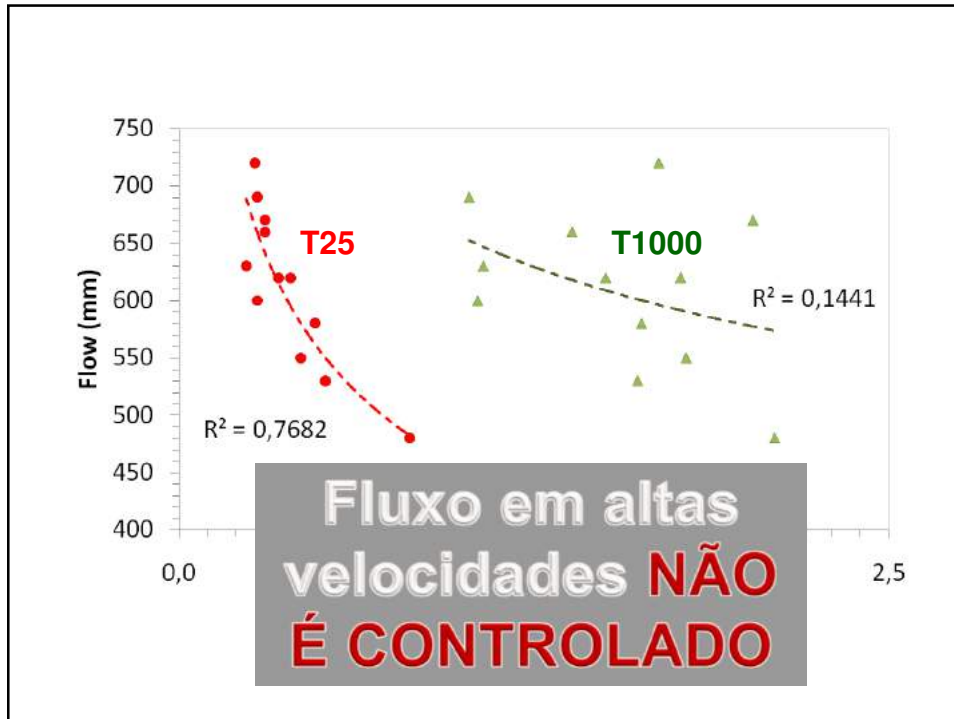
122



123



124



125

Fluidez não é suficiente para os concretos de hoje!!!

126



127



128

Grande desafio reológico



https://images-cdn.9gag.com/photo/aVP98EP_460s.jpg

129

Formulações sustentáveis com baixa água

Inovação em equipamentos

O desafio da reologia em concretos para um mundo sustentável

Técnicas de caracterização

Modelos de formulação

130



rafael.pileggi@usp.br

Obrigado pela atenção