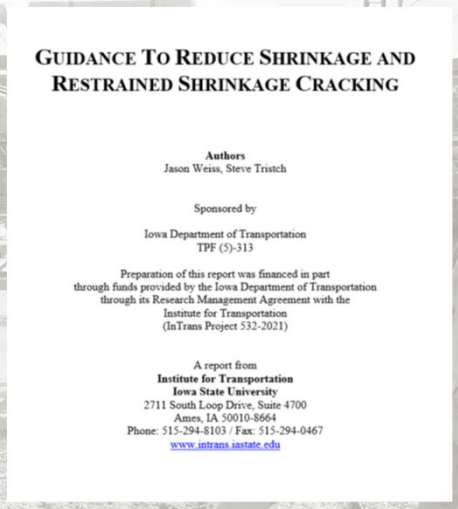
Oregon State University

COLLEGE OF ENGINEERING | School of Civil and Construction Engineering

GUIDANCE TO REDUCE SHRINKAGE AND RESTRAINED SHRINKAGE CRACKING



GUIDANCE TO REDUCE SHRINKAGE AND RESTRAINED SHRINKAGE CRACKING

Authors
Jason Weiss, Steve Tristch

Sponsored by

Iowa Department of Transportation
TPF (5)-313

Preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its Research Management Agreement with the Institute for Transportation (InTrans Project 532-2021)

A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

Jason Weiss, Edwards Distinguished Professor, Oregon State University

Things Shrink

Oregon State University College of Engineering

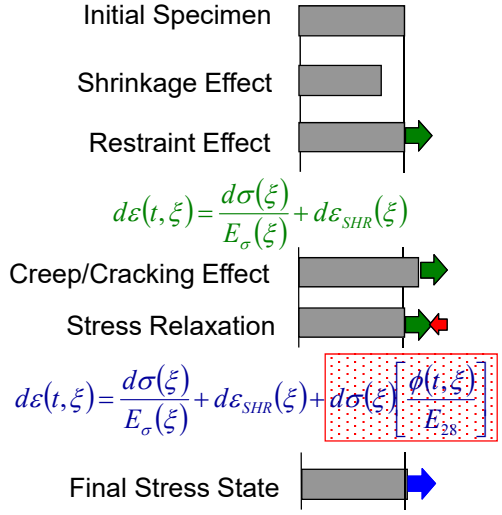
On its own shrinkage is not a big issue

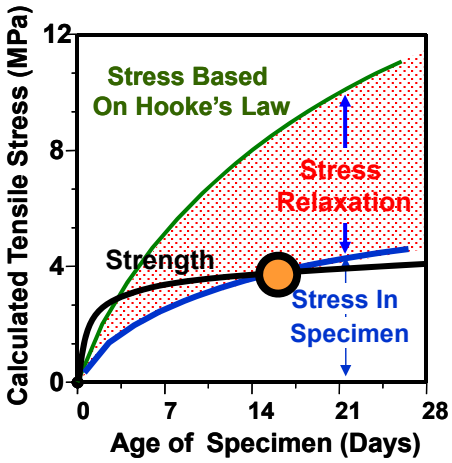
However, if the displacement is fixed, there will be stress

Photo 214024724 © Ljupco | Dreamstime.com

Residual Stress Development

Oregon State University College of Engineering





Weiss et al. 1998, JEM

Outline of Document

Oregon State University College of Engineering

- Summary of Critical Concepts
- Types of Concrete Shrinkage
- Shrinkage of Paste and Concrete
- Concrete Shrinkage Testing
- Shrinkage Reduction Techniques
- Saw-Cutting and Joints
- Moisture Gradients
- Case Studies

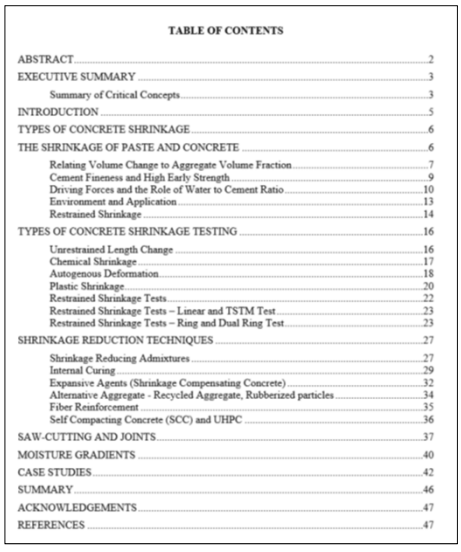
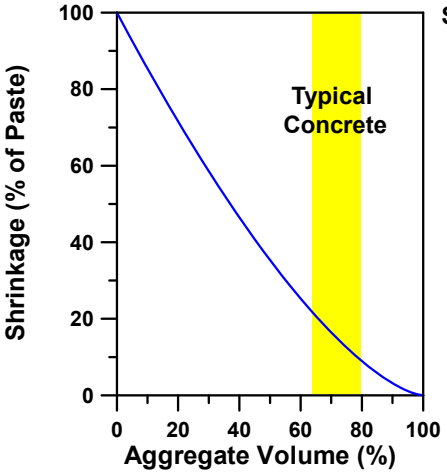


TABLE OF CONTENTS

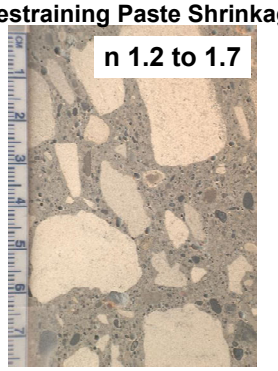
ABSTRACT 2
EXECUTIVE SUMMARY 3
Summary of Critical Concepts 3
INTRODUCTION 5
TYPES OF CONCRETE SHRINKAGE 6
THE SHRINKAGE OF PASTE AND CONCRETE 6
Relating Volume Change to Aggregate Volume Fraction 7
Cement Fineness and High Early Strength 9
Driving Forces and the Role of Water to Cement Ratio 10
Environment and Application 13
Restrained Shrinkage 14
TYPES OF CONCRETE SHRINKAGE TESTING 16
Unrestrained Length Change 16
Chemical Shrinkage 17
Autogenous Deformation 18
Plastic Shrinkage 20
Restrained Shrinkage Tests 22
Restrained Shrinkage Tests – Linear and TSTM Test 23
Restrained Shrinkage Tests – Ring and Dual Ring Test 23
SHRINKAGE REDUCTION TECHNIQUES 27
Shrinkage Reducing Admixtures 27
Internal Curing 29
Expansive Agents (Shrinkage Compensating Concrete) 32
Alternative Aggregate - Recycled Aggregate, Rubberized particles 34
Fiber Reinforcement 35
Self Compacting Concrete (SCC) and UHPC 36
SAW-CUTTING AND JOINTS 37
MOISTURE GRADIENTS 40
CASE STUDIES 42
SUMMARY 46
ACKNOWLEDGEMENTS 47
REFERENCES 47

Shrinkage Occurs in the Paste Portion

Oregon State University College of Engineering

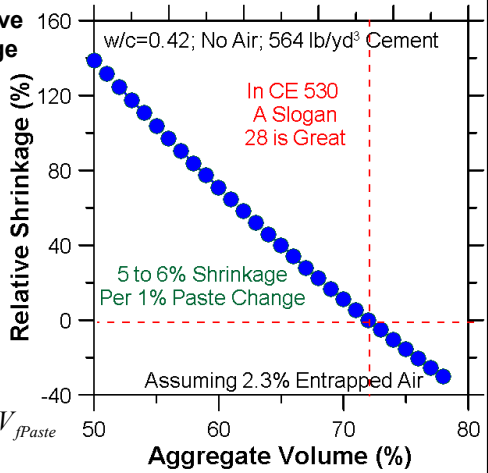


Stiffer Aggregate More Effective In Restraining Paste Shrinkage



$$\varepsilon_{Concrete} = \varepsilon_{Agg} \cdot V_{fAgg} + \varepsilon_{Paste} \cdot V_{fPaste}$$

$$\varepsilon_{Concrete} = \varepsilon_{Paste} \cdot (1 - V_{fAgg})^n$$

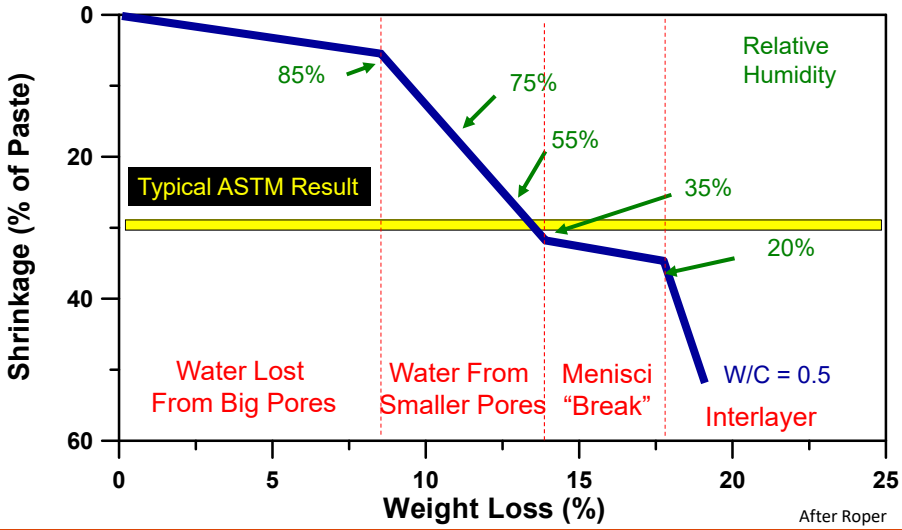


Weiss, CE 530, 2006

April 6th 2022 jason.weiss@oregonstate.edu © Slide 5 of 30

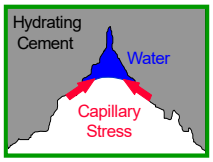
Origins of Non-Linearity

Oregon State University College of Engineering



After Roper

- Capillary Stress > 40-60% RH



$$p_{cap} = -\frac{2\gamma \cdot \cos\theta}{r}$$

- Disjoining Pressure >50% RH

Van der Waals' Forces attract adjacent particles

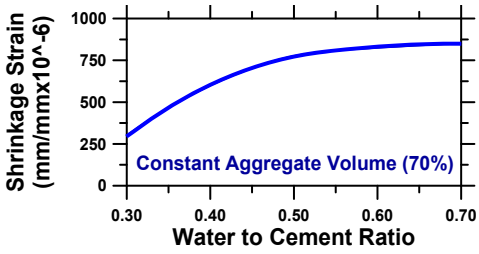
- Surface Tension < 40% RH

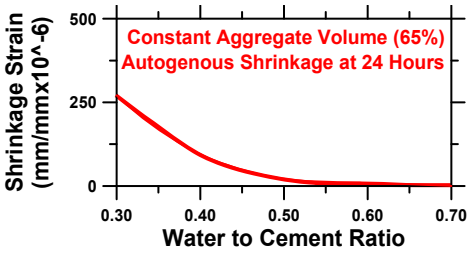
April 6th 2022 jason.weiss@oregonstate.edu © Slide 6 of 30

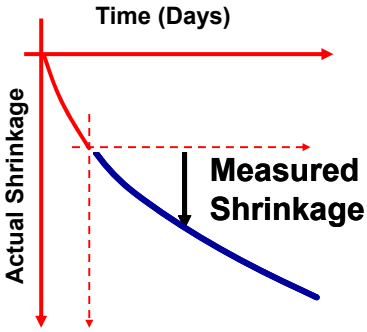
Measuring Shrinkage Starting Time is Critical

Oregon State University College of Engineering

- Typically standard measurements Begin at the Time of Demolding (i.e., 24 Hours)
- Why ?? – This is a Convenient Time for the Technicians to Demold
- More of an Issue in Low W/C Concrete







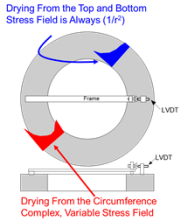
After Aitcin 1999

Weiss, CE 530, 2002

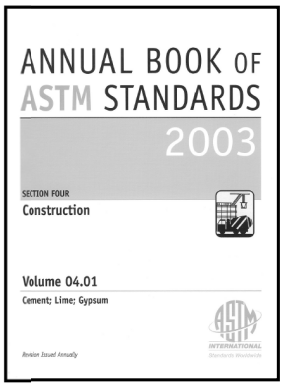
The Ring Test Restrained Shrinkage

Oregon State University College of Engineering

- DOR is very different (ASTM >> AASHTO)
- How close to cracking (stress determination)
- Weiss et al. (2000) t.w. stress computation
- Role of drying direction (circumferential is tricky)
- Dual ring – expansion and thermal

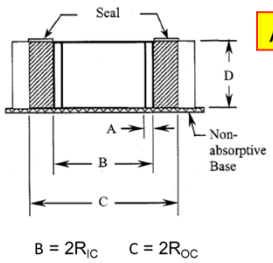


Ring is economic, 'simple to conduct' which lend it to selection & QC/QA



ASTM C 1581-04

Dimensions [mm]	
A	12.5 ± 0.13
B	330 ± 3
C	406 ± 3
D	150 ± 6



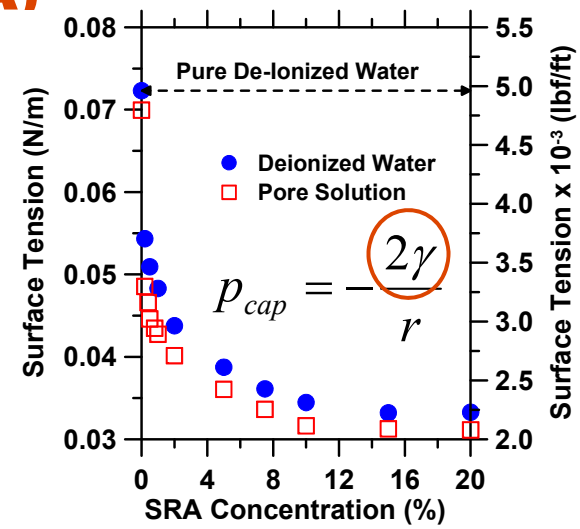
AASHTO PP 34-99

Dimensions [mm]	
A	12.7 ± 0.4
B	305 ± 5
C	457 ± 5
D	152 ± 5

Shrinkage Reducing Admixtures (SRA)

Oregon State University College of Engineering

- SRAs reduce surface tension, in doing so they reduce capillary stress and shrinkage
- Surface tensions can reduce to approximately 50% of the original as do shrinkage values
- Reduce gradients

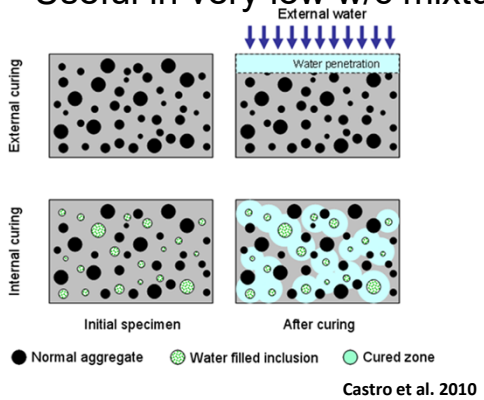


Rajabipour et al. 2006

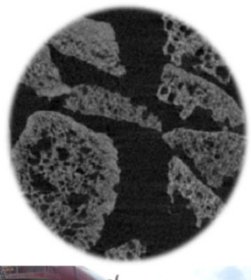
Internal Curing

Oregon State University College of Engineering

- Use LWA or SAP to provide
- Curing water from within
- Useful in very low w/c mixtures



Castro et al. 2010



Barrett et al. 2014

Streeter et al. 2012

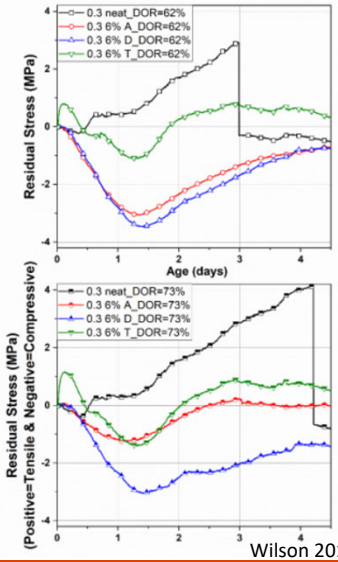
Titrk, Muench, Lura and Weiss 2009

DiBella et al. 2010

Expansive Agents

Oregon State University
College of Engineering

- Expansive agents can be useful
- Generally expansion occurs early
- Requires some restraint to be fully effective (offset drying not reduce it
- Dual rings are useful to evaluate expansive agents
- Different degrees of restraint

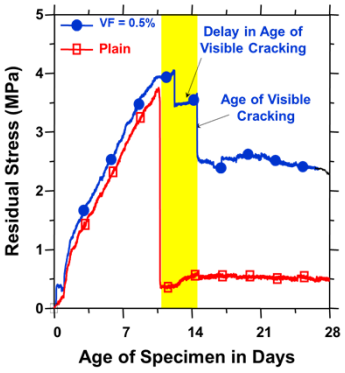


Wilson 2018

Fiber Reinforcement

Oregon State University
College of Engineering

- Fibers in general do not reduce shrinkage
- Fibers do alter plastic shrinkage (fibrillated PP, cellulose) by changing viscosity/settlement and bleed
- Fibers (especially high modulus) bridge cracks and reduce crack width
- Need to be 'careful' in using ring results in field as widths are small and transfer is high due to 'length' of the ring



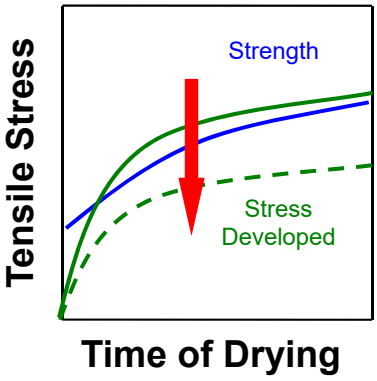
$$w = 2\pi R_{IC}\psi\varepsilon_{SH}\left(1-\frac{\varepsilon_{ST}^{AC}}{\varepsilon_{ST}^{BC}}\right)$$

Shah and Weiss, 2005

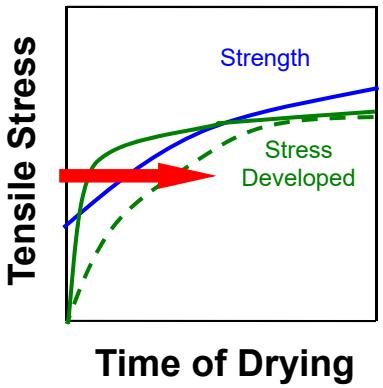
Reducing Cracking: Rate and Magnitude

Oregon State University College of Engineering

Reduce Magnitude



Reduce Rate

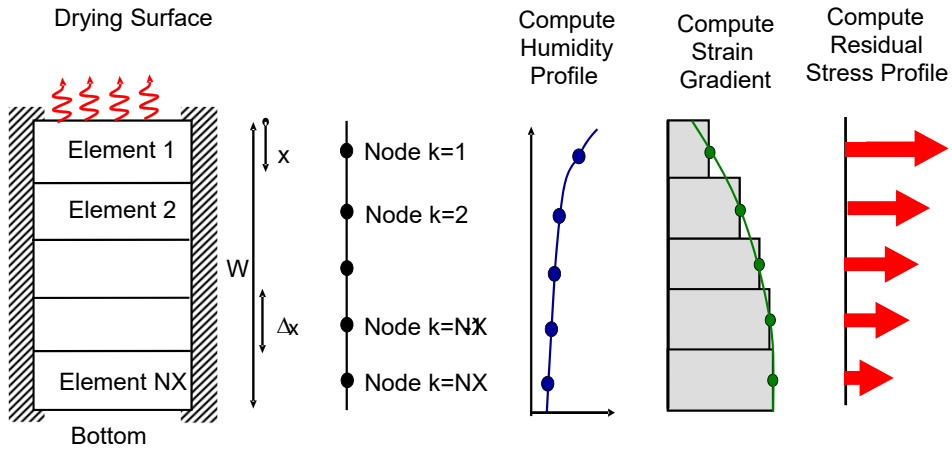


- Reducing both the magnitude and rate of shrinkage are important
- HSC or HESC is a great example

Weiss et al. 1999

Transforming RH Pressure into A Stress Profile

Oregon State University College of Engineering

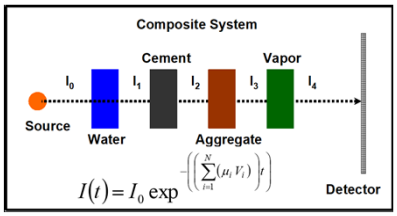


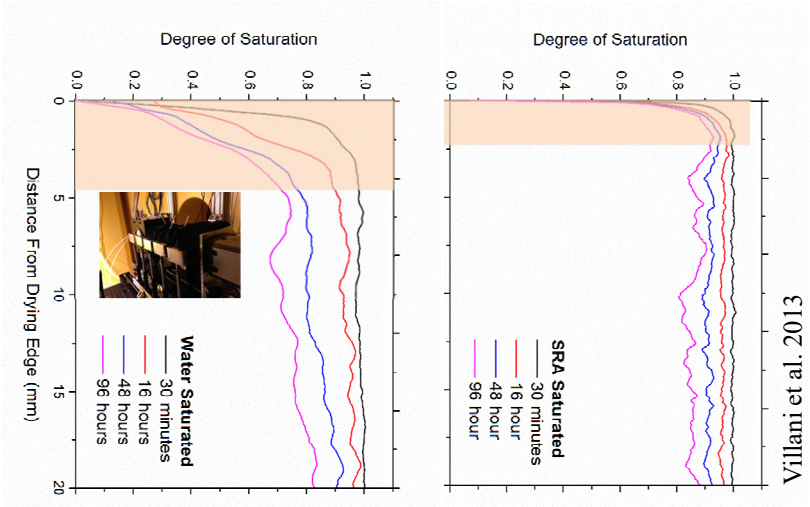
Weiss 1999

Moisture Profiles (NR)

Oregon State University
College of Engineering

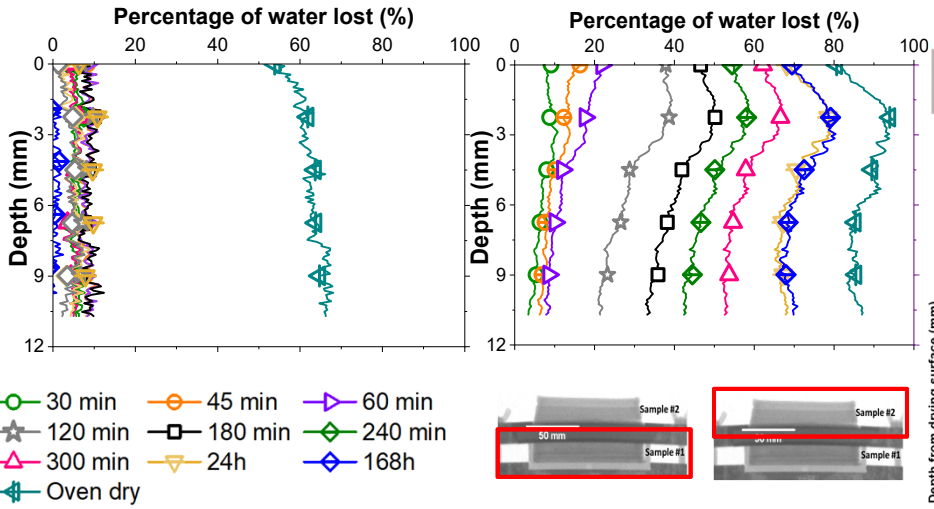
- Slower drying with SRA (keeps core more saturated, lowers moisture gradients, less curl)

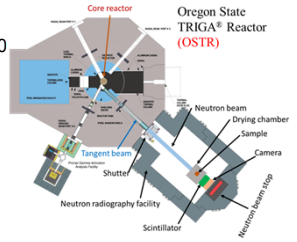


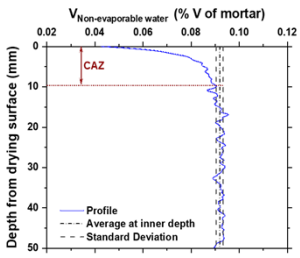


Small Aside – NSF Project (Re-examining Curing)

Oregon State University
College of Engineering







Summary

Oregon State University College of Engineering

- Summary of Critical Concepts
- Types of Concrete Shrinkage
- Shrinkage of Paste and Concrete
- Concrete Shrinkage Testing
- Shrinkage Reduction Techniques
- Saw-Cutting and Joints
- Moisture Gradients
- Case Studies