Studies of the Crack Development of Corroded Reinforced Concrete Members

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1. Introduction
Durability and service-life prediction of reinforced concrete (RC) structures has become a great attention among researchers in Japan and Indonesia as an increasing number of deteriorated structures particularly due to corrosion of reinforcement. Prediction of corrosion-induced cover cracking has also become main concern as an indication of structural deterioration. Through understanding of cracking behavior of corroded RC members, the implications of corrosion on material deteriorations such as steel bars, concrete and bond properties and the deterioration of the structural performance can be also predicted.

2. Aim of Research
This collaborative research aims to study the crack behaviors of corroded members in order to predict the corrosion level through crack development which can be used to control structural damages due to corrosion. Moreover, the collaborative research was carried out in the following steps 1) literature review of current state of the art on prediction of corrosion-induced cover cracking, 2) development of a method to analyze and predict corrosion-induced cover cracks and their implication on material constitutive models 3) estimation of a structural performance of corroded RC members using finite element analysis.

As part of this research collaborative project, the coordinator came to Japan during JCI Annual meeting 2014 in Takamatsu Japan, and met TIT Professor to discuss the program and progress of research collaborative between ITB and TIT researchers.

3. Results
The critical amount of corrosion which induces cover cracking is an important parameter to be identified in order to predict the time of possible initial cracking and the expected remaining life time. This research aims to explore the critical amount of corrosion that initiates cover cracking and to investigate the crack propagation including the crack width growth. From the experimental and analytical results indicates that the initiated in concrete surface occurs in small amount of corrosion penetration around 10 to 115 micrometers. It depends on many parameters such as cover depth, concrete strength, porosity, etc. The concrete strength significantly governs the crack width growth rate (Figure 1) and the stress generated on the transverse bars (Figure 2) which may reduce the residual shear capacity of RC structure. Meanwhile, the presence of confinement up to 0.3% of transverse bar ratio shows an insignificant effect on the crack width growth.

Figure 1. Effect Concrete strength on crack propagation

![Figure 1. Effect Concrete strength on crack propagation](image-url)
Furthermore the study found that the distribution of internal pressure among longitudinal bars (bar distance) influence the cracking pattern but it does not influence the crack width so much if the average corrosion rate is considered. Moreover, the stress developed on the transverse bars is influenced by the bond–slip relationship between transverse bars and concrete.

In addition, as shown in Figure 3, based on the experimental test, the constitutive models for bond stress–slip relationship was developed which can be characterized in the two manners as follows: a) maximum bonds stress decreases with an increasing corrosion level except in low level corrosion, b) slip at maximum bond stress decreases as increase corrosion level.

**Figure 2. Transverse bar strain vs. longitudinal bar corrosion**

**Figure 3. Bond-slip relationship for corroded reinforcement**
4. Conclusions
Through this collaborative research, both researchers at Tokyo Institute of Technology and (TIT) and Institut Teknologi Bandung (ITB) has a great opportunity to work together and share knowledge to develop more accurate method on prediction of corrosion cracking behavior and deterioration of structural performance of corroded RC members.

5. Team Members
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1. Introduction

The phase diagram of the high temperature superconducting cuprates has been under extensive investigation since their discovery, almost three decades ago. In addition to high temperature superconductivity, a variety of ground states have been proposed and partly realized upon charge carrier doping. For example, the parent compound La$_2$CuO$_4$, which is an antiferromagnetic (AF) Mott insulator with Neel temperature $T_N = 325$ K, is known to exhibit a short-range glassy phase and subsequently diagonal stripe order upon doping with e.g. Sr (La$_{2-x}$Sr$_x$CuO$_4$). Recently, research has refocused on the highly underdoped cuprates. However the evolution of the electronic ground state with the very first added charge carriers, in particular in the search for a possible broken symmetry associated with an exotic ground state and subsequent effects on the anomalous normal state properties, remains an enigma.

Recently, we observed a low temperature ferroelectric (FE) phase with an associated magnetoelectric (ME) coupling in highly underdoped La$_2$CuO$_{4+x}$ ($T_N = 320$ K). Notably, ferroelectricity is characterized by broken spatial inversion symmetry and typically emerges in the absence of mobile charge carriers.

2. Aims of Research

To gain insight into the nature of ferroelectricity and magnetoelectricity in La$_2$CuO$_4$ system, measurements of the electric polarization on Sr doped La$_2$CuO$_4$ single crystals were performed.

3. Results

Single crystals were grown by the traveling solvent floating zone (TSFZ) method. All crystals were cut appropriately and pairs of plate-like samples were extracted. Each pair consists of a sample with the thinnest direction along the $c$-axis and another with the thinnest direction along the $ab$-plane. The magnetization of the samples was measured using a commercial MPMS Quantum Design SQUID magnetometer. The impedance and loss of the samples were measured using an LCR meter, over a frequency range 21 Hz - 2 MHz, and the dielectric permittivity was extracted. Electric polarization measurements were performed using home-built experimental stations employing the pyrocurrent technique.
The spins in the AF phase of La$_{2-x}$Sr$_x$CuO$_4$ are weakly canted out of the $ab$-plane due to the presence of a finite Dzyaloshinskii-Moriya (DM) interaction. This spin canting causes a weak ferromagnetic (WF) moment along the c-axis in each CuO$_2$ plane, although the opposite spin canting in alternate planes leads to a net cancellation of the WF moments. By applying an external magnetic field along the c-axis, all the WF moments can be aligned in the same direction above a critical magnetic field $H_{cr}$, which for our La$_{2-x}$Sr$_x$CuO$_4$ samples is $H_{cr} = 6$ T. Figure 1(a) shows $P_c$ as a function of applied magnetic field (here $E \parallel c$ and $H \parallel c$). As seen, $P_c$ decreases abruptly above $H_{cr} = 6$ T, reaching 90% of its initial value at $H = 8$ T. Moreover, the pyroelectric current peak (inset in Fig. 1(a)) shifts abruptly towards lower temperatures above 6 T, indicating a suppression of $T_{FE-c}$ as the material enters the WF state (such abrupt changes are also observed for $H \parallel c$ and $E \perp c$). On the other hand, both $T_{FE-ab}$ and $P_{ab}$ ($E \parallel ab$ and $H \parallel ab$) decrease smoothly with increasing $H$ as seen from Fig. 1(b) (similar changes are obtained for $E \perp ab$ and $H \parallel ab$). Hence, the FE order in La$_{2-x}$Sr$_x$CuO$_4$ is coupled to the underlying AF structure and is influenced by the DM interaction in a manner similar to the recent observations on LCO.

4. Summary

We found evidence for the presence of FE and ME coupling in underdoped La$_2$CuO$_4$ system. We observed distinct electric polarization behavior along in-plane and out-of-plane crystallographic directions. In all cases the electric polarization is strongly influenced by DM interaction. Considering the above experimental evidence, the FE order and its related magnetoelectricity appear to be a generic property of La$_2$CuO$_4$ cuprates. We propose that the observed ferroelectricity originates from the CuO$_6$ octahedral distortions, occurring around the dopant ions and/or due to the formation of charge clustering, resulting to a local-scale spatial symmetry breaking symmetry.

Figure 1. (a) Out-of-plane polarization $P_c$ as a function of applied magnetic field $H$ at $T = 2$ K for La$_{1.999}$Sr$_{0.001}$CuO$_{4+y}$ ($E \parallel c$ and $H \parallel c$). Inset. Pyroelectric current as a function of temperature for various $H$. (b) $P_{ab}$ as a function of $H$ ($E \parallel ab$, $H \parallel ab$). Inset. Pyroelectric current as a function of temperature for various $H$. 

- 19 -
1 Introduction

Nitrogen is a minor element of organic solids recovered from primitive meteorites and cometary grains. The recent discovery of N-rich Ultra-Carbonaceous Antarctic Micrometeorites with high N abundance allowed new chemical insights and proposed new scenario for the formation of those N-rich organics. Experimental simulations are required to test scenario.

2 Aims of Research

This project aims at testing the formation of N-rich refractory organics by the effect of shock waves, which were presumably present in the proto-solar disk. Tholin samples (polymeric hydrogenated carbon nitride) were used as precursors. In an earlier study, we showed that the thermal carbonization of tholin samples leads to fair analogs of UCAMMs, for conditions 500-1000 °C and duration ~1 h. Here we have investigated the effect of very short duration as well as the possible effect of pressure.

3 Results

Six shock experiments were performed on a tholin sample formed from a gaseous mixture N2:CH4=97:3 in cold plasma reactor. They were processed at 5, 10, 20, 30 (x2) and 40 GPa. In all cases samples experienced a thermal carbonization, and at 20 GPa and above the residue has a polyaromatic structure. Raman spectroscopy reveals broad first-order carbon bands that point to a disordered solids.

4 Conclusion / Summary

These experiments reveal that shock waves over very short timescale trigger a thermal carbonization and leads to polyaromatic carbonaceous solids. We have been investigating further these residues by micro-FTIR to evaluate in more details the consistency with UCAMMs, as well as similarities and differences with respect to furnace thermal carbonization.
1. INTRODUCTION

The dense instrumentation array and the spatial completeness of the E-Defense test data [1] offered an unprecedented opportunity to validate a recently proposed parameter estimation algorithm [2-3] that utilizes linear response histories for identifying stiffness and damping properties of shear-type structures. The estimation algorithm is formulated in the time-domain and employs a least-squares based methodology to extract the stiffness and damping matrices of individual stories of the test structure. The identified structural properties are subsequently used to extract modal properties of the structure for comparison with modal properties identified through conventional spectral analysis techniques [4].

2. TEST STRUCTURE AND METHOD

A 75-channel array with five tri-axial sensors at each level of the test structure and on the shake-table was deployed to collect acceleration data during the pre-collapse tests. Force and deformation histories deduced from column strain gauges and displacement wired sensors confirm that the response of the structure remained linear during the 20% Takatori excitation level. Therefore, the acceleration data from the aforementioned test is a suitable candidate to be used with a linear parameter estimation algorithm, which will be briefly described in the subsequent sections.

The parameter estimation algorithm [2-3] employed here utilizes the equilibrium equations between story shear and restoring forces to identify the stiffness and damping matrices of individual stories in a shear-type building structure. Story shear is calculated as the cumulative summation of the inertial forces acting on the portion of the building which is above the story of interest—that is, for the \( i \)th story, we have

\[
k_i u_i + c_i \ddot{u}_i = - \sum_{j=i}^{N} m_j \ddot{x}_j
\]

Lateral mass of story is shown with \( m \). Parameters \( e_x, e_y \), and \( I_o \) correspond to mass eccentricities and mass moment of inertia that are evaluated with respect to the origin of an assumed coordinate system. Given mass properties and history of response, the 18 unknown elements of stiffness and damping matrices can be estimated by fitting the
unknown restoring forces to the measured story shear forces—at \( n \) time instants—by using Eq.(2) in a least-squares sense. That is,

\[
[k_i \ c_i]_{3 \times 6} \begin{bmatrix} u_i(t) \\ \dot{u}_i(t) \end{bmatrix}_6 = - \begin{bmatrix} \sum_{j=i}^{N} m_j \ddot{x}_j(t) \end{bmatrix}_{3 \times 6}
\]  

(2)

The estimation algorithm relies on the full characterization of the in-plane rigid body motion of each floor. Therefore, the structure needs to be instrumented at each level with at least three lateral channels, from which lateral and torsional components of floor acceleration can be deduced. Considering the absence of permanent deformations due to the linearity assumption, the velocity and displacement histories can be calculated by integrating the recorded acceleration response.

3. CONCLUSION

The identified story stiffness and damping matrices were assembled to form the global stiffness and damping matrices, which were subsequently employed for simulating response of the structure to 20% Takatori base excitation. Fig.1 displays measured and simulated absolute lateral floor accelerations. The simulated response appears to be a low-pass filtered version of the measured response. This indicates that the higher modes are absent from the simulated response. Such an observation is consistent with modal decomposition of the estimated damping matrix in overestimating damping for higher modes of vibration. The overestimation of damping in lightly damped structures has been frequently reported in literature, and devising numerical techniques.

Figure 1. Comparison of Simulated and Measured Lateral Response in \( x \) Direction: a) Roof, b) 3\(^{rd}\) Floor, c) 2\(^{nd}\) Floor, and d) 1\(^{st}\) Floor.
References


繊維補強セメント複合体の耐衝撃性評価

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1 はじめに

鉄筋コンクリート構造は経済的・耐久的な建設構造材料として、建築・土木分野において広く用いられている。また、耐衝撃性にも優れており、重要な建造物にも採用している。最近のコンクリート材料の耐衝撃性に関する研究によると、コンクリートの圧縮強度の高強度化や鉄筋による補強は、耐衝撃性に及ぼす効果は小さいと報告されている。それ故、耐衝撃性を高めるために部材の厚さを増加する方法が一般的である。一方、耐衝撃性に必要な部材厚さ低減のために、引張及び曲げ性能を向上させた繊維補強セメント複合体を使用する方法も考えられる。最近、韓国ではトンネルや化学プラントの安全性を高めるために繊維補強コンクリート材料の適用が計画されているが、耐衝撃性を評価するための試験装置及び評価手法がまだ確立されていない。

2 研究目的

繊維補強セメント複合体はその調合及び使用繊維の能力によって力学特性が大きく異なり、高速飛翔体の衝突実験の研究事例が少ない。また、繊維補強セメント複合体を用いた耐衝撃性能を構造材料に適用するためには、まだ解決しなければならない問題が多く、構造材料の設計に繊維補強セメント複合体を実用化するためには破壊特性の把握が重要な問題になっている。

そこで、本研究ではポリビニールアルコール繊維（以下、PVA 繊維という）、ポリプロピレン繊維（以下、PP 繊維という）、鋼繊維を 1.5%（体積混入率）混入した繊維補強セメント複合体を用いて、高速飛翔体の衝突実験を行い、衝撃破壊性状を繊維無補強セメント複合材料と比較し、破壊抑制効果について検討することを目的とした。

3 研究成果

表-1 実験計画

図-1 高速衝撃試験装置
表-1 に本研究の実験計画を示す。高速飛翔体の衝突実験に用いた試験体は 4 種類として繊維無補強の Plain, PP 繊維, PVA 繊維及び鋼繊維を補強した試験体とし, 飛翔体の寸法や衝突速度によって 20 体の試験体を計画した。試験体の寸法は 300×300×100mm(横×縦×厚さ)であり, 球体のステンレス(SUS 304)の直径と質量が異なる 2 種類の飛翔体を約 400 〜 1,000m/s の速度で衝突実験を行った。

また, 評価項目は衝突実験後の試験体の外観破壊状況によって破壊等級, 表面貫入(以下, クレータという)直径, 裏面剥離(以下, スポールという)直径, クレータ深さ, スポール厚さ, 損傷面積率, 質量変化率及び破壊状況と衝突条件の関係とした。

図-1 に高速飛翔体衝突試験装置の概要及び衝突条件の設置状況を示す。衝突条件は, 火薬式飛翔体衝突試験装置により加速された高速飛翔体を試験体に衝突させる方法である。試験体の衝突条件は飛翔体速度の計測は, 試験体衝突面の直後に配置された 2 対のレーザーセンサーにより測定した。速度計測器は, 等間隔に配置された 2 対のレーザーセンサーで構成されており, 飛翔体がレーザー光を横切る時間差を計測することにより飛翔体速度を求める仕組みとなっている。また, 飛翔体を加速させるためにつけたサボは, 衝突直前でサボキャッチャーによって先端のステンレス球と分離し, ステレンス球のみを衝突させた。本研究では, 直径 9.54mm, 質量 3.52g と直径 19.05mm, 質量 28.13g の 2 種類のステンレス製 (SUS 304) 球を飛翔体として使用した。

図-2 に高速飛翔体の質量と速度から計算した試験体が受ける運動エネルギーとクレータ深さの関係を示す。クレータ深さの場合, 運動エネルギーの増加によって比例的な関係が見られた。図-3 に高速飛翔体の衝突条件による試験体が受ける運動エネルギーとスポール厚さの関係を示す。Plain 試験体の場合は, 飛翔体の運動エネルギー1,500J 以上から試験体厚さの半分以上のスポールが生じた。試験体の衝突面に生じるクレータ厚さを除いて裏面のスポール厚さは試験体の全体厚さの約 80%以内の範囲で形成されることがわかった。また, 繊維補強セメント複合体において, S4 試験体は裏面の一部が隆起したが, 飛翔体の運動エネルギー7,000J 以内では試験体のスポールを抑える耐衝撃性が見られた。さらに飛翔体の貫通に伴ってスポールが観察された PVA2 試験体は, 試験体の厚さの 50%以内とおり, 裏面損傷は限定的であった。図-4 に高速飛翔体の衝突条件によって試験体が受ける運動エネルギーと質量変化率の関係を示す。飛翔体の運動エネルギーが増加するほど質量減少率が大きく, より多く飛散する傾向が見られた。また, その関係式の勾配は Plain 試験体が最も大きく, 相関係数 R2 も 0.93 で高い相関性が認められた。一方, 繊維補強セメント複合体の質量変化率において, 本研究で飛翔体の運動エネルギーが一番大きい約 7,500〜8,000J の場合においても, 約 5%以下の質量変化率であり, Plain 試験体より著しく小さく, 飛散に対する繊維補強の効果が認められた。
図-5 繊維補強セメント複合体の混入繊維による繊維とマトリックスの関係

図-5 に繊維補強セメント複合体において、PVA 繊維と鋼繊維がマトリクス内に分散されている状況を示す。PVA 繊維と鋼繊維の物理的特性の差からマトリクス内の分散は異なり、例えば、1m³の体積に1.5%の体積混入率の場合、繊維の比表面積は、径の細いPVA 繊維で1.5E+9mm²、径の太いS 繊維で3.8E+8mm²となる。すなわち、PVA 試験体の方がS 試験体より密にマトリクスを補強でき、高速飛翔体の衝突による損傷抑制に対して効果が高くなった要因と考えられる。

図-6 高速飛翔体の衝突による試験体の断面破壊状況

図-6 に高速飛翔体の衝突による試験体の断面破壊状況を示す。繊維補強セメント複合体は裏面剥離が生じる支点が Plain 試験体より裏面に近いため裏面剥離による損失量が低減される。また、その差は混入繊維の種類によるひび割れの分散（応力分散能力）程度の影響も作用する。

4 ま と め

高速飛翔体の衝突実験による繊維補強セメント複合体の耐衝撃性を検討した結果、本実験範囲内で以下の結論を得た。

1) 繊維補強セメント複合体は繊維無補強 Plain 試験体より約4倍以上の飛翔体の運動エネルギーでもクレータのみ生じる結果となった。また、繊維補強セメント複合体は貫通した破壊等級においても、Plain試験体のように破断されることなく、試験体の形状が保持することが出来た。

2) 試験体のクレータ深さとスポール厚さの比率については、Plain 試験体は約2.5:7.5、繊維補強セメント複合体は約6:4となり、繊維補強セメント複合材料の方がスポール発生の区間を裏面に近いことに制限できた。

3) 衝突実験前後の試験体の質量変化率と飛翔体の運動エネルギーの関係から、最低破壊等級（貫通）でも繊維補強セメント複合材料は質量変化率が最大5.26%であり、高い損傷養成効果が認められた。

4) ある体積に分散されている混入繊維全体とマトリックスとの比表面積はS 試験体よりPVA 試験体が大きいため、繊維補強セメント複合材料中でも異なる破壊性状が見られたが、使用する混入繊維の引張強度や繊維表面特性、繊維混入率などの影響については、今後検討する必要がある。
1 Introduction

We have had two exchange visitors as a result of the MML collaboration project. Dr Vlado Lazarov from the University of York has visited Tokyo Institute of Technology and Dr Kosuke Matsuzaki has visited the University of York. During these visits useful discussion between the York and Tokyo Institute of Technology group have taken place. Discussion on the obtained results (as summarised below) has been conducted and research direction for future direction has been carefully considered.

2 Aims of Research

While III-V binary nitrides have been playing central roles in modern electronic devices, non III-V nitrides have not been studied very much. Sn3N4 has attracted renewed attention due to its outstanding chemical and physical properties. Among group IV nitrides, e. g. Ge3N4 has three different crystalline structures such as α-Ge3N4, β-Ge3N4 and spinel γ-Ge3N4. In the case of Sn3N4, only γ-Sn3N4 is experimentally observed which has high thermally stability and has a band gap within the visible range, thus making it suitable for optical and electronic applications [1, 2]. However, current growth methods for synthesizing Sn3N4 are not straight forward, and its structures are not well understood due to lack of experimental results. Therefore, experimental investigation of phase transformation in Sn3N4 is important for optimizing a growth condition which is viable for industry as well as for its structure dependent properties for device applications. In addition to Sn3N4, semiconducting Cu3N thin films have been studied using high resolution transmission electron microscopy, electron diffraction and X-ray diffractometry to identify crystal and interfacial defects, as well as phase, in the copper nitride films in order to understand the nucleation processes in forming these films and the observed Cu3N phases for future device development. Cu3N films are an example of non-toxic earth abundant material that can be bipolar doped for p-type and n-type applications, important for MOSFET and solar cell devices. Homojunctions of Cu3N previously produced have demonstrated acceptor and donor level states in the band gap associated with Cu and N vacancies [4] providing p-type and n-type behaviour respectively. The Cu3N films, which are of the order of 20nm in thickness, have been produced using plasma assisted molecular beam epitaxy (PA-MBE) at various temperatures and nitrogen pressures in order to control the doping level in the films. Copper indium gallium selenide (CIGS) hetero-junctions (CIGS/CdS/ZnO) are already being commercially produced but due to band offsets at the interface, the efficiency of the device is only around 20% [5]. Although this is high for CIGS based solar devices, homo-junctions would reduce the anomalies associated with significant shifts in the band structure at the interface.

3 Results

In this work, SnNx thin films were grown on YSZ(111) substrate by plasma assisted pulsed laser deposition under different substrate temperatures, i.e. 400°C (sample #43), 450°C (sample #47) and 500°C (sample #48). Using x-ray diffraction (XRD), we observed that the films are oriented to the substrate and have two distinctive cubic phases, noted phase A and phase B as shown in Figure 1, of which lattice parameters are 5.4 Å and 4.9 Å, respectively. The sample #43 is a mixture of spinel γ-Sn3N4 and phase A, whereas sample #47 and #48 are of phase B type. We also found that the phase B is stable at 400°C - 500°C, according to XRD results (not shown). Cross sectional high resolution transmission electron microscopy (HRTEM, Jeol 2200) results are shown in Figure 2, 3, 4. Figure 2 shows overall film quality of each sample. Film thickness and island sizes are tabulated in the Table 1. Figure 3 is a HRTEM image of sample #43 viewed from [1-10] direction, the inset is a corresponding diffractogram. Images show many twins and missing planes in this film. The film is cubic structure and the inter-atomic spacing of the film is identical to that of substrate. HRTEM images and diffractograms of sample #47 and #48 are shown in Figure 4. Likewise, these samples are also cubic structure, the inter-atomic spacing is identical but slightly less than sample #43. The ratio is the same with the lattice.
parameter ratio of phase A and B calculated from XRD patterns. Sample #47 has good crystallinity, both samples show island growth. However, sample #48 has some amorphisation, this could be due to sample preparation.

**Figure 1 (left):** XRD of the prepared samples in as prepared state. **Figure 2 (right):** Cross sectional TEM images showing SnNx films deposited on YSZ (111) substrates. HRTEM image of the sample #43 with a corresponding diffractogram.

**Table 1:** Film thickness and island size of the prepared films extracted from TEM results.

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<td>15.3</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>#47</td>
<td>9.8</td>
<td>5.2</td>
<td>17.5</td>
</tr>
<tr>
<td>#48</td>
<td>11.6</td>
<td>9.3</td>
<td>18.3</td>
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**Figure 3:** HRTEM images of the sample #47(left) and #48(right) with corresponding diffractograms.

Cu$_3$N films have been produced using sputtering techniques in nitrogen or ammonia atmosphere yet have not yielded perfectly ordered films [3]. Copper segregation is a problem in films produced by these methods. This work aims to show that PA-MBE and PLD grown Cu$_3$N films are ordered for both p-type and n-type films. By using lower energy growth processes the doping level can be more accurately controlled whilst reducing the presence of impurities in the films [6]. In summary, samples 41 (p-type) and 42 (n-type) present epitaxial Cu$_3$N with little mismatch between film and substrate, as shown by FFT. The distinct interfaces shown at both high and low magnification support the stoichiometry of the films. Sample 57 (p-type) at low magnification, shows discontinuity in the film structure. Sample 57 has a thicker non-epitaxial film and presents signs of possible copper segregation.
Figure 4: Bright field STEM imaging of the Cu$_3$N/STO interface for sample #42 viewed in the [1-10] zone axis - n-type Cu$_3$N. (a) Overview of the interface showing a sharp interface and uniform film thickness over long range. (b) Atomically resolved imaging showing the film/substrate interface is atomically sharp and the structural motif of perovskite STO continues through the interface into the Cu$_3$N. (c) Digital diffraction pattern from (b) shows the structure has ReO$_3$ type cubic structure and has very low mismatch with SrTiO$_3$ substrate.

Figure 5: (a) Bright field STEM image of sample 41 in [1-10] zone axis - p-type Cu$_3$N. The interface is clearly distinct and smooth. The overlaid FFT shows that the anti-ReO$_3$ type cubic structure has very little mismatch with the perovskite structure SrTiO$_3$ substrate. (b) Low magnification image of the overall film structure showing a smooth distinct interface. The film thickness is 21 nm.

Figure 6: (a) Bright field STEM image of sample 57 in (1,-1,0) zone axis – p-type Cu$_3$N. The interface is distinct however the film is not well ordered and shows patches of possible Cu segregation. FFT analysis also confirms that the film is not single crystal. (b) Low magnification image of the overall film structure. The interface is smooth and distinct between film and substrate and the film thickness is 36 nm.

Research on damping modification factors for pulse-like ground motions

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Affiliation: Wuhan University of Technology

1 Introduction

Response spectra are dependent on damping ratio of structural system in consideration, and usually regulated in seismic codes with a specific damping ratio (typically 5%, which is commonly used to represent the internal equivalent viscous damping ratio of elastic structures). Response reduction effect of damping has been recognized long ago, and supplemental damping devices have been purposely applied in the last decades to raise damping ratios of structures and thus reduce the vibration and damage caused by earthquakes. For analyzing structures instrumented with dampers, high damping spectra are generally desirable. As a usual approach, high damping spectra can be derived from 5% damping spectra by multiplying damping modification factors (DMFs) which serves to describe the variation of spectra value due to increased damping ratios.

Most of the code regulation bodies have not stated the application conditions of DMFs related to earthquake type. A problem of accuracy may rise in a situation where DMF derived from far-fault ground motions is inappropriately used in design against near-fault ground motion. It has been proved by many researches that near-fault ground motions with forward directivity effect typically present severe loading to structures and cause large deformation demand to structures. In response to this effect, various research results and seismic codes provided corresponding quantitative design approaches. Amplification of response spectrum makes design more accurate and reasonable. However, there is no currently available code having presented DMFs specifically for near-fault ground motions, and no conclusive research findings stating that whether the DMFs derived from far-fault ground motions are applicable for near-fault ground motions.

2 Aims of Research

The objective of this research is to investigate DMF of near-fault ground motions. To highlight the effect of forward directivity, which is the main reason causing severe structural damages, ground motions are carefully selected by employing a quantitative pulse index to assure that each ground motion contains a dominant pulse. The effects of dominant pulse on DMF of displacement, velocity, and acceleration spectra are comprehensively investigated, and some new findings are presented. Based on analysis results, estimation formulas of DMF dependent on pulse period are developed for different type of spectra.

3 Results

Statistical investigation of DMF is performed based on 50 carefully selected pulse-like near-fault ground motions. By modifying conventional transfer ratio function of system subjected to harmonic excitation, the
empirical estimation formulas for damping modification factor of displacement, velocity, and acceleration are developed. As example, Eq. (1) gives the suggested formulation, which includes three functions depending on \( T/T_p \). Equation (1a) is applicable for \( T \geq 0.01T_p \), it is considered that the structure is close to a rigid body, and \( DMF_d \) is assume to be 1. As \( 0.01 < T/T_p < 0.6 \), the linear interpolation in \( DMF_d \cdot \log(T/T_p) \) coordinate could be used, and the estimation formula can be explicitly expressed by Eq. (1c). Figure 1 compares the real DMF calculated from spectra with different damping ratios and those calculated by Eq. 1. Similar empirical estimation equation for velocity spectra are developed, and Fig.2 compares the DMF obtained through different ways. It is found that the proposed estimation formulas are able to produce good estimation of damping effect on structural response induced by pulse-like ground motions.

1. When \( T/T_p \geq 0.6 \),

\[
DMF_d = \sqrt{\left[1 - \left(\frac{T}{T_p} + 0.2\right)^2 + 6.44\left(\frac{T}{T_p} + 0.3\right)\right]};
\]

(1a)

2. When \( T/T_p \leq 0.01 \),

\[
DMF_d = 1
\]

(1b)

3. When \( 0.01 < T/T_p < 0.6 \),

\[
DMF_d = 1 + \frac{\log\left(\frac{T}{T_p} + 2\right)}{1.778} \left(\frac{1}{0.59 + 0.1B_{eq}} - 1\right)
\]

(1c)

![Figure 1. Distribution of computed DMF_d and estimated value by Eq. (1)]

![Figure 2. Distribution of computed DMF_a and estimated value by Eq.(17)]
4 Conclusion / Summary

(1) The near-fault ground motions used in the present study each contains a dominant pulse, which plays important role in responses and consequently damping modification factors of systems. Damping modification factor exhibit strong dependence on $T/T_p$. When $T/T_p$ is greater than 0.6, the responses of systems are controlled by dominant pulse, so damping modification factor exhibits very similar values among different ground motions in consideration. When $T/T_p < 0.6$, the responses of systems are mainly excited by high frequency components of ground motions, damping modification factor exhibits large dispersion.

(2) Damping modification factor attains minimum at $T \approx 0.8T_p$. The minimums are at the same level as those of far-fault ground motions. The existing estimation formulas of damping modification factor regulated in seismic codes are generally applicable for pulse-like ground motions only if $T \approx 0.8T_p$. Otherwise, these formulas will overestimate the response reduction effect of damping.

(3) Damping modification factors for velocity and acceleration spectra show similar dependence on $T/T_p$ as observed in displacement spectra, but increased damping leads to different levels of response reduction in different kind of spectra. Estimation formulas should be constructed respectively for displacement, velocity and acceleration.

(4) Based on computed mean of damping modification factors, empirical formulas were derived for estimating damping effect on displacement, velocity and acceleration, respectively, of pulse-like near-fault ground motions.
1 Introduction

The seismic performance of braced frame depends on the ability of the brace to fully develop inelastic deformations. Therefore, the complete response of the system is dependent on the connections and framing elements, which must be considered in the design in order to meet the desired level of performance. The connections must be able to tolerate large rotations as well as support the full compressive and tensile capacity of the brace. Gusset plate connections are common in braced frames. The UFM and effective area method are widely adopted for the gusset plate designs for steel braced frames in US and Japan, respectively, as it provides a straightforward design procedure to obtain an economical and admissable force distribution. In addition, when the braced frame is deformed, the beam-to-column joint would either open or close. Thus, the corner gusset plate in the braced frame is required to sustain not only the brace axial force but also additional forces resulted from the frame action. Several studies have reported that the gusset plate to beam or column interface fractures and the gusset plate ruptures in large-scale steel braced frame tests. It is found that the frame action forces could create large force demands on the gusset plate. However, these force demands were often ignored in the current design.

2 Aims of Research

In order to investigate the gusset force distributions on the beam and column interfaces, finite element models were constructed and analyzed using ABAQUS. To realistically simulate the behavior of corner gusset plate connections, the frame is incorporated in the finite element model. The analyses will provide knowledge of the frame action, brace action, and stress distribution in the connection components and the ability of the components to redistribute load. In the previous study, the effects of brace action on the gusset plate connections were studies by both experiments and analytical studies on local gusset plate connections. The frame to which the gusset plate is attached was excluded. A revised effective area method was proposed by considering the brace angle, eccentricity, and other parameters. Following the previous study, this study aims to offer the structural engineering community methods for determining the moments and force resultants on the gusset plate connection considering both the frame action and brace action. The proposed research will render reliable and efficient methods to analyze braced frames, determine gusset plate interface loads and stress distributions for a variety of brace configurations.

3 Results

Two braced frames were simulated using ABAQUS, as shown in Figure 1. One frame (H-S) was
comprised by wide flange beams and columns, and the other (B-S) was comprised by wide flange beams and box section columns. In the simulation, the connection portion was simulated in details by using solid elements C3D8 for H-S and shell elements S4R for B-S. The other portion was simulated using beam element B31, since these portions were in elastic in the loading and has quite few contributions on the connection behavior. The BRB was simulated by using truss element T3D2. The material properties were assigned to the model following the material test results.

![Figure 1 Numerical model: (a) H-S; (b) B-S](image)

Monotonic loading was applied on the frame, as shown in Figure 1. In this loading, the brace was in tension. The reaction force of the loading and story drift angle was shown in Figure 2.

![Figure 2 Load-story drift angle relationship: (a) H-S; (b) B-S](image)

The stress distribution along the gusset interface was forced to investigate the contribution of brace action and frame action. The stress distribution of story drift angle of 1/600, 1/250, 1/50 and 1/25 was shown in Figure 3. It is noted the stress distribution at the gusset plate interface of two frames was similar. It is might because the stiffness ratio of column and beam of the two frames was the same. And the column section has minimal effect on the stress distribution of the gusset plate interface.

The stress distribution of the gusset plate interface was quite small when the BRB yielded, in which the story drift was 1/600. And the shear stress of the weld all reached yield level when the story drift was 1/50, in which the frame was yield. After it, the stress distribution did not change much till the end of loading. The same tendency was observed when the loading is opposite direction, in which the brace was in compression.
To investigate the frame action on the gusset plate interface, the frame without BRB was investigated, too. The stress distribution of the interface when the story drift angle was 1/600, 1/250, 1/50, and 1/25 in both positive loading was shown in Figure 4.

![Figure 3 Stress distribution of gusset interface in positive loading](image)

![Figure 4 Stress distribution of gusset interface without brace action in positive loading](image)

It is noted that there is a difference of normal stress, shear stress, and von Mises stress on the gusset plate interface between braced frame and pure frame. And the difference of normal stress was increased as the story drift increased. It is supposed to be the contribution of brace action. However, the difference of shear stress and von Mises stress was reduced to nearly zero when the story drift angle was 1/50, in which frame yielded.

4 Conclusion / Summary

Based on the simulation results, the following conclusions were summarized.

1. Before the main frame yield, the gusset plate interface stress distribution was mainly affected by the brace action. After that, the stress distribution was mainly affected by the frame action. And this is the same when brace either in tension or compression.

2. The shear stress and von Mises stress distribution of the gusset plate interface were the same when the frame in positive loading or negative loading (brace in tension or compression). The normal stress distribution of the gusset plate interface was similar but the stress direction was different when the frame in positive loading and negative loading.
Exploration for Os–based spinel AOs$_2$O$_4$ (A=Ca, Sr and Ba) under high pressure

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1 Introduction

Theoretical work has played a key role in the discovery of novel topological insulators (TIs), where time reversal symmetry protects unusual surface states which could lead to electronic devices with new functionalities[1-3].

In addition to these unusual electronic properties, introducing magnetic order on the surface of TIs can gap the surface states leading to completely insulating behavior. Here, novel phenomena such as the half quantum Hall effect [4] and the quantized magnetoelectric effect [5] appear. The latter is parameterized by the quantized value of the axion electrodynamics parameter $\theta=\pi$ [5,6]. However, in most known materials, it is extremely small, e.g., $\theta=10^{-3}$ and $10^{-4}$ in Cr$_2$O$_3$ and BiFeO$_3$, respectively [7]. Thus, achieving large values of the parameter, even in the absence of quantization, is an important materials challenge.

Because of the interplay of strong spin-orbit coupling and moderate electronic correlations, very recently systems with 5$d$ electrons have received a lot of research attention. It has been suggested that pyrochore iridates exhibit novel phases such as TI [8,9] and topological semimetal [10] behavior. As in pyrochlores A$_2$B$_2$O$_7$, spinel compounds AB$_2$O$_4$ have their four B sites forming a corner-sharing tetrahedral network. Furthermore, it may be expected that 5$d$ systems in the spinel structure will be more tunable by pressure, external fields, or doping as compared to the closely packed pyrochlore lattice. Previous studies suggested that the electronic $d^0$ configuration can realize an insulating state in 5$d$ compounds [11].

X. Wan et al performed theoretical calculations on spinel osmates AOs$_2$O$_4$ (A is an alkali metal element such as Mg, Ca, Sr, or Ba) and investigated their electronic structure and magnetic properties by using density functional theory. Their results showed that the ferromagnetic configuration was the ground state of the candidate orders considered and the electronic properties were sensitive to the A site. Depending on the strength of the Coulomb correlation, they showed some exotic properties, and for the range of U’s relevant to the Os element, they predicted that CaOs$_2$O$_4$ and SrOs$_2$O$_4$ to behave as magnetic axion insulators with $\theta=\pi$ [12].

2 Aims of Research

To synthesize spinel osmates AOs$_2$O$_4$ (A is an alkali metal element including Ca, Sr and Ba) using high-pressure and high-temperature conditions, and study their electronic structure and magnetic properties. Meanwhile, verifying the theoretical results of X. Wan et al [12] (i.e. the so-called Axion Insulators).
3 Results

During the CRP-B in 2014, we focused on the high-pressure and high-temperature synthesis of spinel osmates $\text{AO}_2\text{O}_4$. We tried Ca, Sr and Ba for A site in turn to change the tolerance factor and tried several synthesis pressures ranging from 2 GPa to 6 GPa. But we were failed to get a spinel phase. X-ray diffraction (XRD) showed that the resulting compound were always consisted of perovskites or pyrochlores.

Instead, we were successful to prepare a new compound $\text{CaOs}_2\text{O}_6$ at 9 Gpa and 1200°C. XRD shows that $\text{CaOs}_2\text{O}_6$ crystalized into a cubic phase which belongs to $\text{Pm-3}$ space group with lattice constant $a = 3.89 \text{ Å}$. And the dc magnetic susceptibility of $\text{CaOs}_2\text{O}_6$ at $H = 1000 \text{ Oe}$ shows paramagnetism behavior. The susceptibility data between 300 K and 170 K can be well fitted based on the Curie–Weiss law with the formula $\chi = C/(T-\theta)$, giving the Curie constant $C = 0.944 \text{ emu K/mol Oe}$ and the Weiss constant $\theta = -626 \text{ K}$. The resistivity of $\text{CaOs}_2\text{O}_6$ is very large, indicating the insulating nature. We are now summarizing all the data for publication.

4 Conclusion / Summary

For the synthesis of spinel osmates $\text{AO}_2\text{O}_4$, although different alkali metal elements Ca, Sr and Ba were used for the A site and adequate synthesis pressure ranging from 2 Gpa to 6 Gpa were applied, we were failed to get an spinel osmates $\text{AO}_2\text{O}_4$. However, we are fortunately to get a new compound $\text{CaOs}_2\text{O}_6$ at 9 Gpa and 1200°C. It behaves as a paramagnetic insulator.

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References:


1. Introduction

Topological insulators (TIs) are unconventional materials recently discovered with electronic structure topologically different from regular insulators. A TI is insulating in the bulk, but has conducting surface states formed by an odd number of Dirac fermions with helical spin structure. Moreover, these unusual surface states are protected by the time-reversal symmetry, and thus immune to any time-reversal invariant perturbations, such as crystal imperfections/disorders and non-magnetic impurities. Since their theoretical proposal in 2007, TIs have grown as one of the most intensively studied subjects in condensed matter physics due to its great scientific significance and many application potentials.

2. Aims of Research

The realization of many unusual properties of TIs (e.g. the topological surface transport and topological magneto-electric effects) and potential applications (e.g. topological p-n junctions) requires the tunability that either the Fermi energy resides in the bulk band gap, or bi-polar junctions are formed by oppositely doped TIs. Therefore, we study systematically how TI materials are affected by dopants, thus helping to guide the applications in a technologically controlled manner.

3. Results

High-quality single crystals of Bi$_2$Se$_3$/Bi$_2$Te$_3$/(Sn,Bi)$_2$Te$_3$/(Sb,Bi)$_2$Te$_3$ were prepared by the melt growth technique, and the samples were cleaved in situ along (1 1 1) direction before measurement. The ARPES measurements were carried out at Beamline 10.0.1 of Advanced Light Source in Lawrence Berkeley National Lab and Beamline 5.4 in Stanford Synchrotron Radiation Lab.

As-grown Bi$_2$Se$_3$/Bi$_2$Te$_3$ samples are bulk $n$-type, as Se and Te can easily escape from the crystal and cause anion vacancies. An efficient way to $p$-dope TI materials is to introduce holes by substitution. Figures 1(a) and (b) show the comparison between the electronic
structures of Sn-doped and undoped Bi$_2$Te$_3$. The clear energy shift of the $E_F$ into the bulk gap shows the $p$-doping effect of Sn (as it has one less valence electrons than Bi).

Interestingly, opposite to Bi$_2$Te$_3$, as-grown Sb$_2$Te$_3$ are usually $p$-type in bulk, possibly due to the Sb substitution on Te sites. This provides a possibility to tune the bulk carrier type and concentration by controlling the Sb/Bi ratio in (Sb$_x$Bi$_{1-x}$)$_2$Te$_3$ compounds. Figures 1(c)–(f) show the electronic structures of different Sb substitutions in (Sb$_x$Bi$_{1-x}$)$_2$Te$_3$. With increasing Sb doping, the Fermi surface shrinks and the chemical potential is lowered with respect to $E_D$. A similar effect can be also achieved by cation substitution.

![Figure 1](image)

Figure 1. Bulk chemical potential tuning by different methods as examined by ARPES measurements. (a)-(f) Fermi surface maps (upper) and band structure plots along Γ-K (lower) of (Sn$_{0.67}$Bi$_{1.33}$)$_2$Te$_3$ ($\delta = 0.67\%$), Bi$_2$Te$_3$, (Sb$_{0.25}$Bi$_{0.75}$)$_2$Te$_3$, (Sb$_{0.5}$Bi$_{0.5}$)$_2$Te$_3$, (Sb$_{0.75}$Bi$_{0.25}$)$_2$Te$_3$, and Sb$_2$Te$_3$, respectively. The energy positions of Dirac points ($E_D$), SSB, BCB and BVB are indicated.

4. Summary

We systematically studied the doping effects on topological insulators (TIs) Bi$_2$Se$_3$ and Bi$_2$Te$_3$, and demonstrated the possibility of full range tuning of $E_F$. To tune down the $E_F$ in bulk, we could introduce $p$-type dopants (e.g. Sn), or partially substitute Bi by Sb. The ability to control the carrier types and the concentration of TIs will greatly facilitate future applications.
Passive Controlled RC Building Structures with Novel Configurations of Buckling Restrained Braces

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1 Introduction

Buckling restrained braces (BRBs), which exhibit stable hysteric behavior and provide superior energy dissipation capacity to building structures, have been extensively studied and applied to various types of steel braced frames since 1980s. In contrast, however, the applications of BRBs in reinforced concrete (RC) structures are quite limited, and are mostly confined to the retrofit of existing buildings. A major limitation comes from the troublesome connection between steel braces and concrete member, which are usually incapable of accommodating large concentrated tensile force. Innovative solutions are needed for the local connection of BRBs and concrete members in order to promote the applications of BRBs in the seismic protection of RC buildings.

2 Aims of Research

For more efficient and reliable connections for BRBs in RC frames, the “unconstrained gusset connection” by Berman and Bruneau (2009) was tried out for BRBs in RC frames through experimental investigation (Figure 1). A “damage control” scheme is proposed for the local connection region in which the RC beam end that receives an unconstrained BRB gusset is expected to remain free of damage even if the structure is subjected to major earthquakes. In other words, the potential plastic hinge zone at the RC beam end is expected to be relocated outside the gusset connection region, that is, forward to the center of the span, similar in concept to the reduced beam sections (RBS) in steel moment-resisting frames developed after the 1994 Northridge earthquake.

Figure 1. Unconstrained gusset connection for buckling restrained braces
3 Results

The unconstrained gusset connection together with the damage control scheme is examined through subassemblage cyclic loading tests. Cantilever beams with diagonal braces were taken as specimens assuming the column has little to do with the local behavior of the proposed connection. Each cantilever beam was rotated 90° in the test setup and was cast into an RC stub at the bottom, which was fastened to the lab strong floor through six post-tensioned steel rods and was anchored by a pair of steel shear keys on both sides (Figure 2). The beam free end (i.e. the upper end in the test setup) was driven by two 200 kN displacement controlled actuators in parallel. Instead of using real BRBs, a 1000 kN force-controlled actuator was used to simulate the brace force acting on the gusset plate. The nominal strength of the BRB in test is assumed to be 500 kN.

![Figure 2. Test setup](image)

4 Conclusion / Summary

From the test results and the above discussions, the following conclusions can be drawn: (1) In addition to eliminating the impairment to the RC column, it is possible to minimize the influence of the unconstrained gusset connection on the RC beam performance by adjusting the flexural strength of the beam section outside the connection region, where the potential plastic hinge is relocated. Besides, the BRBs generally begin to sustain plastic deformation at much smaller story drift (less than 1/500) than the RC beam does (around 1/100), even if the deformation loss at the gusset connection is taken into account. This makes it possible to take full advantage of BRBs to dissipate energy and reduce the global seismic response before the RC frame sustains considerable damage. (2) The design for local damage control at the RC beam end was effective in moving the potential plastic hinge outside the connection region. This is confirmed by the observed crack pattern on the beam surface as well as the strain readings of the beam longitudinal bars. An immediate benefit of doing so is to
prevent the dislocation of the BRBs from the rest of the structure in case the beam fails in extreme earthquake scenarios. (3) Another benefit of the local damage control is to reduce the deformation loss at the gusset connection. The test results proved that the RC beam deformation does have an effect on the deformation loss especially when the beam end sustained considerable damage.