STUDIES ON IMPACT RESISTANCE BEHAVIOR OF WOVEN TEXTILE STRUCTURES TREATED WITH SHEAR THICKENING FLUIDS

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by

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CERTIFICATE

This is to certify that the thesis titled **Studies on impact resistance behavior of woven textile structures treated with shear thickening fluids**, being submitted by Mrs. Ankita Srivastava to the Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy, is a record of bonafide research work carried out by her. She has worked under our guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this institute.

The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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Dedicated To my Daughter- Sanvi

ABSTRACT

Use of shear thickening fluids (STF) to improve the impact resistance performance of soft body armor materials like woven Kevlar fabrics is a novel and relatively new concept which has generated a lot of interest among scientific community. However, there is still no clear understanding about the mechanism behind this improvement primarily because the textile fabrics are complex structures whose combination with STFs can lead to very complex interactions.

It can be assumed that the degree of penetration and uniformity of distribution of STF in yarn and fabric structures would play a key role in such enhancements. Since the distribution of STF in yarn and fabric structures would depend a lot on application process parameters like padding pressure and solvent to STF ratio, their role in influencing the impact resistance performance of Kevlar fabrics becomes important. However, no such study has been conducted so far which is an important missing link in this area.

This thesis is an attempt to investigate the role of different process parameters of STF application in improving impact resistance performance of Kevlar fabrics and optimization of the process parameters using the design of experiment methodology.

The materials chosen for this study were 200 and 465 GSM plain woven Kevlar fabrics with and without a water repellent fluorocarbon finish respectively. Shear thickening fluid was prepared by mixing 100 nm size silica with PEG at 50, 60 and 70% w/w concentrations. The STFs were diluted by ethanol and then applied on Kevlar fabrics using a padding mangle at pressures of 0.5, 1 and 2 bar. The characterization and testing of the treated fabrics were done

by STF add-on %, SEM, yarn pull-out test, dynamic impact test and low velocity ballistic test.

Rheological analysis of STFs revealed that after initial shear thinning, shear thickening takes place. Critical shear rate decreases with increase in silica concentration and reduction in temperature.

It was found that STF application significantly enhances the impact resistance performance of Kevlar fabrics. It was also seen that higher silica concentration and lower padding pressure increase the add-on % of STF which results in higher yarn pull-out force. However, impact resistance measured with dynamic impact tester shows a different trend where higher silica concentration and higher padding pressure result in higher impact resistance performance. It is postulated that higher padding pressure facilitates uniform distribution and penetration of STF within yarn and fabric structures. Hence, even though add-on % of STF may be lower at higher padding pressures, it helps to improve impact resistance. This behavior suggests that friction (represented by yarn pull-out force) plays only a partial role and shear thickening plays a more pivotal role in improving impact energy absorption.

A new treatment method was designed to study the effect of sequential padding on impact energy absorption by subjecting the Kevlar fabrics to the process of padding twice with a given STF at different padding pressure combinations. It was found that impact resistance performance increases significantly with sequential padding as compared to untreated and single padding processes. Better results were obtained when the first padding pressure was higher even with same combination of pressures. A low velocity ballistic test also confirmed the findings as sequentially padded fabric showed almost 125% increase in impact energy absorption than untreated Kevlar fabrics.

Optimization of three parameters (silica concentration, padding pressure and solvent: STF ratio) was carried out using Box and Behnken experimental design plan. Contour plots were generated to analyze the interactive effect of process parameters on STF add-on % and impact energy absorption. It was found that higher silica concentration, higher padding pressure and lower solvent: STF ratio contributed to the higher impact energy absorption. It could also be concluded that higher STF add-on % is a necessary but not the sufficient condition for achieving higher impact energy absorption.

Impact energy absorption modes were analyzed for untreated and STF treated Kevlar fabrics. Three distinct zones of energy absorption were identified. In untreated Kevlar fabrics, failure was dominated by pull-out of primary yarns and there was negligible contribution of secondary yarns in energy absorption. However, in case in STF treated Kevlar fabrics, failure was dominated by the rupture of primary yarns and there was significant contribution of secondary yarns in impact energy absorption. It is postulated that STF helps to engage the secondary yarns in energy absorption during impact and thus the entire fabric structure contributes to it.

CONTENTS

LIST OF FIGURES

LIST OF TABLES