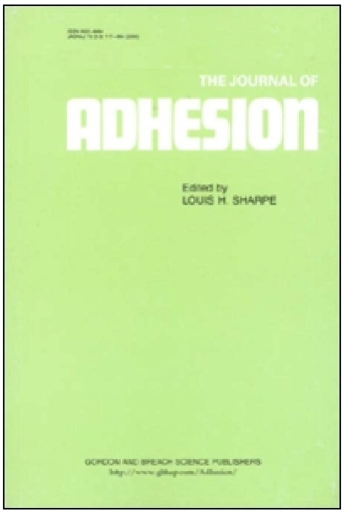
This article was downloaded by:
On: *21 January 2011*
Access details: *Access Details: Free Access*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



The Journal of Adhesion

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453635

Effects of Disturbing Parameters on the Stability of Latex and Resorcinol Formaldehyde Latex Based Adhesives

Berrin Yilmaz[a]
[a] Kordsaglobal Industrial Yarn and Tire Cord Fabric Manufacturing and Trading Inc., Izmit-Kocaeli, Turkey

Online publication date: 15 April 2010

To cite this Article Yilmaz, Berrin(2010) 'Effects of Disturbing Parameters on the Stability of Latex and Resorcinol Formaldehyde Latex Based Adhesives', The Journal of Adhesion, 86: 4, 430 — 446

To link to this Article: DOI: 10.1080/00218461003704410

URL: http://dx.doi.org/10.1080/00218461003704410

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

The Journal of Adhesion, 86:430–446, 2010
Copyright © Taylor & Francis Group, LLC
ISSN: 0021-8464 print/1545-5823 online
DOI: 10.1080/00218461003704410

Effects of Disturbing Parameters on the Stability of Latex and Resorcinol Formaldehyde Latex Based Adhesives

Berrin Yilmaz
Kordsaglobal Industrial Yarn and Tire Cord Fabric Manufacturing and Trading Inc., Izmit–Kocaeli, Turkey

Synthetic cords may be coated with resorcinol formaldehyde latex (RFL)-based adhesives to adhere the cord to the rubber in industrial goods such as tires and conveyor belts. The stability of the adhesive and the stability of its component latex are crucial, both for ideal adhesion and for the homogeneity of the cord surface. Latex is a colloidal polymeric dispersion, which may lose its stability upon mechanical stress or upon interaction with some chemicals that lead to the formation of coagulated polymeric particles. This article reports on the influences of both external mechanical stresses and chemical interactions on RFL adhesives and latex stability, adhesion, and viscosity. High speed mixing, treatment with excess RF, and temperature variations were applied as disrupting parameters.

Keywords: Adhesion; Adhesive solution; Latex; Mechanical stability; Resorcinol formaldehyde latex

INTRODUCTION

Tire cord fabric, conveyor belt fabric, and single end cord are examples of reinforcing materials for rubber goods. These are usually made of synthetic yarns such as polyamide 6.6, polyamide 6, polyethylene terephthalate, viscose rayon, aramid, etc. Reinforcing textile cords are treated with resorcinol formaldehyde latex (RFL) adhesive to improve bonding between the cord and the rubber. RFL is applied to the surface of cords by immersing the cord in a RFL solution, followed by drying at moderate temperatures and curing at high temperatures.

Received 12 June 2009; in final form 14 December 2009.

Address correspondence to Berrin Yilmaz, Kordsaglobal Industrial Yarn and Tire Cord Fabric Manufacturing and Trading Inc., Kordsaglobal A. S. Alikahya, 41310 Izmit-Kocaeli, Turkey. E-mail: berrin.yilmaz@kordsaglobal.com

RFL forms an interface layer between synthetic cord and rubber, so it is critical to the integrity of the final rubber composites, such as tires. To investigate the performance of the RFL layer, some parameters such as uniformity of cord surface and curing conditions should be considered. The uniformity of the cord surface means a smooth coating of the cord surface with RFL which is free from any impurities or contaminants. Coagulated polymeric particles are considered as contaminants that occur as a consequence of RFL and latex destabilization. The influences of chemicals and mechanical agitation on latex and RFL stabilities were analyzed.

RFL adhesive is a well known water-based system. Although there are some variations between RFL recipes, a typical recipe contains 80% water and the remaining solid (20%) is comprised of resorcinol, formaldehyde, catalyst, and rubber derived from latex; in most cases, 18% of this solid is rubber. The properties of RFL-based adhesives have been investigated in detail within the literature [1–7].

Latex is, in general, an aqueous system in which polymer particles are homogeneously distributed as a colloidal dispersion. It is a two-phase system, made of aqueous and solid polymer particles and, therefore, the surface interaction phases are: water to polymer particles and, aqueous to air. Surface active agents, liquid phase modifiers, and elastomeric phase modifiers are the other ingredients of synthetic latex that keep the polymer particles suspended in the liquid without any phase separation, in other words, maintaining the stability of the latex. The interaction between the aqueous phase and the particles has a certain effect on the latex stability [5]. Improper interaction causes the coagulation of particles to create larger particles. It was found that as the particle size increases the interfacial energy decreases. Therefore, latex may be considered as thermodynamically unstable.

The stability of latex can be disturbed if the barrier keeping the polymer particles away from each other in an aqueous system is overcome. This can be caused either by the contribution of chemical coacervants or by physical interactions like high-speed mixing. Some examples of chemical coacervants are strong acids, metallic ions, and organic solvents. Once polymer particles are desorbed from an aqueous medium, they agglomerate irreversibly, either staying suspended within the solution or migrating toward the surface and floating, depending on the size of the agglomerates. Such agglomerated particles are considered as contaminants or impurities in tire cord applications. If they stick to the cord, they create a defect point for adhesion, which is regarded as a serious quality defect [5].

Latex can be exposed to considerable mechanical and chemical agitations at different stages, from transportation to adhesive preparation and treatment in the dipping line. During transportation, assuming the absence of any chemical attack, latex may be exposed to severe temperature changes or shaking, which may cause agglomeration of particles. Pumping to storage tanks exerts a pumping pressure. Latex is exposed to some mechanical and chemical disturbances during the preparation of adhesive solution and during treatment of cord. These necessary processes define the stability required for colloidal dispersion. In the present study, some of these activities were simulated on a laboratory scale. Indeed, there are many subheadings for each activity, for instance how to store latex, how to mix, how to prepare adhesive, etc.

As mentioned above, the main component of an adhesive solution is water. The contaminants in water directly affect the agglomeration behavior of polymer particles. Metals and metal salts available in water are considered as contaminants. Porter reported that metals such as iron, copper, nickel, and chromium and metal salts such as lead nitrate, nickel nitrate, sodium chloride, etc., have significant effects on the agglomeration of particles, demonstrated by observing residue on the cord surface [8].

MATERIALS AND METHODS

Materials

Commercially available vinyl pyridine latex (VP) and styrene butadiene latex (SBR) were utilized in all analyses.

VP latex (Eliokem, Courtaboeuf, France) is an aqueous dispersion of terpolymer of butadiene, styrene, and vinyl pyridine with 41% solid content. The butadiene, styrene, and vinyl pyridine contents of VP latex are approximately 70, 15, and 15%, respectively. It is basic in nature, having a pH above 9.

SBR latex (Polymer Latex GmbH, Marl, Germany) is an aqueous colloidal dispersion of a copolymer of butadiene and styrene with a composition of approximately 70 and 30%, respectively. The solid content of SBR is approximately 41% and it is a basic dispersion with pH above 9. Both VP and SBR latices are utilized in tire cord fabric, conveyor belt fabric, and single end cord.

A typical RFL adhesive recipe is given in Table 1 [8]. The main components are resorcinol, formaldehyde, SBR, and/or VP latex. The solid content in most cases is around 20% and almost 40% of the formulation is latex. Two types of adhesive formulations, termed

TABLE 1 A Typical RFL Recipe [8]

Chemicals	Wet quantity, g
Resorcinol	1.89
Formaldehyde	2.79
Sodium hydroxide	0.05
Latex	41.97
Water	51.35
Total	100.00

Adhesive A and Adhesive B, were analyzed. Adhesive A is a VP latex-based formulation containing no SBR; 41% of Adhesive A is VP latex and 59% is other components, including water. Adhesive B contains both VP and SBR latex. Total latex quantity is 45%, of which 22% is VP and 23% is SBR; the remaining 55% of Adhesive B is comprised of other components, including water. The adhesive formulations were prepared using distilled water.

The resorcinol (Indspec Chemical Corporation, Pittsburgh, PA, USA), formaldehyde (37%) (Polisan, Istanbul, Turkey), and sodium hydroxide (Ak-kim, Yalova, Turkey) used in adhesive preparation are all commercially available products.

Methods and Measurements

The methods used for analysis were in accordance with ASTM D1417 (Volume 7.02).

The mechanical stability of the samples was measured by using a CSI latex stability tester (Custom Scientific Instruments, Inc., Easton, PA, USA). 50 g of the sample was poured into the glass vessel of the instrument. The samples were subjected to 14000 rpm for 10 minutes. Temperature variations were then recorded.

The foaming tendency of latex and adhesives solutions was also investigated. 50 mL of the sample was poured into a graduated cylinder which was rotated slowly for 2 minutes. Foaming occurred on top of the liquid. The initial foam height and its decay with time were recorded from the graduated cylinder.

The chemical stability of latex and adhesive solutions was measured by addition of RF resin solution. Resorcinol (7 g) and formaldehyde (37%) (4 g) were dissolved in water (13 g). The RF solution was left for maturation for 1 hour. Latex and adhesive solution (39 g) were diluted with water (37 g). RF solution was poured into a latex or adhesive solution. The mixture was stirred gently for 2 hours, after which it was filtered through a 100 mesh sized filter. The residue remaining on the filter was dried and weighed. The result was recorded as % coagulum = (weight of residue/weight of solution) × 100. Increased residue on filter indicates decreased chemical stability.

Particle size measurement used a Malvern Zetasizer 1000HS (Malvern Instruments Ltd., Worcestershire, UK). One drop of the sample was added to 50 mL of 0.010 mol of NaCl solution. The mixture was poured into the sample cell of the instrument for measurement.

Measurement of pH used an Orion Expandable Ion Analyzer (Thermo Scientific, Waltham, MA, USA) and glass electrode. Viscosity was measured by a Brookfield LVTDV-II viscometer (Brookfield Engineering Laboratories, Inc. Middleboro, MA, USA) with a UL spindle, rotating at 60 rpm.

Adhesion tests were carried out by coating synthetic cord with an RFL solution. RFL-dipped cords were heat treated at 220°C for 15 minutes. The heat-treated cords were rubberized at 160°C for 20 minutes. The rubberized cords were pulled out from the rubber to measure the adhesive force using an Instron tension tester (Instron, Norwood, MA, USA) instrument with a speed of 300 mm/min.

A Leica MZFLIII microscope (Leica Microsystems GmbH, Wetzlar, Germany) was used to take the photographs of coagulated latex and the adhesion samples. The magnification was 8.

Observations were made to analyze visible change in the samples, mainly skin formation, color change, and any phase separation and sedimentation.

Latex and adhesive solutions were kept at different temperatures for different time intervals. In order to establish the effect of temperature, the samples were kept at different temperatures (10, 30, or 50°C) for 1 hour. In order to establish the effect of long exposures, the samples were kept at these temperatures for 4 and 8 hours. Chemical stability, particle size, pH, viscosity, adhesion, and visual observations of the samples were carried out.

Test results of chemical stability, pH, and viscosity experiments were analyzed by Taguchi L9 (2^3) design to determine the main effects of temperature and time. Temperature and time factors each have three levels, such as 10, 30, 50°C and 1, 4, 8 hours, respectively. In the response table for means of Taguchi analysis, the mean values of the levels for respective factors is calculated and then the difference between levels is reported as delta values. The delta value indicates the degree of influence of the factor. The higher the delta value, the higher the influence of the respective factor. The factors are ranked from high to low delta values.

RESULTS AND DISCUSSION

Latex undergoes some physical disturbance, beginning with its production to the RFL preparation. Transportation and also pumping from one container to another induce a physical stress to the latex. In the case of RFL-dipped cord applications, latex undergoes some mechanical stress during both adhesive preparation and adhesive treatment of synthetic cords. Mixing of adhesive solutions with the propeller of the solution preparation tanks creates a mechanical stress on adhesive solutions. During RFL treatment of synthetic cords in an adhesive treatment machine (dipping line), latex undergoes mechanical shearing between the rotating rollers. The latex and adhesive solution must remain stable under these condition; therefore, latex producers and users routinely simulate the above conditions in order to test the mechanical stability of latex. Mechanical stability testing basically creates a mechanical influence by very high speed mixing of the samples. The test violently increases the number of collisions between the particles, increasing both kinetic energy and temperature. The colliding latex particles may potentially coagulate. Latexes have approximately 0.05–0.1% coagulated residue, indicating significant improvements to the mechanical stability of commercially available products.

The RFL reaction is exothermic, so evolved heat is removed from the system to control the kinetics of the reaction. On the other hand, the temperature experienced by the adhesive solution and synthetic cord during dipping may be as high as 200–250°C. The cord is dried at lower temperatures then cured at higher temperatures. The mechanical stability test indicates the temperature behavior of the samples. When the sample is exposed to high mechanical stirring forces, an increase in the temperature of the sample was observed. The change of temperature of the samples was measured at 2 minute intervals for 10 minutes. The high speed stirring caused foaming of the samples; therefore, 0.08 g antifoaming agent was added to the samples. The data are given in Fig. 1. The temperature of the VP latex rapidly increased to 59°C, and the rate of temperature increase was approximately 3.5°C/min. In comparison, the SBR latex ran cooler; the temperature increased to a maximum of 34°C at a rate of 1.2°C/min. The adhesive solutions ran cooler than VP latex up to a maximum temperature of 45°C.

Latex has a tendency to foam, usually caused by the presence of surface active agents necessary for latex production. These agents have a certain effect on surface tension and a foaming tendency. The foaming tendency of latex is reflected by the foaming behavior of adhesive solutions. During RFL treatment of the synthetic cords,

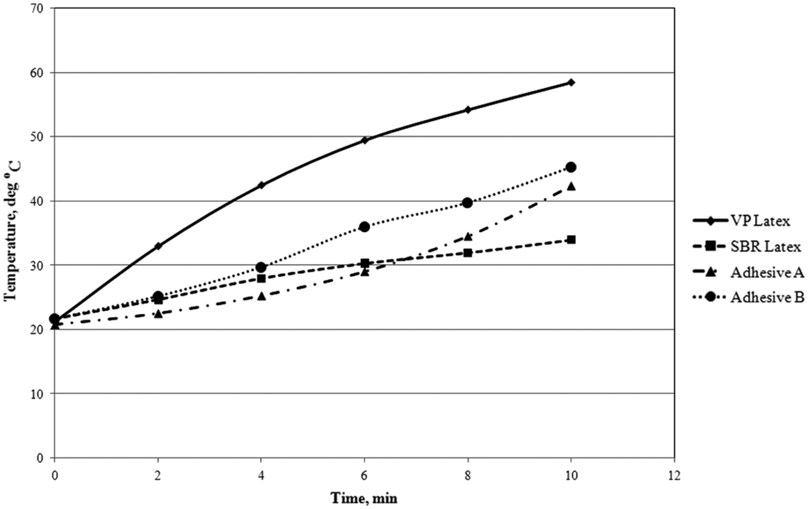


FIGURE 1 Temperature variations of samples during mechanical stability testing.

uncontrolled foaming for long periods creates some agglomerated polymer particles on parts of the dipping machine or in the adhesive solution. These particles may adhere to the surface of synthetic dipped cord, resulting in contaminated cord, which is considered to be a quality defect. Using anti-foaming agents or de-foamers eliminates or minimizes this foaming, but care should be taken in antifoam usage, because it can also inhibit adhesion. The foaming tendencies of latex and adhesive solutions were analyzed on a laboratory scale. The samples were agitated to induce foaming. It was observed that both latex and adhesive solution samples foamed. A thick layer of foam occurred on top of samples and the foam was permanent for 90 sec. For instance, latex samples had foam 25–35 mm in height, whereas adhesive solutions had 50 mm of foam. The foam was stable for a period of 90 sec, during which no change was observed in the height of the foam. The adhesive solutions had a higher foaming tendency compared with the latex. However, the addition of 0.01 g antifoaming agent eliminated the foaming of the samples.

RFL preparation mainly consists of bringing the latex into contact with RF and the catalyst of the adhesive solution. It can be considered as typical chemical agitation. If the correct method of mixing is not performed, agglomeration of polymer particles is inevitable to varying extents. In some cases, the agglomeration becomes so large that the adhesive solutions cannot be processed. Therefore, care should be taken during this process. In this study, chemical agitation was achieved by using excess RF solution.

The influence of temperature in the presence of chemical disturbance was also investigated. Experimental temperatures were chosen as 10, 30, and 50°C. The temperatures were selected as limiting points that latex solution may undergo in the life cycle from transportation to the dipping process.

The latex and adhesive solutions were kept at the selected temperatures for 1, 4, and 8 hours and then their chemical stability was measured by overloading with a RF solution. RF solution has an acidic nature with a pH 2.9–3.0; it, therefore, behaves as a destabilizing agent for the media surrounding the polymer particles of anionic latex and adhesive solutions. Coagulum percentage values (normalized to 100) are given in Fig. 2. The higher the coagulum (normalized) value, the less chemically stable the latex or adhesive solution is to RF solution and the more residue present on the filter. The latex samples had almost the same coagulum percentage (normalized) value at 10°C after 1 hour aging. As the temperature increased, the coagulum percentage (normalized) increased, whereas the VP latex had a higher tendency to coagulate at higher temperatures. The difference may derive from the chemical additives or may be due to the presence of a vinylpyridine component. This could also be due to the use of different soap systems.

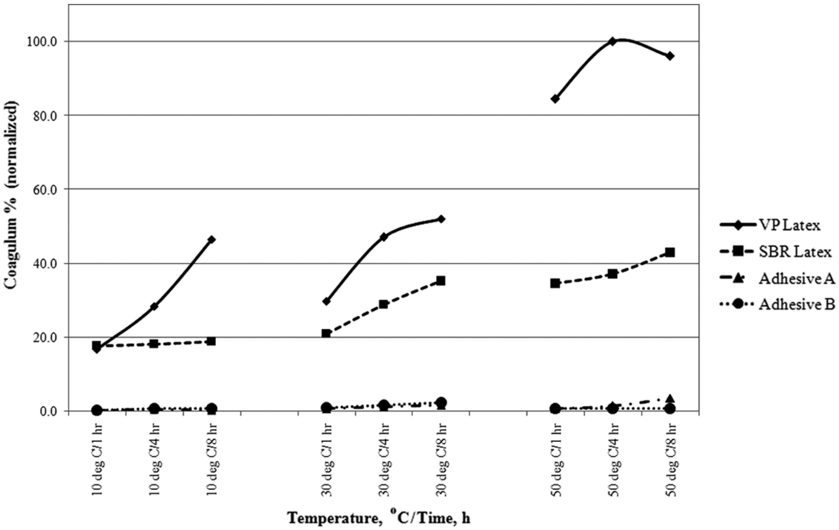


FIGURE 2 Coagulum % (normalized) of latices and adhesive solutions after treatment with RF solution.

At lower temperatures the solutions were more stable as long as the samples were not frozen. As the temperature of the samples was increased, the tendency for skin formation on the top of the sample increased. The details will be discussed during visual observations. As the samples were filtered through a mesh, this thick skin layer remained on top of the filter, causing a high level of residue. As the exposure time increased for each temperature, the samples left more residue on the filter and became chemically less stable. As the temperature increased, the chemical stability of samples decreased. VP latex has a higher coagulum percentage (normalized) than that of SBR latex. Adhesive solutions seemed also to have a tendency to lose their chemical stability with increased temperature and time. However, the magnitudes of coagulum percentage (normalized) were very low compared with latex. If the magnitudes of coagulum percentage (normalized) of latex and adhesive solutions were compared, the chemical stabilities of adhesive solutions seemed to be almost negligible. Latex solid concentration was 41%, whereas the solid concentration in adhesive solution was in the range 18–25%. The concentration gradient most probably created such a difference in the coagulation tendency of the solutions. Taguchi L9 analysis of coagulum percentage (normalized) showed that the influence of temperature changes was approximately 2.5 times as great as that of exposure time for latex. In the case of adhesive solutions, the influence of temperature was 1.3 times as great as than that of exposure time. A typical graph for the main effect analysis of VP latex is given in Fig. 3.

The particle size of latex and adhesives are given in Table 2. The particle size ranged between approximately 60–80 nm. There was no significant variance in the particle size between the samples at different temperatures. This can be interpreted as indicating no change in micelle structure. The particle size is an intrinsic property of latex controlled during latex production. Previous studies have reported that no change in latex particle size was observed following long storage times [9].

The pH values of both latex and adhesive solutions aged at the above-mentioned temperatures for 1, 4, and 5 hours were monitored for their pH change. As can be seen in Table 3, the pH of the latex and adhesive solutions kept at a constant temperature did not show a large change with time. However, the pH of the samples increased with temperature, which can be attributed to the evaporation of water. Taguchi L9 analysis of temperature and time showed that the influence of temperature variation was, at a minimum, 5 times as great as that of exposure time. A typical main effect plot of pH for VP latex is given in Fig. 4. A previous study reported that storsage of latex for

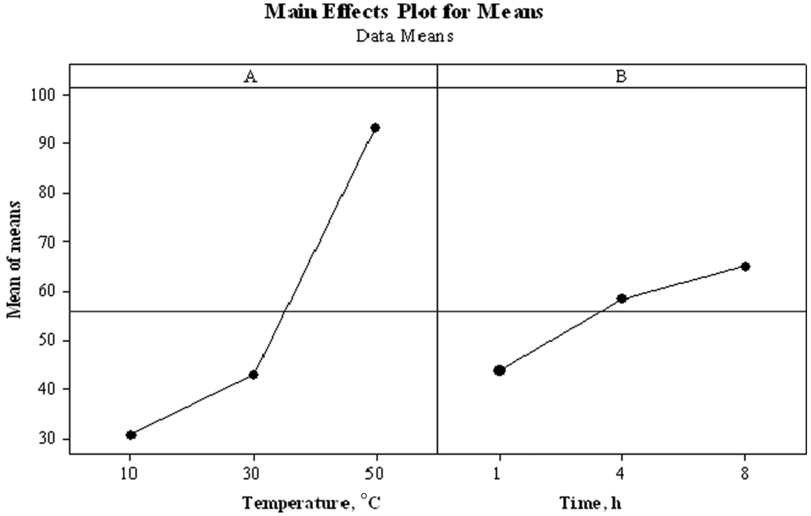


FIGURE 3 Main effect plots of temperature and exposure time on coagulum % (normalized) of VP latex at 10, 30, and 50°C and 1, 4, and 8 h aging.

TABLE 2 Particle Sizes of Latex and Adhesive Solutions

	Particle size, nm (average/standard deviation)		
Temperature, °C	10	30	50
VP Latex	68.8/0.222	70.5/0.181	73.5/0.129
SBR Latex	74.0/0.226	69.8/0.283	73.4/0.269
Adhesive A	75.3/0.125	63.8/0.305	67.4/0.271
Adhesive B	75.6/0.165	77.4/0.170	79.4/0.122

TABLE 3 pH of Latex and Adhesive Solutions aged at 10, 30, and 50°C for 1, 4, and 8 Hours

	pH								
Temperature, °C	10			30			50		
Time, h	1	4	8	1	4	8	1	4	8
VP Latex	9.4	9.3	8.7	10.6	10.7	10.7	10.7	10.7	10.7
SBR Latex	8.9	8.8	8.7	9.8	9.9	9.9	10.5	10.3	10.4
Adhesive A	8.1	8.5	8.5	9.8	9.8	10.1	10.5	10.5	10.5
Adhesive B	8.8	7.6	7.5	10.8	11	10.9	12.5	12.5	12.4

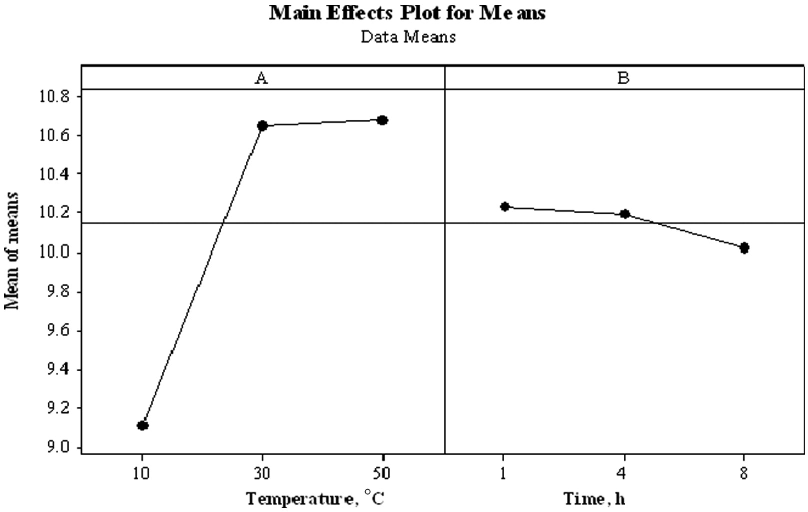


FIGURE 4 Main effect plots of temperature and exposure time on pH of VP latex at 10, 30, and 50°C and 1, 4, and 8 h aging.

several months under different conditions caused the pH of the latex to decrease gradually [9]. This can be attributed to two main factors. Firstly, the availability of carbon dioxide, in the empty part of the storage barrel, which reacts with water to form carbonic acid. Secondly, a small proportion of the ingredients may be converted to mild acids; this process is more prominent at higher temperatures.

The viscosities of latex and adhesive solutions were measured by a Brookfield viscometer. This method measures the resistance of a liquid to a rotating disc. Brookfield viscosity is a function of particle size, particle distribution, and the total solid content of the sample. Assuming the same solid content for any sample, the one with a smaller particle size will have a higher viscosity value, because the rotating disc will interface with more solid particles. The particle size results indicated that there was no significant difference between samples. Viscosity test results are given in Fig. 5. The viscosities of all samples decreased with increasing temperature. The reason for this change may be thicker skin formation with higher temperature. The viscosities of latex dispersions and adhesive solutions have a slight tendency to decrease but this change can be regarded as negligible, due to the nature of the viscosity test. Since the adhesive solutions were relatively dilute compared with the latex, they have considerably different viscosities. The solid content of the latexes was approximately 41%,

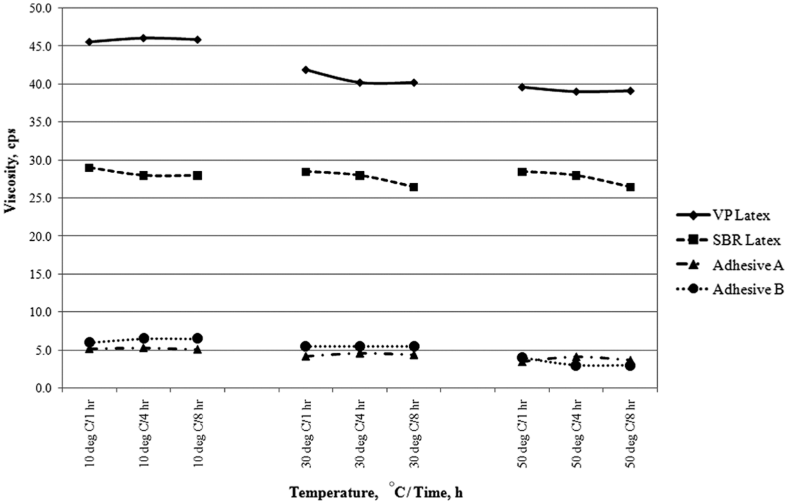


FIGURE 5 Viscosities of latices and adhesive solutions aged at 10, 30, and 50°C for 1, 4, and 8 h.

whereas the viscosities were 30–40 cps. In comparison, the adhesive solutions had a solid content in the range 18–25%, whereas the viscosities were 5–6 cps. Taguchi L9 analysis of the viscosities of samples showed temperature had approximately 3 times as much effect on the viscosity variation of the samples as that of exposure time. The main effect plot of viscosity of VP latex is given in Fig. 6.

Adhesion analysis of RFL-dipped cords was carried out. RFL adhesive solutions are usually matured after mixing the ingredients at a specified temperature. Maturation time can vary, such as 12, 24, and 30 hours [4,7,10]. Therefore, heat aging of adhesive solutions for a short time may have a positive or adverse effect on adhesion. If the adhesive solution is not matured sufficiently, the temperature aging may have positive effect on chemical reactions or *vice versa*. In the present study, RFL solutions were exposed to different temperatures for different periods following maturation and adhesion tests were then carried out. Adhesion force (normalized) values are given in Fig. 7. The adhesion values of all samples were found to be acceptable. The results suggest that adhesion increases with increasing temperature after 1 and 4 hours aging.

The effect of dip pick-up on adhesion was investigated by Porter [8]. He reported that the adhesion of RFL-treated cords increased with increased dip pick-up level of the cord and then reached a plateau after approximately 5–6% dip pick-up. Further increases of dip pick-up did

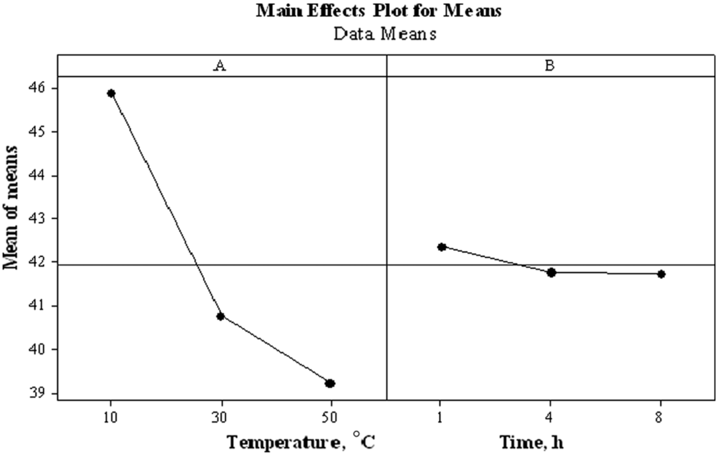


FIGURE 6 Main effect plots of temperature and time on viscosity of VP latex at 10, 30, and 50°C and 1, 4, and 8 h aging.

not substantially improve adhesion. In our study the dip pick level is within the 7–8% range.

Factors such as skin formation, sedimentation, phase separation, and color change were analyzed *via* visual observations. There was no phase separation or sedimentation observed in any of the present

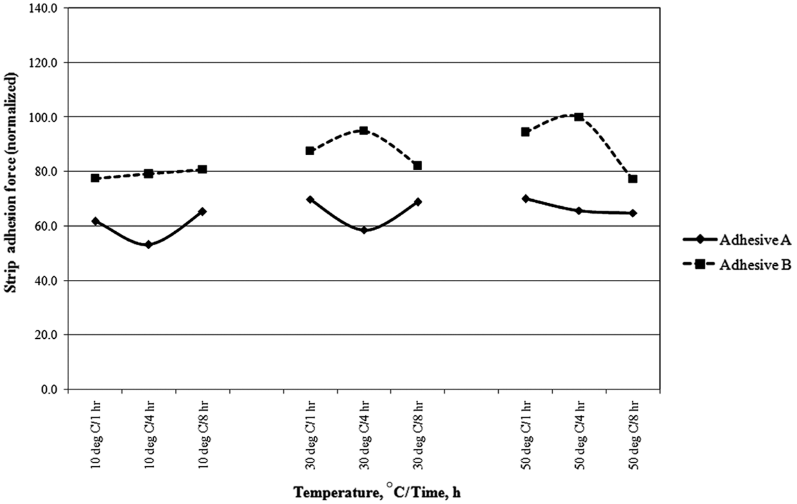


FIGURE 7 Strip adhesion force (normalized) test results of adhesive solutions aged at 10, 30, and 50°C for 1, 4, and 8 h after RFL maturation.

cases. However, skin formations and color changes were observed, depending on the temperature and time. Visual observations are summarized in Table 4. The latex and adhesive samples were observed for potential defects at the first, fourth, and eighth hours at 10, 30, and 50°C, respectively. If a defect was observed in the samples during the early stages of exposure, the defect became strongly marked over time. For example, skin formation of VP latex began at the first hour of exposure and the density and thickness of skin increased after 8 hours of exposure. Skin formation was observed earlier in latex and color changes were observed earlier in adhesive solutions.

In the present study, a series of exaggerated tests were carried out to simulate large scale coagulation of latex in adhesive solution, sticking of coagulated polymer particles to the fabric surface, and failure of adhesion due to polymer particles adhered to the fabric surface. The observations were photographed and are presented in Fig. 8. In the case of exaggerated coagulation of latex in RFL adhesive, it was obvious that some solid polymer particles separated from the liquid phase (Fig. 8a) when the colloidal stability was destroyed, so that suspended polymer particles came together to form large agglomerates. The polymeric particles may stick to the surface of the fabric (Fig. 8b) during dipping. After heat treatment of the cord fabric at high temperatures, coagulated polymer particles became fixed to the surface. A visual comparison of correct adhesion and deteriorated

TABLE 4 Visual Observations of Latices and Adhesive Solutions Aged at 10, 30, and 50°C for 1, 4, and 8 Hours

		Temperature, °C		
Sample	Defect type	10	30	50
VP Latex	Skin formation	No skin formation at the end of 8 h	Begins at 1 h	Begins at 1 h
	Colour change	No colour change at the end of 8 h	No colour change at the end of 8 h	No colour change at the end of 8 h
SBR Latex	Skin formation	No skin formation at the end of 8 h	Begins at 1 h	Begins at 1 h
	Colour change	No colour change at the end of 8 h	Begins at 4 h	Begins at 4 h
Adhesive A	Skin formation	No skin formation at the end of 8 h	No skin formation at the end of 8 h	No skin formation at the end of 8 h
	Colour change	Begins at 4 h	Begins at 1 h	Begins at 1 h
Adhesive B	Skin formation	No skin formation at the end of 8 h	No skin formation at the end of 8 h	No skin formation at the end of 8 h
	Colour change	Begins at 4 h	Begins at 4 h	Begins at 1 h

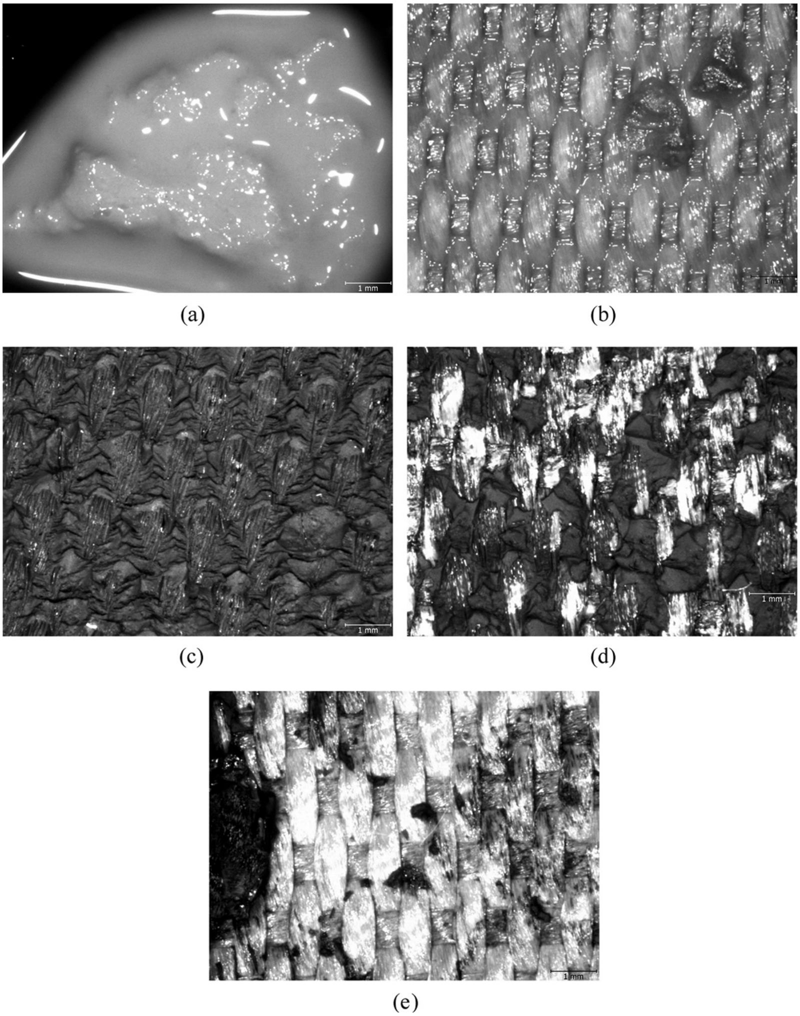


FIGURE 8 (a) Simulation of latex coagulation in RFL adhesive solution. (b) Simulation of adhesion of coagulated polymer particles (dark areas) shown in Figure 8a to the fabric surface during RFL treatment. (c) Typical visual appearance of good adhesion sample of rubberized fabric without defects. (d) Visual appearance of inadequate adhesion caused by adhered polymer particles originating from RFL solution, where darker parts are rubber failure and lighter parts are from RFL to the rubber failure. (e) Visual appearance of exaggerated inadequate adhesion caused by a very large quantity of adhered polymer particles originating from RFL solution, where darker parts are rubber failure and lighter parts are from RFL to the rubber failure.

adhesions are given in Figs. 8c, d, and e. If the adhesion of RFL to the fiber and to the rubber is good enough, the failure may occur in the rubber. The adhesion test generates a rubber-coated cord surface. Figure 8c shows that a sample with good adhesion is typically coated with a layer of black rubber. However, in the presence of coagulated polymer particles between the rubber and the RFL-coated surface of the cord, the coagulated polymer particles act as an impurity and, as a consequence, adhesion failure occurs. The visual appearance of an adhesion failure caused by relatively small and distributed coagulated polymer particles is shown in Fig. 8d. The sizes of coagulated particles were 1 to 5 mm and were not homogenous. Figure 8e shows a similar failure, caused by large pieces of coagulated polymer particles of approximately 10 to 20 mm. The darker parts of the adhesion samples in Figs. 8d and 8e were covered by rubber, indicating rubber failure. Lighter parts of samples in Figs. 8d and 8e indicate a failure from the RFL to the rubber interphase. Since more and larger coagulated particles adhered to the fabric surface in Fig. 8e, fewer rubberized sections were observed compared with Fig. 8d. The sample with good adhesion had a normalized adhesion force value of 100 (Fig. 8c), the adhesion-failure sample with smaller particles had a normalized adhesion force of 87 (Fig. 8d), and the adhesion-failure sample with larger particles had a normalized adhesion force of 48 (Fig. 8e). In an RFL adhesive system, it is known that [11,12] the RF part of the adhesive reacts with the active groups of the synthetic cord, and the latex part reacts with the double bond of rubber. RF and L reacted with each other by methylene bridges. However, coagulated latex breaks the true linkage between RFL and rubber, so it acts as an impurity. The result is inadequate adhesion.

CONCLUSION

A series of analyses were carried out to determine how the properties of VP latex, SBR latex, and RFL adhesive solutions were influenced by mechanical and chemical agitation. Coagulated latex residues, temperature variation upon mechanical shear, particle size, pH, adhesion, and viscosity were investigated. Mechanical and chemical disturbances created agglomeration of VP and SBR latices. The influence of such factors on adhesive solutions was not as significant as in the latices. Most probably, the behavior difference recorded between latex and adhesive solutions came from the latex solids' concentration. Particle size is an intrinsic property and remained almost unchanged. The pH has a tendency to increase and viscosity has a tendency to decrease with increasing temperature. Taguchi analysis of samples to identify the main effect of temperature and time on properties such as percentage coagulum, pH, and viscosity showed that temperature has a greater influence on the variation of properties compared with duration of exposure. The samples had an acceptable level of adhesion. Latex showed visual changes, including skinning and color change with increasing temperatures. The chemical and physical stability of latex and adhesive solutions are critical parameters for the adhesion performance of RFL-dipped synthetic cords. The consequence of any improper treatment, mentioned above, can be failure in adhesion. Latex producers, therefore, strongly suggest that the latex should remain within the temperature limits of 5 to 40°C and that temperature fluctuations should be avoided during both transportation and storage. Latex should not be exposed to sunlight or freezing conditions. Sufficient attention needs to be paid during RFL preparation and dipping to factors such as controlling the order and rate of the addition of RFL components to each other, avoiding harsh mixing conditions of adhesive solution, controlling the temperature of adhesive solution, and avoiding prolonged exposure to ambient conditions, all of which have an influence on either loss of colloid stability, skin formation or color change.

ACKNOWLEDGMENT

The author is thankful to Ayhan Dogan Ozkan of Kordsaglobal for his valuable contributions.

REFERENCES

[1] Dietrick, M. I., *Rubber World* **136**, 847–852 (1957).

[2] Iyengar, Y., *J. Applied Polymer Science* **13**, 353–363 (1969).

[3] Rijpkema, B. and Weening, W. E., *Rubber World*, Sept. **1**, 26–31 (1994).

[4] Blackley, D. C., *High Polymer Latices Their Science and Technology*, (Maclaren & Sons London, Palmerton Publishing Co. Inc., New York, 1966), Vol. 2, pp. 743–787.

[5] Blackley, D. C., *High Polymer Latices Their Science and Technology*, (Maclaren & Sons London, Palmerton Publishing Co. Inc., New York, 1966), Vol. 1, pp. 19–52.

[6] Porter, N. K., *Journal of Industrial Textiles* **25** (4), 268–275 (1996).

[7] Porter, N. K., *Journal of Industrial Textiles* **21** (4), 230–239 (1992).

[8] Porter, N. K., *Journal of Industrial Textiles* **23** (1), 34–45 (1993).

[9] Santra, R. and Mohanty, S., *Effect of severe environmental condition on storage stability of vinyl pyridine latex*, www.indiarubberdirectory.com/education/vinyl_pyridine.asp

[10] Jamshidi, M., Afshar, F., Mohammadi, N., and Pourmahdian, S., *Applied Surface Science*, **249** (1–4), 208–215 (2005).

[11] Solomon, T. S., *Rubber Chemistry and Technology* **58**, 561–576 (1985).

[12] Blackley, D. C., *Polymer Lattices Science and Technology*, (Maclaren & Sons London, Palmerton Publishing Co. Inc., New York, 1966), Vol. 2, pp. 260–290.