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TRENDS IN CONVEYOR BELT RESEARCH

TRENDOVI U ISPITIVANJU TRAKASTIH TRANSPORTERA

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Abstract: *In modern industry, the needs for conveyor belts use is increased. Because of that one is searching for longer conveyors with larger capacity and with possibility of whelming the horizontal curves. This paper is dealing with new trends in conveyor belt research, especially the carrying belts as the most expencive and the least durzable element.*

Key words: *trends, conveyor belt, research*

Apstrakt: *Potrebe za primenu trakastih transportera su sve veće u savremenoj privredi. Zbog toga se traže što duži transporteri, većeg kapaciteta i sa mogućnostima savladavanja horizontalnih krivina. U ovom radu su obrađeni trendovi u ispitivanju trakastih transportera, posebno nosećih traka kao najskupljih i najmanje izdržljivih elemenata.*

ključne reči: *trendovi, trakasti transporter, istraživanje*

1 INTRODUCTION

The current trends in belt conveyor transport are towards greater length of single belt conveyors, greater inclination of conveyor routes and pipe and curvilinear conveyor designs and at the same time towards greater forces carried by the belt. As a result the requirements which the most expensive and least durable element of the belt conveyor must meet have been growing. Today belts with steel cables have the strength as high as 8100 kN/m and the strength of fabric belts reaches 4000 kN/m. As the strength of belts increases so do the costs of their manufacture and installation on conveyors. Therefore the matching of belt parameters to particular operating conditions and the investigation of the properties of belts and belt splices become increasingly more important. The research in this field leads to the better use of belt strength and to higher belt durability and consequently to reductions in belt conveyor transport costs.

1 UVOD

Današnji trendovi istraživanja trakastih transportera se odnose na povećanje dužine trakastih transportera, cevastih i krivolinijskih transportera, a u isto vreme se povećavaju i tereti koje traka nosi. Kao rezultat toga, potrebe za trakom, koja su najskuplji i najmanje izdržljiv element kod transportera, postaju sve veće. Današnje trake sa čeličnim užadima, imaju čvrstoću visine 8100 kN/m, a čvrstoća tkanih traka dostiže 4000 kN/m. Kako se povećava čvrstoća trake, tako se povećavaju i troškovi njene proizvodnje i postavljanje na transportere. Zbog toga postaje izuzetno važno podešavanje parametara trake prema određenim eksploatacionim uslovima i ispitivanje osobina trake i spojeva na traci. Istraživanja na ovom polju vode do povećanja čvrstoće trake i povećanja izdržljivosti trake, a da se pri tome smanjuju troškovi transporta trakastim transporterima.

2 BELT TESTING

Tests of conveyor belts can be divided into three groups: standard tests, certification tests and non-standard tests. The first group includes tests of physicomechanical properties for their compliance with the standards in force. The second group comprises certification tests on belts required for permitting the latter to be operated in underground mines. The third group embraces non-standard tests – specialist tests performed on special test stands, usually not covered by standards but concerning parameters important for the operation of belts. Tests of belt splices form a separate group. Belt research today is mainly concerned with specialist tests and belt splices testing.

2.1 Belt puncture resistance

Belt puncture resistance is a very important belt parameter determining the durability of the belt on the conveyor. Research has shown that the main reason for removing the belt from the conveyor is the damage inflicted on the belt by falling down sharp-edged lumps of winning. Belt puncture resistance is most conveniently expressed by critical energy defined as the energy of a falling body at which the first damage to the belt's carcass or covers occurs. In fabric belts damage occurs most often first in the belt carcass fabric. In belts with steel cables the rubber is usually damaged before the steel cables. Thus the critical energy is the energy of a falling body at which the rubber between the cables is ruptured. This energy can be quite precisely determined experimentally since at a fall energy exceeding the critical energy the curve representing the relationship between the maximum impact force and the energy of the falling body clearly bends downwards. Also the trace of the force impulse during the impact stops being symmetrical when there is any damage to the belt.

The critical energy value is not characteristic of a particular type of belt. It depends on how the belt is supported when a lump falls on it, on the spacing of the idlers and the radius of the cone curvature or the edge of the falling body [7]. An increase in critical energy in belts supported by impact idlers with rollers with rubber rings in comparison with stiffly supported belts is considerable and it occurs irrespective of the belt carcass design or the geometric-material parameters of the belt. But much higher critical energy values are recorded for impacts between the idlers. The belt support mode also determines the type of damage to the belt. Tests carried out on belts with steel cables showed that the steel cables were damaged almost

2 TESTIRANJE TRAKE

Testovi za ispitivanje trakastih transportera podeljeni su u tri grupe: standardni testovi, testovi za sertifikat i nestandardni testovi. Prva grupa podrazumeva ispitivanje fizičko-mehaničkih osobina i njihovo usaglašavanje sa standardima koji su na snazi. Druga grupa obuhvata ispitivanja za sertifikat za trake koje će biti korišćene u rudnicima sa podzemnom eksploatacijom. Treća grupa obuhvata nestandardna ispitivanja - specijalne testove koji se izvode u posebnim uslovima testiranja koji su bitni za rad traka. Ispitivanja spojeva na trakama čine posebnu grupu. Istraživanja traka, danas su, uglavnom, usmerena na specijalne testove i testiranje spojeva na trakama.

2.1 Otpornost trake na proboj

Otpornost trake na proboj je veoma važan parametar trake koji određuje trajnost trake na transporteru. Istraživanja su pokazala da je glavni razlog za uklanjanje trake sa transportera, oštećenje na traci koje je uzrokovano padanjem krupnih komada rovne rude oštrih ivica. Otpornost trake na proboj se najbolje izražava kritičnom energijom, koja se definiše kao energija padajućeg tela koje izaziva prvo oštećenje noseće konstrukcije trake ili obloge. Kod tkanih traka, oštećenja se najčešće pojavljuju prvo u strukturi tkanine trake. Kod traka sa čeličnim užadima, obično se gumeni omotač oštećuje pre čeličnih užadi. Prema tome, kritična energija je energija padajućeg tela kojom je probušena guma između užadi. Ova energija se sasvim precizno može eksperimentalno utvrditi, jer kada energija pada, postane veća od kritične energije, kriva, koja predstavlja odnos između maksimalne snage udara i energije padajućeg tela, jasno savija naniže. Takođe, putanja sile udara, za vreme udara, prestaje da biva simetrična kada postoji bilo kakvo oštećenje na traci.

Vrednost kritične energije nije karakteristična za svaki tip trake. Ona zavisi od toga kako je traka oslonjena kada komad padne na nju, od razmaka između valjaka i radijusa konusa krivine ili ivice padajućeg tela [7]. Povećanje kritične energije kod traka koje su oslonjene na valjke za primanje udara i valjcima sa gumenim prstenovima u poređenju sa kruto oslonjenim trakama je znatno, i javlja se nezavisno od projektovane noseće konstrukcije trake ili geometrije parametara trake. Inače, mnogo veće vrednosti kritične energije su registrovane prilikom udara između valjaka. Način oslanjanja trake, takođe određuje i vrstu oštećenja na traci. Ispitivanja rađena kod traka sa čeličnim užadima exclusively when stiff support was employed. No damage to the cables has been detected for impacts between the idlers but long ruptures in the rubber and a 10-20 cm long tear in the rubber between the cables are found. In fabric belts, both stiffly supported and on impact idlers, damage to the cover rubber and the carcass has the form of local irregular ruptures and holes with a diameter of up to 40 mm. The damage resulting from impacts between the idlers has the form of long cuts (invisible on the outside) in the threads. For impacts in the middle of the belt between the idlers, the critical energy of the belt increases with the spacing of the idlers. The impact force in the tested range decreases appropriately. The results of tests also indicated the influence of the corner radius of the "impactor" on the obtained critical energy values.

When analysing the effect of the parameters of the belt on its puncture strength one should take into account:

- the thickness of the top and bottom cover,
- the belt carcass design,
- the properties of the belt cover materials,
- the protective plies.

The thickness of the covers significantly affects the critical energy value for the whole range of damage at different belt support modes.

It has been determined that puncture strength must be taken into account in the design of a belt. By properly matching the strength of the warp with that of the weft in the fabric and taking into account the elastic properties of the interacting fibres one can obtain a belt with the optimum puncture strength.

pokazuju da se čelična užad skoro uvek oštećuju kada je traka kruto oslonjena. Nikakvo oštećenje užadi nije pronađeno kod udara između valjaka, osim dugih pukotina na gumi i rascepa na gumi između užadi dužine 10-20 cm. Kod tkanih traka koje su kruto oslonjene na valjke za primanje udara, oštećenja gumenog omotača su formirana od nepravilnih pukotina i rupa prečnika i do 40 mm. Oštećenje nastalo udarom između valjaka ima oblik dugih procepa (nevidljivih spolja) u vlaknima. Kod udara u sredini trake između valjaka, kritična energija trake se povećava sa povećanjem rastojanja između ležajeva. Jačina udara u testiranom opsegu odgovarajuće opada. Rezultati testova takođe ukazuju na uticaj ugla radijusa "udarača" na dobijene vrednosti kritične energije.

Pri analiziranju uticaja parametara trake na njenu otpornost na proboj, mora se uzeti u obzir sledeće:

- debljina gornjeg i donjeg omotača,
- struktura noseće konstrukcije trake,
- osobine materijala od kojeg je izrađen omotač trake i
- zaštitni slojevi.

Debljina omotača značajno utiče na vrednost kritične energije za ceo opseg oštećenja kod različito oslonjenih traka.

Zaključeno je da se pri projektovanju trake mora uzeti u obzir otpornost trake na proboj. Kod odgovarajućeg podudaranja otpornosti na uvijanje u tkanini i ako se uzmu u obzir elastične osobine vlakana, može se dobiti traka sa optimalnom otpornošću na proboj.

2.1 Slit resistance

Belts particularly with steel cables are often slit longitudinally if a metal element or a sharp-edged lump wedges itself into them. The resulting damage entails high costs since in a short time several hundred meters of the belt are slit. The research on slitting is conducted at several centres, e.g. Hanover, Hamburg and Wroclaw.

A stand for testing belt slit resistance was built at the Institute of Mining of Wroclaw University of Technology (fig.1) [4]. The slitting force is measured by a gauge coupled with a microprocessor force meter hooked up to a computer.

2.1 Otpornost na cepanje

Trake, posebno one sa čeličnim užadima, cepaju se po dužini ako na njih padne metalni predmet ili komad oštrih ivica. Oštećenje koje nastaje povlači visoke troškove, jer za kratko vreme stotine metara trake biva pocepano. Istraživanja o cepanju trake vršena su u nekoliko centara, npr. Hanoveru, Hamburgu i Vroclavu.

Postolje za ispitivanje otpornosti trake na cepanje je izgrađeno u Rudarskom institutu Vroclavskog univerziteta tehnologije (slika 1) [4]. Snaga cepanja merena je meračem spregnutim sa mikroprocesorom priključenim na kompjuter.

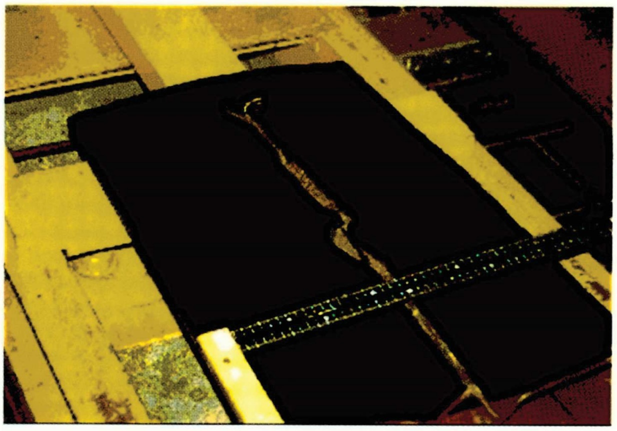

Figure 1 Slit resistance testing stand
slika 1 Postolje za testiranje otpornosti trake na cepanje

Slit resistance test were carried out under these conditions:

- a 5 mm thick cutting tool rectangular in cross-section,
- the slitting rate of 600 mm/min.,
- the measuring range of 100 kN,
- the 500 mm wide and 1000 mm long belt specimen.

Belts of various types, both belts with steel cables and fabric belts with and without breakers, were tested. The slit resistance and the character of the slitting process were determined and on this basis the effect of brecers and their design on slit resistance was assessed. New belt designs for primary machines where the slit hazard is very high have been proposed. It is interesting to note that fabric belts were slit with minimum separation of the covers. Single interlayer belts were found to have quite high slit resistance.

Ispitivanje otpornosti trake na cepanje je izvođeno pri sledećim uslovima:

- sečica debljine 5 mm pravougaonog preseka,
- brzina cepanja od 600 mm/min,
- merni opseg od 100 kN i
- uzorak trake širine 500 mm i dužine 1000 mm.

Ispitivane su trake različitih tipova, kako sa čeličnim užadima, tako i tkane trake, sa osloncima i bez njih. Utvrđeni su otpor cepanja i karakter procesa cepanja i na ovim osnovama procenjen je uticaj postolja i njegove konstrukcije na otpor cepanja. Predloženi su novi nacrti za konstrukciju traka za primarne mašine, gde je opasnost od cepanja trake veoma visoka. Interesantno je zapažanje da su tkane trake cepane sa minimalnim odvajanjem od omotača. Pronađeno je da trake sa jednostrukim međuslojem imaju veoma visoku otpornost na cepanje.

2.2 Effect of moistness on belt properties

It was often reported that moistness affected the strength parameters of conveyor belts but no research was undertaken to prove this relationship. Investigations of the strength properties of moist fabric-rubber conveyor belts were carried out at the Institute of Mining (WUT) by subjecting belt specimens to the action of aggressive mine water from the Polkowice-Sieroszowice Mine [3].

The following strength properties of dry and soaked belt specimens were determined:

- tensile strength,
- adhesion strength,
- shear strength,
- fatigue strength (by a method developed at the Institute of Mining [2]).

2.2 Uticaj vlage na osobine trake

Često je zapažano da vlaga utiče na parametre čvrstoće trakastih transportera, ali nije rađeno nikakvo istraživanje koje bi to dokazalo. Ispitivanja otpornosti na vlagu tkanih-gumenih trakastih transportera vršena su u Rudarskom institutu (WUT), gde su uzorci trake izloženi agresivnom delovanju rudničke vode iz rudnika Polkowice-Sieroszowice [3].

Utvrđena su sledeća svojstva suvih uzoraka trake i uzoraka trake natopljenih vodom:

- zatezna čvrstoća,
- adheziona čvrstoća,
- čvrstoća na smicanje i
- trajna čvrstoća (metodom razvijenom u Rudarskom institutu [2]).

The investigations began with absorbability tests. Fabric-rubber belts soaked in water reach a state of saturation after about 2 months. A belt of type P 1000/4 absorbs about 0.52 kg water per 1 m^2 and a belt of type EP 1000/4 about 0.42 kg water per 1 m^2.

Ogledi su započeti testovima apsorpcije. Tkane-gumene trake, potopljene u vodu dostigle su stanje zasićenosti posle 2 meseca. Traka tipa P 1000/4 apsorbuje oko 0,52 kg vode po 1 m^2, a traka tipa EP 1000/4 oko 0,42 kg vode po 1 m^2.

The polyamide belt after moistening lost a significant percentage of its strength properties: about 12% of its tensile strength, 13-32% of its adhesion strength and 17-23% of its shear strength. The belt's fatigue strength, high in the dry condition, decreases about five times. The polyester belt showed low sensitivity to moisture. Its material properties diminished by only a few percent and its fatigue strength decreased by about 35% (fig.2).

Poliamidna traka posle kvašenja gubi značajan procenat čvrstoće: oko 12% zatezne čvrstoće, 13-32% adhezione čvrstoće i 17-23% čvrstoće na smicanje. Dinamička/trajna čvrstoća trake, koja je visoka u suvim uslovima, opada za oko 5 puta. Trake od poliestera pokazuju slabu osetljivost na vlagu. Bitne osobine ove trake umanjuju se za samo nekoliko procenata, a njena trajna čvrstoća opada za oko 35% (slika 2).

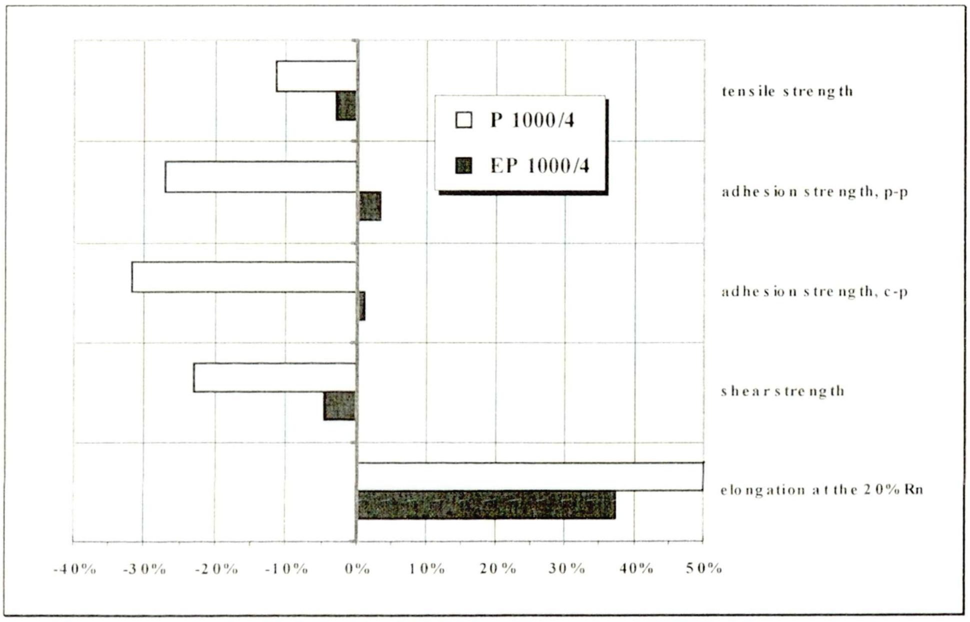

Figure 2 Influence of moisture content on the belt properties
slika 2 Uticaj sadržaja vlage na osobine trake

If polyamide belts are to work in conditions of high moisture one should take into account the fact that not only their strength properties but also the strength of the glue or vulcanisation splices will deteriorate. Also the susceptibility to ply separation will increase. This is due to a considerable decrease in the fatigue life of the interlayer rubber.

Ako poliamidne trake rade u uslovima gde je visoka vlaga, mora se uzeti u obzir i činjenica da će se pogoršati ne samo njihova čvrstoća, već i čvrstoća spojeva koji su lepljeni lepkom i onih koji su spojeni vulkanizacijom. Takođe će se povećati i osetljivost uložaka gumene trake na razdvajanje. Ovo vodi značajnom umanjenju trajnosti međusloja gumenog omotača,

The moist condition of belts results in a few tens percent increase in their elongation under working loads.

Vlažni uslovi, kod traka dovode do toga da sa njihovo istezanje pri radnim opterećenjima uvećava za nekoliko desetina procenata.

2.3 Fatigue testing of belts

2.3 Ispitivanje trajnosti trake

Fatigue tests of multiple-ply conveyor belts have been conducted for several years. In the testing method which was developed the shear stress in the interlayer is assumed to be a reliable quantity

Testovi trajnosti kod trakastih transportera sa uloškom gumene trake spojenim iz više delova rađeni su nekoliko godina. U metodi testiranja koja je razvijena, pretpostavlja se da je napon smicanja and the fatigue strength is expressed in the number of stress cycles until the failure of a belt specimen. During the tests the force, elongation, time and the number of cycles were measured.

The test program [2] design enabled the analysis of the effect of a wide range of material and constructional parameters on the fatigue strength of belts. Comprehensive laboratory fatigue tests were carried out on 42 kinds of specimens in which the belt parameters were changed. The obtained amount of data enabled a multifaceted analysis of the test results by means of statistical methods. The analysis showed that there is a statistical correlation between belt fatigue strength and the following parameters (listed from the strongest to weakest correlation):

- the static shear strength of the interlayer,
- adhesion strength,
- the tensile strength of the plies tensioned towards the warp,
- elongation at the rupture of the plies,
- friction ratio,
- the tensile strength of the rubber.

2.4 Optical methods in investigation of conveyor belts

Besides standard methods, non-standard methods are applied to investigate conveyor belts, e.g. optical methods. It was at the Institute of Mining of WUT that optical methods: the method of photoelastic superficial layer and the speckle photography method were first applied to the identification of the state of strain in a steel-cable belt at the transition section of a pipe conveyor.

The method of photo-elastic superficial layer is used to determine the state of strain in the investigated elements but it also allows one to determine indirectly the state of stress in them. The investigated element is coated with a layer of material having the property of double refraction (birefringence). As the investigated material is loaded it deforms together with its photoelastic coating. The measured photoelastic effect depends on the difference between the principal strains in the plane of the photoelastic layer. Thus the places of the greatest effort of the material become visible

To study [6] the state of strains in the belt at the transition section of a pipe conveyor, the area where the belt runs on the drum was chosen. The investigations were conducted on a measuring position which allowed one to change the belt stretching force, the length of the transition section

međusloja pouzdana veličina i da je trajna čvrstoća izražena brojem ciklusa naprezanja do propadanja uzorka trake. Za vreme testiranja mereni su snaga, dužina, vreme i broj ciklusa.

Projektovani program za testiranje [2] omogućava analize uticaja širokog spektra materijalnih i konstrukcionih parametara za merenje trajne čvrstoće trake. Rađena su opsežna laboratorijska ispitivanja trajnosti na 42 uzorka sa različitim parametrima trake. Dobijeni rezultati omogućavaju analize rezultata ispitivanja statističkim metodama. Analize su pokazale da postoji statistička korelacija između trajne čvrstoće i sledećih parametara (nabrojani su od najače do najslabije korelacije):

- statička čvrstoća smicanja međusloja,
- adheziona čvrstoća,
- čvrstoća na izvlačenje uložaka gumene trake koji su uvijani,
- elongacija do pucanja uložaka gumene trake,
- koeficijent trenja i
- čvrstoća na izvlačenje gume.

2.4 Optičke metode u ispitivanju trakastih transportera

Pored standardnih metoda, za ispitivanje trakastih transportera koriste se i nestandardne metode, kao, na primer, optičke metode. Ove metode rađene su u Rudarskom institutu Vroclavskog univerziteta tehnologije i to: metoda fotoelastičnosti površinskog sloja i metoda tačkaste fotografije SPECKLE PHOTOGRAPHY, gde je prvo primenjeno utvrđivanje stanja naprezanja u traci sa čeličnim užadima na kritičnom delu cevastog transportera.

Metod fotoelastičnosti površinskog sloja je korišćen sa ciljem utvrđivanja stanja naprezanja u ispitivanim elementima, ali, takođe, dozvoljava da se indirektno utvrdi stanje opterećenja u njima. Ispitivani element je obložen omotačem sačinjenim od materijala koji ima osobinu dvostruke refrakcije. Kako je ispitivani element opterećivan, on se deformisao zajedno sa svojim fotoelastičnim omotačem. Mereni fotoelastični efekat zavisi od razlike između glavnih naprezanja u ravni fotoelastičnog omotača. Tako postaju vidljiva mesta najvećeg napora materijala.

Za proučavanje [6] stanja naprezanja u traci na kritičnom delu cevastog transportera, izabrana je oblast gde traka prelazi preko bubnja. Ispitivanja su vođena na mestu merenja koje dopušta promenu zatezne sile trake, dužine kritičnog dela i pozicije bubnja. Ispitivanje je rađeno za četiri različita parametra geometrije kritičnog dela i različita and the position of the drum. The research was conducted for four different parameters of the transition section geometry and different loads. On the basis of the obtained results the most advantageous belt design for pipe conveyors was patented.

3 INVESTIGATION OF BELT SPLICES

A splice in the belt is an area in which the continuity of the plies or that of the cables is broken. In this area a zone appears in which the stresses in the adjacent plies or cables differ considerably from each other. This results in differences in the elongation of these elements and in additional shearing stresses in the rubber layer. Consequently the splice is less strong than the solid belt. The strength of splices depends on several factors such as: the parameters of the spliced belt, the bonding layer, the splicing technology and the materials used to make the splice. The strength of the splice is the main criterion for the choice of a belt for particular operating conditions. This means that methods of testing belt splices are highly important.

Belt splices have been the subject of research for several years. Recently new measuring and calculation methods such as:

- measurement by strain gauges,
- photoelastic investigations,
- the video recording technique and
- Finite Element Method (FEM) calculations

have been introduced.

Electric resistance wire strain gauges (with the measuring range of up to 10%) for testing highly deformable materials are used for such measurements. These allow one to determine directly the magnitude of strains and stresses in the whole area of a splice subjected to loading. Strain gauges are installed in each glue layer of the splice as the latter is being made and subsequently together with the belt are subjected to vulcanisation.

In the photoelastic method, mechanical models of the actual structural elements are used [5]. The models are made of transparent, optically sensitive materials which in a stress-and-strain free state are optically isotropic, whereas in a state of stress they stop being isotropic and exhibit forced birefringence which makes it possible to study this state in polarised light by the optical method. Because of double refraction a ray of polarised light passing through a model is split into two rays shifted in phase relative to each other and vibrating in

opterećenja. Na osnovu dobijenih rezultata patentirani su najnapredniji projekti trake za cevaste transportere.

3 ISPITIVANJE SPOJEVA NA TRACI

Spoj na traci se javlja na mestu gde je prekinut kontinuitet uložaka gumene trake ili užadi. U ovoj oblasti pojavljuje se zona u kojoj se naprezanja u ulošcima gumene trake ili užadima, koji se međusobno graniče, značajno međusobno razlikuju. Kao rezultat ovoga, javljaju se razlike u izduženju ovih elemenata i dodatni naponi smicanja u gumenom omotaču. Zbog toga su spojevi na trakama slabiji od celokupne trake. Čvrstoća spojeva zavisi od nekoliko faktora, kao što su: parametri spajanja trake, vezni sloj, tehnologija spajanja i materijali od kojih su napravljeni spojevi. Čvrstoća spojeva je glavni kriterijum pri izboru trake za određene eksploatacione uslove. Ovo znači da su metode za ispitivanje spojeva trake veoma važne.

Spojevi na trakama su bili predmet istraživanja nekoliko godina. Nedavno su usvojene nove metode merenja i izračunavanja, i to:

- merenje pomoću elektrootpornih mernih traka,
- fotoelastično ispitivanje,
- tehnika video zapisivanja i
- proračun metodom konačnih elemenata.

Za ova merenja, za ispitivanje visoko deformabilnih materijala korišćen je električni otpor žice elektrootpornih mernih traka (sa mernim opsegom do 10%). Ona dozvoljavaju da se direkno odredi intenzitet naprezanja i opterećenja u celoj oblasti spoja izloženog opterećenju. Elektrootporne merne trake su instalisane u svakom lepljenom sloju spoja, a zatim su oni zajedno sa trakom izloženi vulkanizaciji.

U fotoelastičnoj metodi, korišćeni su mehanički elementi postojećih strukturnih elemenata [5]. Uzorci su napravljeni od providnih, optički osetljivih materijala koji su u stanju opterećenja i rasterećenja optički izotropni, dok u stanju opterećenja prestaju da budu izotropni i prikazuju pojačano dvostruko prelamanje koje omogućava da se ovo stanje proučava optičkom metodom u polarisanoj svetlosti. Zbog dvostrukog prelamanja, zrak polarisane svetlosti se, prolazeći kroz uzorak , deli na dva zraka koji se međusobno fazno smenjuju i titraju mutually perpendicular planes. After the rays pass through a polarisation filter, interference of the appropriate component rays and thus an image of the model covered with a pattern of dark interference lines can be obtained (fig.3).

u zajedničke vertikalne ravni. Pošto zraci prođu kroz polarizacioni filter, može se dobiti interferencija odgovarajuće komponente zraka, a prema tome i slika uzorka pokrivenog prugastom šarom tamnih linija interferencije (slika 3).

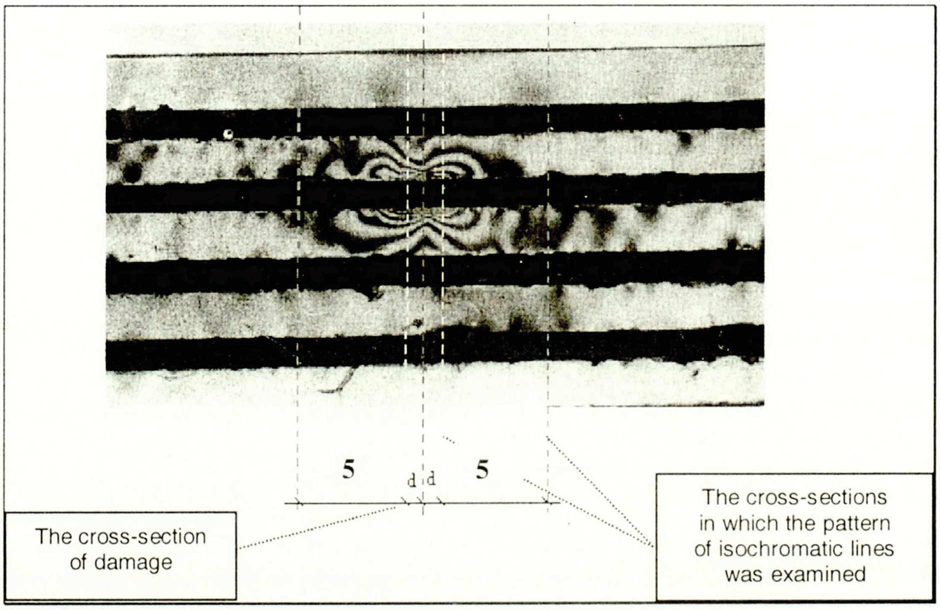

Figure 3 Example of recorded pattern of isochromatic lines (dark spectral interference lines)
slika 3 Primer zabeležene šare izohromatskih linija (tamne spektralne linije interferencije)

It should be noted that a photoelastic model made of an optically sensitive material with mechanical properties similar to those of the interlayer rubber is subjected to the tests and not the actual splice. But the investigation of the models furnishes a lot of (mainly quantitative) information about the stress pattern in the splice area. This information is needed for the description of the phenomena, which occur in the contact area. The photoelastic method can be used to carry out a qualitative and quantitative analyses of the two- and three-dimensional state of stress to determine the values and directions of the principal stresses and to find the places of stress concentration. An image of stresses recorded in the neighbourhood of the second- and third-degree contact shows a stress pattern which is most hazardous to the strength of the splice. The investigations have also shown that differences in the mechanical properties of the plies of the spliced belts affect the strength of the splice.

Three sections of multiply, fabric conveyor belts made by different manufacturers having:

- the same tensile strength of 1000 kN/m,
- an identical number of plies (four-ply belts),
- the same width of 1000 mm,

were selected for the tests.

Treba naglasiti da je ispitivanjima podvrgnut fotoelastični uzorak, napravljen od optički osetljivog materijala sa mehaničkim osobinama sličnim onima iz međusloja gume, a ne postojeći spoj. Međutim, ispitivanjem uzorka su dobijene mnoge (uglavnom kavnititativne) informacije o raspodeli opterećenja u obalsti spoja. Ove informacije su potrebne za opis pojava koje se javljaju u kontaknoj oblasti. Fotoelastična metoda se može koristiti za izvođenje kvalitativnih i kvantitativnih analiza dvo i trodimenzionalnih stanja opterećenja, da bi se utvrdile vrednosti i pravci najvažnijih opterećenja i da bi se našla mesta koncentracije opterećenja. Slika opterećenja zabeležena u blizinu dvo i trostepenog kontakta pokazuje raspodelu opterećenja koja su i najopasnija po čvrstoću spoja. Ispitivanja su, takođe, pokazala da razlike u mehaničkim osobinama uložaka kod spojenih traka utiču na čvrstoću spoja.

Za ispitivanja su izabrane tri sekcije trakastih transportera sa više uložaka, izrađenih od različitih proizvođača, a koji imaju:

- istu čvrstoću na izvlačenje od 1000 kN/m,
- isti broj uložaka (trake sa četiri uloška) i
- istu širinu od 1000 mm.

The belts had not been in service before. They were delivered in 10 m long sections straight from the manufacturers. Prior to the tests, the belts' parameters were checked for their compliance with Polish Standard PN-74/C-94143. The belts met the requirements specified in the standard. To determine the mechanical properties of the belts, they were tested using the INSTRON 4467 tester installed in the Belt Conveyor Transport Laboratory of the Institute of Mining Engineering Wrocław University of Technology. The test stand consists of the tester equipped with an extensometer and hooked up with a computer. The specimens secured in the grips of the tester were tensioned at the rate of 100 mm/min until they ruptured. At the same time, 100 mm measuring base strains were recorded by a strain gauge. The specimens' dimensions and shape con-formed to Polish Standard PN-75/C-05011 relating to tensile strength testing and the unit and permanent elongation of fabric conveyor belts. Five samples were taken at random from each of the selected belts. The tests showed a reduction in the strength of splices between belts with different ply properties in comparison to splices between identical belts. The strength of splices between different belts, designated as 1-1, 1-3 and 2-3, was from 70 to 97% of that of splices 1-1, 2-2 and 3-3 (table 1). There is a difference in the values of the moduli of elasticity of the plies between the tested belts for the whole loading range.

Trake pre toga nisu bile u upotrebi. Dopremljene su direktno od proizvođača u delovima dužine 10 m. Pre ispitivanja, proverena je saglasnost parametara traka sa Poljskim standardom PN-74/C-94143. Trake su ispunjavale uslove koji su zadati standardom. Da bi se utvrdile mehaničke osobine trake, one su testirane na aparatu za testiranje INSTRON 4467 koji je instaliran u tehnologije. Postolje za testiranje se sastoji od aparata za testiranje sa ekstenzometrom priključenim na kompjuter. Uzorci, osigurani u Laboratoriji za transport trakastim transporterima Rudarskog instituta Vroclavskog univerziteta kablovskim čarapama aparata za testiranje, su naprezani brzinom od 100 mm/min do pucanja. U isto vreme, pomoću elektrootporne merne trake izmereno je 100 mm osnovnih naprezanja. Dimenzije i oblik uzoraka odgovaraju poljskom standardu PN-75/C-05011 koji se odnosi na ispitivanja na istezanje i uređaje, kao i permanentne elongacije trakastih transportera. Od svake izabrane trake nasumično je uzeto po pet uzoraka. Testovi su pokazali smanjenje čvrstoće spojeva između traka sa različitim osobinama uložaka u poređenju sa spojevima kod istih traka. Čvrstoća spojeva između različitih traka, obeleženih kao 1-2, 1-3, i 2-3 kretale su se od 70 do 97%, u odnosu na spojeve 1-1, 2-2 i 3-3 (tabela 1). Postoji razlika u vrednostima modula elastičnosti uložaka trake između testiranih traka za ceo opseg opterećenja.

Table 1 Results of strength tests on splices
Tabela 1 Rezultati ispitivanja čvrstoće na spojevima

Splice designation	Medium rupture strength of splice [kN/m]	Strength of splice related to standard value [%]	Strength of splice related to that of splices between identical belt [%] 1-1	2-2	3-3	Strength of splice related to nominal strength of belt [%]
1-1	670	105				67
2-2	635	100				64
3-3	780	122				78
1-2	468	73	70	74		47
1-3	605	95	90		78	61
2-3	613	96		97	79	61

It follows from the obtained image of the stress pattern that the splice is most threatened with rupture in the cross-section where two plies characterised by lower module of elasticity interact with a single ply with a high modulus of elasticity.

Digital video recording is a novelty [1] in belt splice research. The main parameter measured is the angle of non-dilatational strain in the adhesive-bonded joint. The values of this angle are read out

Iz dobijene slike raspodele opterećenja sledi da spoj ima najviše pukotina na preseku gde su dva uloška sa nižim modulom elastičnosti u vezi sa uloškom sa visokim modulom elastičnosti.

Digitalno video zapisivanje je novina [1] u istraživanju spojeva na traci. Glavni mereni parametar je ugao nedilatacionog opterećenja u adheziono-spojenom zazoru. Vrednosti ovog ugla su proučavane za određena opterećenja for prescribed loads tensioning the splice. A suitable computational model, which takes into account also the properties of the spliced belts, is assumed. The stresses (fig.4) and strains (fig.5) in the investigated layer of the joint are calculated numerically. This method combines theoretical models and real properties of spliced belts (neglecting simplifying assumptions) and yields promising results.

naprezanjem spojeva. Usvojen je odgovarajući kompjuterski model koji uzima u obzir i osobine spojenih traka. Opterećenja (slika 4) i naprezanja (slika 5) u ispitivanom sloju sa zazorom su numerički proračunata. Ova metoda kombinuje teorijske obrasce i stvarne osobine spojenih traka (zanemarujući proste pretpostavke) i daje obećavajuće rezultate.

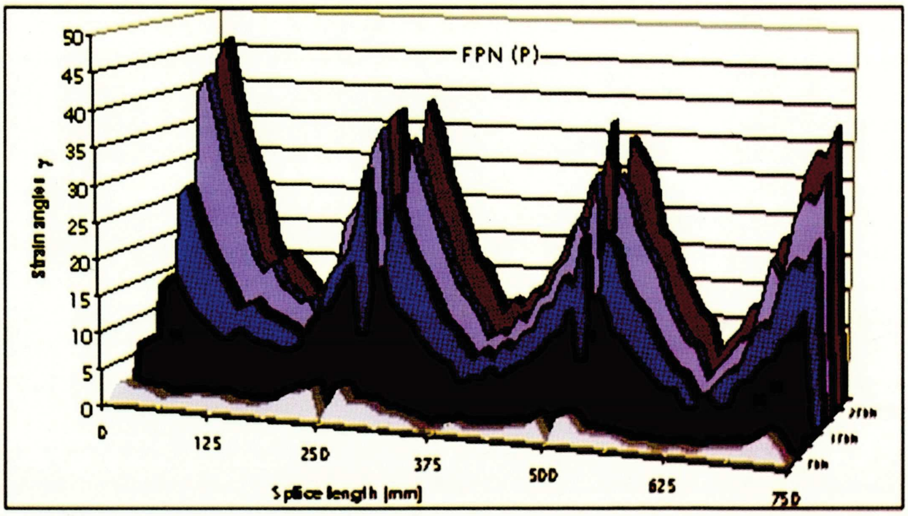

Figure 4 Distribution of strain angles in a joint belt splice
slika 4 Raspodela uglova naprezanja u zazoru spoja trake

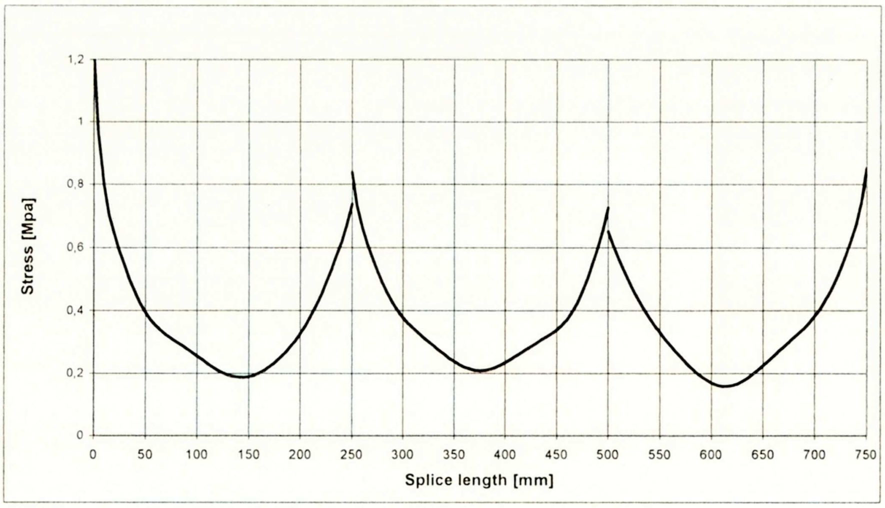

Figure 5 Stress distribution in a joint belt splice
slika 5 Raspodela opterećenja u zazoru spoja trake

Numerical modelling techniques are more and more frequently used as a tool aiding the investigation of real objects. By applying the FEM method one can shorten the time of the investigations and reduce their costs and at the same time increase the number of simulations run. On the basis of detailed design and material data a geometrical model is built which in turn forms a

Tehnike numeričkog modeliranja se sve češće primenjuju kao pomoćno sredstvo pri ispitivanju stvarnih objekata. Primenom FEM metode može se skratiti vreme istraživanja i redukovati njihova cena, a u isto vreme se može povećati broj simulacija. Na osnovu detaljnih proračuna i materijalnih podataka izgrađen je geometrijski model koji formira baze za zasebne modele spojeva. Ovaj model je podvrgnut basis for a discrete model of the splice. This model is subjected to loading (according to a computational model and specific assumptions) and the results of the analysis are represented graphically. This method allows one to determine not only the distribution of stresses (fig.6) and strains in the splice joint but also to obtain information about other factors such as heat losses and energy spent and quantities which are difficult to measure in standard laboratory measurement conditions.

proveri (prema kompjuterskom modelu i određenim pretpostavkama) i rezultati ovih analiza su grafički predstavljeni. Ova metoda dozvoljava da se utvrde ne samo raspodela opterećenja (slika 6) i naprezanja u zazaoru spoja, već se, takođe, dobijaju informacije o drugim faktorima, kao što su gubici toplote i utrošene energije i veličina koje je teško meriti u standardnim laboratorijskim uslovima.

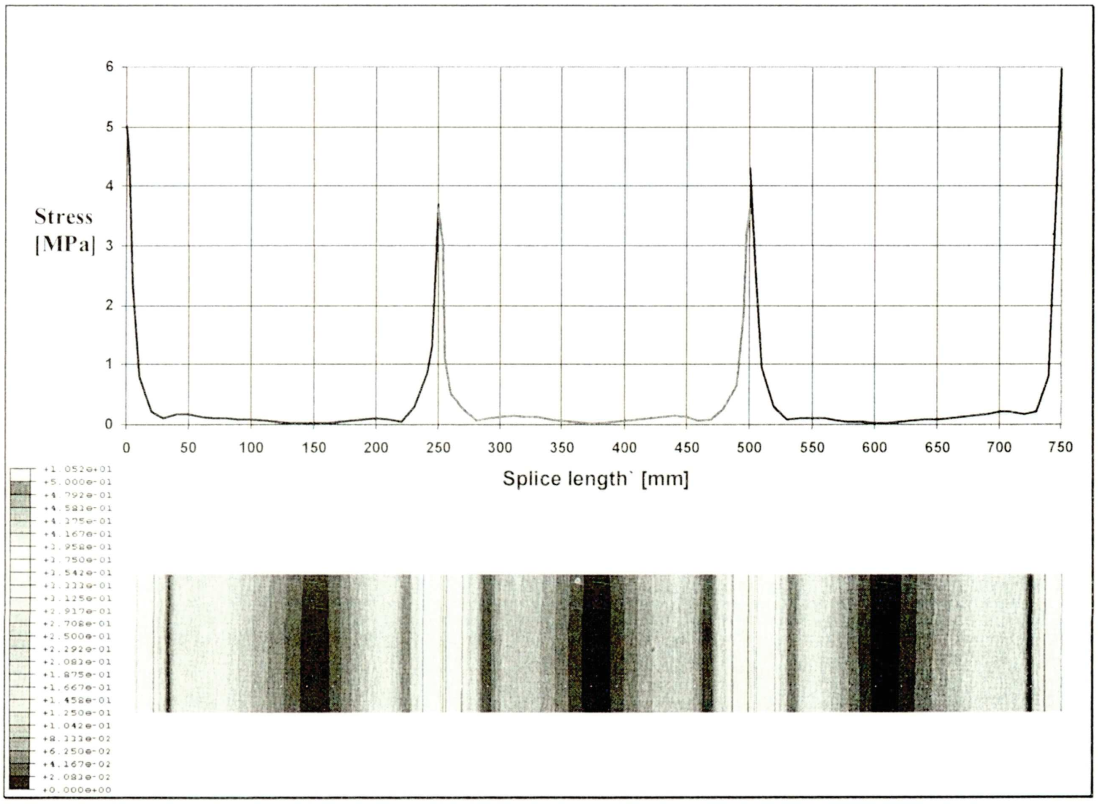

Figure 6 Stress distribution in a whole length of belt splice
slika 6 Raspodela opterećenja u celoj dužini spoja trake

4 CONCLUSIONS

The advances in technology, the state-of-the-art hardware and software have made it possible to develop increasingly more precise research methods and to verify their usefulness. Also the aim of the investigations of multiply belt splices is to make analytical methods (forecasting of stresses in the plies of a splice and the fatigue strength of the latter) more precise. The results of the theoretical and experimental research obtained so far indicate that it is possible to optimise belt splices by shortening their middle steps. As the numerical model is improved, more accurate results will be obtained, which in turn will open up new possibilities in splice research.

4 ZAKLJUČCI

Napredovanja u tehnologiji, izuzetne mogućnosti hardvera i softvera, omogućila su da se razviju izuzetno precizne metode ispitivanja koje su potvrdile svoju korisnost. Takođe, cilj ispitivanja traka koje su spojene na više mesta je da se izrade preciznije analitičke metode (koje predviđaju opterećenja u uloščima spojeva i trajnu čvrstoću). Rezultati teorijskih i eksperimentalnih istraživanja dobijenih do sada ukazuju da je moguće optimizirati spojeve trake skraćivanjem njihovih zaseka. Pošto je numerička metoda poboljšana, bili bi dobijani precizniji rezultati koji bi otvorili nove mogućnosti u ispitivanju spojeva.

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