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Gum Tragacanth Fibers from *Astragalus gummifer* Species: Effects of Influencing Factors on Mechanical Properties of Fibers

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Abstract: Gum Tragacanth (GT) is one of the most widely used natural gum across the globe and it is shown that GT from *Asteragalus gummifer* can be processed into fiber via alkaline treatment. In this study a complementary description of GT fibers is provided and the effects of influencing factors on properties of GT fibers investigated. Spinning Dope (SD) prepared by adding ribbon type GT of *Astragalus gummifer* species to alkaline solutions and fibers produced by solution spinning method. The effects of some processing factors including: draft ratio, residence time in coagulation bath, GT concentration in SD, ripening time of SD, kind of coagulant agent and the pH of washing bath on some mechanical properties of GT fibers studied. It was concluded that with increasing the coagulant concentration the mechanical properties of fibers improved, but it caused formation of sheet core structure. $ZnCl_2$ as coagulant agent improved mechanical properties and applying glycerol caused more flexibility in GT fibers, even though their tenacity reduced.

Key words: Gum tragacanth fiber, *Astragalus gummifer*, solution spinning, ripening time, coagulant agent, draft ration

INTRODUCTION

Gum Tragacanth (GT) is exudates from several species of shrubs of the genus *Astragalus* mostly found in certain areas of Asia and in the semi desert and mountainous regions of Iran, Syria, Turkey and other near eastern countries (Anderson and Grant, 1989a; Mohammadifar *et al*., 2006; Verbeken *et al*., 2003; Whistler and Smart, 1953).

There are almost fourteen species of *Astragalus*, which produce GT. Among them, *Astragalus gummifer*, *Astragalus kuridcus* and *Astragalus microcephalus* are the most important species for the production of GT, as reported by Anderson and Bridgeman (1985). By incision on the trunk of shrub, the gum exudes and after being naturally dried by the air, it is collected as ribbons (the highest quality gum), or flakes (Davidson, 1980). Both types exhibit similar pseudoplastic properties, but there is a marked difference in the viscosity of flake and ribbon types, the later yields more viscous solutions in the same concentration (Kiumarsi, 1998; Stauffer and Andon, 1975; Verbeken *et al*., 2003).

It is mostly believed that GT consists of at least two major components: a water-swellable (about 60 to 70%) and a water-soluble portion, as reported by Davidson (1980) and Whistler (1953). However, this ratio may be different according to the species of the original shrub, for example the ratio of soluble/insoluble components for *Astragalus microcephalus*, *Astragalus gummifer* and *Astragalus kuridcus* are 65/35, 40/60 and 30/70, respectively (Anderson and Bridgeman, 1985; Anderson and Grant, 1989b; Mohammadifar *et al*., 2006).

Aspinal and Baillie (1963) and Anderson and Bridgeman (1985) call the water-swellable part as bassorin and the water-soluble part which is a colloidal hydrosol as tragacanthin, while Davidson (1980) refers to the water soluble part, a neutral polymer as an arabinogalactan (Fig. 1a)(Tischer *et al*., 2002) and the water-swellable part as tragacanthic acid (TA) (Fig. 1b).

TA, the major component of GT has a main backbone chain of (1→4)-α-D-galacturonic acid residues similar to pectic acid. The major difference between pectic acid and TA is that the latter has many neutral side chains bonded to the acidic backbone. The conformation of TA is resembles to Xanthan, but the electroactive components in the latter are located within the side chains instead of along the main backbone (Davidson, 1980).

Kiumarsi (1998) reported that the majority of D-galacturonic acid residues in TG carry xylose-containing side chains through C-3 (5). Three types of

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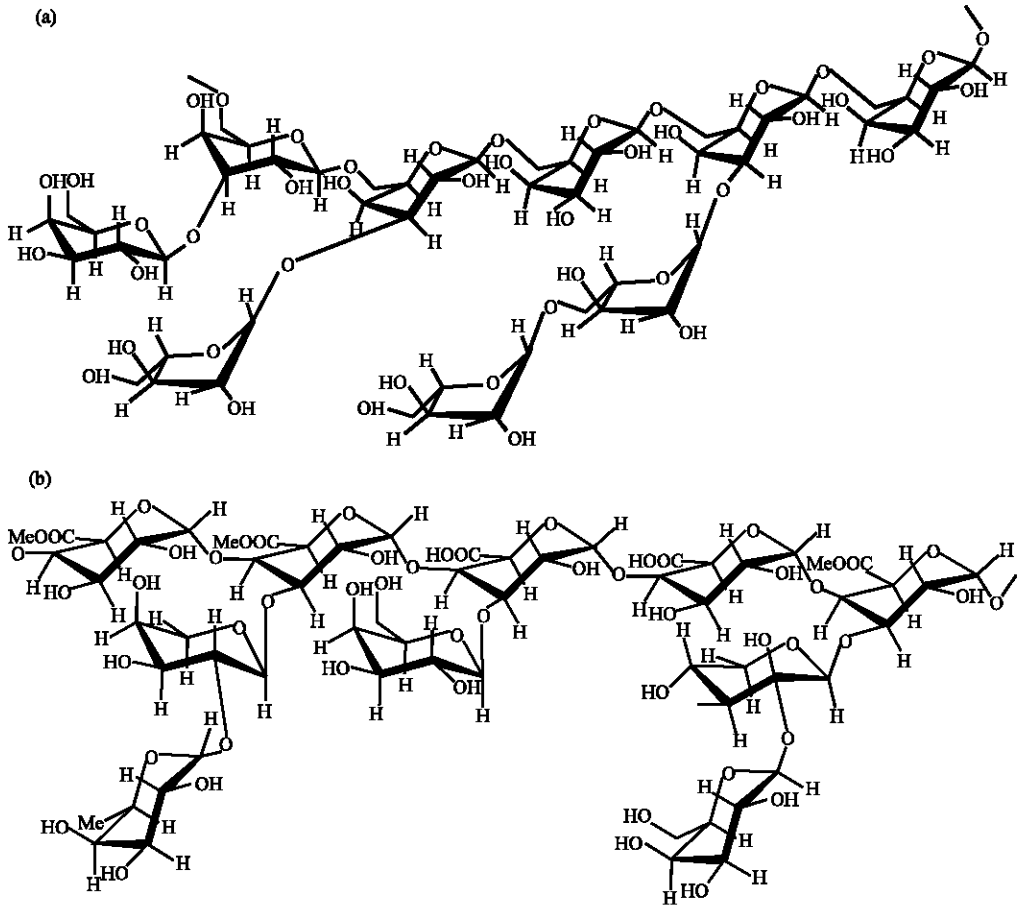


Fig. 1: Chemical structure of GT: (a) Arabinogalactan and (b) Tragacanthic acid

side chains have been recognized namely, single β-D-xylopyranose residues, disaccharide units of 2-0-α-L-fucopyranosyl-D-xylopyranose and 2-0-β-D-galactopyranosyl-D-xylopyranose and these must account for the majority of the sugar residues in the outer chains (Aspinal and Baillie, 1963).

Gum tragacanth has been known and used for over five thousand years. It is one of the most widely used natural gums across the globe. GT can typically be used as stabilizer, thickener, emulsifier, moisture retaining agent, binding agent, anti-freezing agent and adhesive agent (Anderson and Bridgemen, 1985; Aspinal, 1982; Davidson, 1980; Kiumarsi, 1998; Shimotoyodome *et al*., 2006; Verbeken *et al*., 2003; Whistler, 1973).

The gum tragacanth fibers were produced in our previously study (Khajavi *et al*., 2004, 2005). In this study it was intended to characterize GT fiber and study some factors, which are effective in the quality of produced fibers including concentration in spinning dope, dope ripening time, residence time of as spun fiber in the coagulation bath, concentration and the kind of coagulant, the pH of the coagulation bath and washing bath, using glycerin and the effect of draw ratio was studied.

MATERIALS AND METHODS

All the experiments were done at Research and Science Campus of IAU in 2004-2006. Gum tragacanth of *Astragalus gummifer* prepared from local lands near Isfahan, Iran in. The cleaned gum was grinded using a ball mill type (Damavand Co. Iran) and powdered gum with a diameter between 150 to 250 μm used for experiments. For preparing the spinning dope SD required amount of GT powder was add to alkaline solutions (1% w/w NaOH on weight of GT) during stirring. Samples were allowed to stand for a period of time to ripen (ripening step) at room temperature. The viscosity of prepared samples measured in different ripening times (up to 330 h) using a Brookfield viscometer (model RVDV-I+) at 1.5 rpm (Spindle number 5 was used for all the viscosity measurements).

To produce fibers, a laboratory spinning unit equipped with a winder (made by Khajavi in 2003 at IAU, Science and Research Campus Branch) used. A stainless steel spinneret with one orifice (inlet diameter 2.5 mm, outlet diameter 1 mm and thickness 1.43 mm) installed on laboratory spinning unit and prepared dopes pumped into the coagulation bath with a speed of 5 m min^{-1}. The mechanical properties of produced samples were measured by a Shirley fibre strength tester (model micro 50, speed 31 mm min^{-1} and sample length 10 mm).

RESULTS AND DISCUSSION

As producing Gum Tragacanth fibers is a novel work, the obtained data are considering as a basis for future research. The used process in the present experiment is solution spinning, or accurately wet spinning method and some common and determining factors in this process is as the same for producing GT fibers such as draft ratio and dope concentration.

With increasing GT concentration in SD some mechanical properties of produced GT fibers including load and energy improved (Table 1), but strain decreased. At concentrations higher than 6% some unsolved masses were observed and as it can be shown in Fig. 2, the cross sections of GT fibers with high GT concentration in SD are more circular.

According to Table 2 all the investigated mechanical properties improved with increasing ripening time. The viscosity reaches to a maximum which is a sign of outmost opening of the entangled molecular chains. Over ripening times cause degradation of molecular chains and deterioration of mechanical properties of the produced fibers (after 72 h all mechanical properties declined, which are not reported here) and loss of viscosity (Fig. 3).

With increasing resident time of as spun fiber in coagulation bath, all the mechanical properties improved, which can be related to the better interaction of the coagulant with the GT polymer. Strain and tenacity were increased up to 133 and 29% orderly. When the concentration of coagulant agent in the coagulation bath increased almost all the mechanical properties of produced fibers increased (Table 3-5). The results implies that with increasing the amount of coagulant more links are formed between the molecular chains of GT. But with increasing the concentration of the coagulant the sheet core structure forms (Fig. 4). This structure is formed by rapid coagulation of the outer surface of polymer when the concentration of coagulant is high.

Some of mechanical properties are increased with washing and changing the pH of washing liquor. Strain decreased 46% but tenacity increased about 14% for the case of washing of samples and strain and tenacity increased 94 and 276% when the pH of washing liquor dropped to 4. Washing can reduce the alkaline pH of the as-spun fiber. In neutral pH the polymer chains repulse

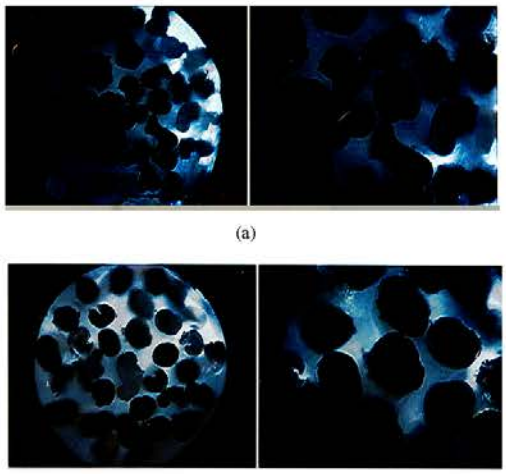
Table 1: Effect of GT concentration in SD on mechanical properties of GT fibers

	GT conc. in dope (%)		
Quantity	6	8	10
Load (cN)	248.03	284.05	128.00
Strain (%)	10.80	8.83	5.01
Energy (cNm)	0.14	0.09	0.03
Tenacity (cN/Tex)	3.54	4.06	1.84

Table 2: Effect of SD ripening time on mechanical properties of GT fibers

	Dope ripening time (h)*		
Quantity	12	48	72
Load (cN)	225.96	248.03	256.92
Strain (%)	3.01	10.80	10.94
Energy (cNm)	0.05	0.14	0.14
Tenacity (cN/Tex)	3.22	3.54	3.67

*: After 72 h all the quantities declined which are not reported here



(a) (b)

Fig. 2: Effect of GT concentration in SD on resulted. cross sections. (a) 6% (w/w) and (b) 8% (w/w)

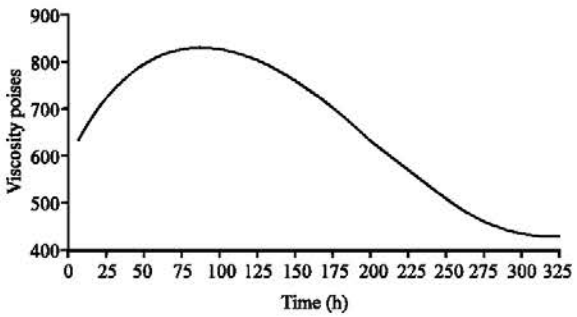


Fig. 3: Effect of SD ripening time on viscosity

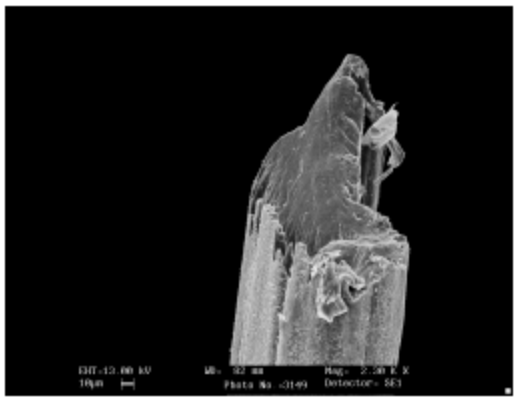


Fig. 4: Forming of sheet core structure due to high concentration of coagulant agent ($CaCl_2$ as coagulant agent with 150 g L^{-1} concentration)

Table 3: Effect of $CaCl_2$ concentration in the coagulation bath on mechanical properties of GT fibers

	$CaCl_2$ concentration in coagulation bath (g L^{-1})			
Quantity	25	50	100	150
Load (cN)	34.75	172.830	175.84	200.50
Strain (%)	1.96	3.675	4.45	6.20
Energy (cNm)	0.01	0.050	0.09	0.13
Tenacity (cN/Tex)	0.86	4.320	4.39	5.01

Table 4: Effect of $ZnCl_2$ concentration in coagulation bath on mechanical properties of GT fibers

	$ZnCl_2$ concentration in coagulation bath (g L^{-1})		
Quantity	20	50	100
Load (cN)	13.79	89.86	219.98
Strain (%)	3.13	2.72	2.83
Energy (cNm)	0.00	0.01	0.05
Tenacity (cN/Tex)	0.34	2.12	5.50

Table 5: Effect of $Cu(SO_4)_2$ concentration in coagulation bath on mechanical properties of GT fibers.

	$Cu(SO_4)_2$ concentration in coagulation bath (g L^{-1})			
Quantity	20	40	50	80
Load (cN)	11.97	46.55	53.33	109.00
Strain (%)	4.23	2.62	2.91	3.40
Energy (cNm)	0.00	0.01	0.01	0.02
Tenacity (cN/Tex)	0.30	1.16	1.33	1.95

each other (due to negatively charged carboxylic groups on backbone or side chains of polymer) and the chance of inter molecular bonding decreases, but in acidic state this chance increases, which is confirmed by the increasing of strain in the neutral and acid pH washing conditions. This is confirmed by the result of dope viscometery in various pH too (Table 6). Reducing the pH of coagulation bath has the same effect as before so strain and tenacity increases with lowering the pH of coagulation bath to 4. Drying under tension gives order to molecular chains and improves the mechanical properties GT fibers (Table 7).

Table 6: Viscosity of treated GT with alkaline in different pH conditions

Viscosity (cp)	pH
39330	7.0
44000	5.5
58260	3.5
Gel-like state	<3

Table 7: Effect of applying tension during drying on mechanical properties of GT fibers ($ZnSO_4$ as coagulant agent)

Drying condition	Load (cN)	Strain (%)	Energy (cNm)	Tenacity (cN/Tex)
Tensionless	106.32	2.83	0.02	2.66
Under tension	220.22	3.02	0.05	5.51

Table 8: Effect of adding glycerin to washing bath on mechanical properties of GT fibers ($ZnSO_4$ as coagulant agent)

Coagulation bath	Load (cN)	Strain (%)	Energy (cNm)	Tenacity (cN/Tex)
Normal (water)	72.23	2.20	0.01	1.81
Glycerine (pure)	51.11	6.53	0.03	1.28
Glycerine+Water (50:50) pH = 7	44.25	11.97	0.06	1.11
Glycerine+Water (50:50) pH = 4	47.03	12.04	0.06	1.18

Table 9: Effect of adding glycerin to washing bath. ($CaCl_2$ 50 g L^{-1} as coagulant agent and draft ratio 1:8)

Coagulation acidity	Load (cN)	Strain (%)	Energy (cNm)	Initial modulus (cN/Tex)	Tenacity (cN/Tex)
Normal (water)	486.76	39.30	1.16	61.58	12.17
Glycerin (pure)	503.50	50.80	1.54	40.67	12.59
Glycerine+Water (50:50)	432.60	23.92	0.64	81.32	10.81

Table 10: Mechanical properties of produced GT fibers. [GT Conc. (60 g L^{-1}) + Glycerine (20 g L^{-1}) and $ZnCl_2$ (20 g L^{-1}) as coagulant agent]

Mechanical property	Quantity
Load (cN)	110.600
Strain (%)	15.020
Energy (cNm)	0.098
Initial modulus (cN/Tex)	27.640
Tenacity (cN/Tex)	2.760

According to Table 8 and 9, with adding glycerin to coagulation bath the strain of produced GT fibers improves and it will be increased at acidic conditions, but load and tenacity decrease. With adding glycerin the consolidation process of gel fiber took place more uniformly and knot ability of GT fibers increased (Fig. 5 and 6). It can also be seen in the Table 10 that application of glycerin in the dope itself can cause increasing flexibility properties. Increasing the take up speed from the coagulant bath improves the mechanical properties that can be related to increasing molecular chains orientation in fibers with higher draft ratio, so strain and tenacity increases 63 and 87% orderly.

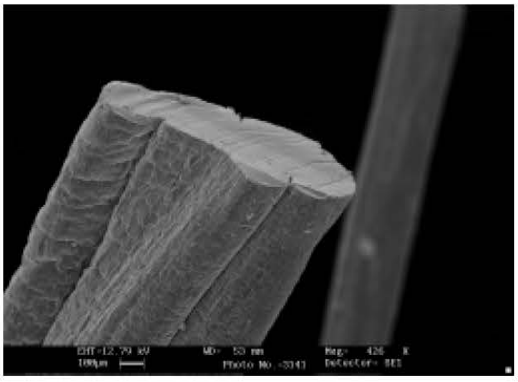


Fig. 5: Application of glycerin cause ordered dehydration

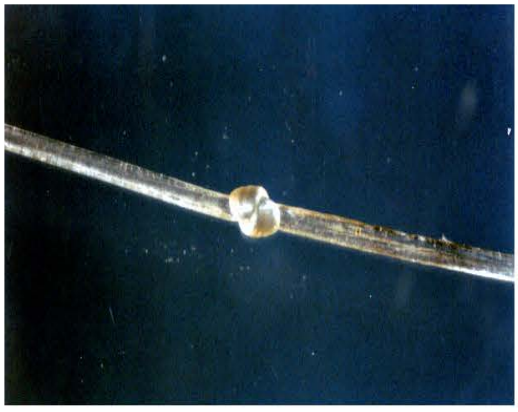


Fig. 6: Knot ability of GT fiber with the aid of glycerin

CONCLUSIONS

It is shown that the ribbon type gum tragacanth from *Astragalus gummifer* species can be processed into fibre and alkaline treatment experienced for increasing GT processability in wet spinning method. Gum tragacanth fiber, a biodegradable product and natural origin, may find its use in medical textiles and applying some coagulant agents such as zinc salts, increases its medical function. Gum tragacanth fiber should fulfill some mechanical properties. To improve the mechanical properties of GT fibers some well known parameters in wet spinning method should be optimized. The effect of increasing draft ratio, applying plasticizer in spinning process of regenerated or synthetic fibers is as the same as for gum tragacanth fibers too, but there are some exclusive factors for GT fibers such as the acidity of coagulation bath, which play an important role in the quality of produced fiber.

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