Instrumental Probe and Method to Measure Stickiness of Cooked Spaghetti and Noodles[1]

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ABSTRACT

A multifaced probe, a sample-restraining device, and a sample holder were built to measure stickiness on a single cooked strand of spaghetti or noodle. The probe and sample-restraining device were attached to a commercial texture analyzer. Stickiness measurements, requiring 1.5 cm of undisturbed length along a strand, were made at one of 14 positions along a strand. Cooked strands were mounted on the sample holder, and the stickiness measurements were made at intervals of up to 150 min as the strands aged under ambient conditions (23–25°C and 50–74% rh). The probe was used to compress a strand to 100 *g*-force, then the probe was retracted and the tensile portion of the force-time (distance) curve was captured and stored, all in less than 1 min. The peak tensile force and the total tensile work required to separate the probe from a strand were used to measure stickiness. Both parameters increased and then decreased as a cooked strand was aged under ambient conditions. Throughout the aging period, spaghetti and noodles made from a hard white winter wheat flour were stickier than those made from a durum wheat flour; a maximum difference occurred after 70 min of aging. Within the variation of relative humidity in our laboratory, the peak tensile force observed upon aging the cooked spaghetti and noodle strands under ambient conditions was reproduced with a 5.1–6.0% coefficient of variation. The coefficient of variation for tensile work was 8.8–13.0%.

Various types of noodles and spaghetti differ in internal firmness and elasticity, but their surface must be the same: smooth and free of stickiness. Surface stickiness of string pasta products is differentiated readily by sensory analysis, but a rapid instrumental method, using a small sample size, has long been sought. Instrumental measurement of stickiness is complicated by water on a product's surface and by the changing properties of the cooked strings as they age, especially under different ambient conditions. There is one added complication. When probing the stickiness of a strand's surface, the strand must be firmly anchored to a base to ensure that the adhesive force measured is that between the strand and the probe, and not that between the strand and the base. Extra water collects at the bottom of a strand as it rests on a base, which results in increased lubrication at the bottom of a strand. The lubrication reduces stickiness and causes slippage of the sample.

Voisey et al (1978) and Dexter et al (1983a) showed that the maximum tensile force from stickiness (adhesion) was independent of the applied compression force over a fairly wide range. Too low a compression force, however, gave reduced stickiness values, probably because of poor contact of strands with the plate. Too high a compression force gave elevated stickiness values, probably because of extensive deformation of strands. An optimum compression force was chosen.

Dexter et al (1983a) also reported that, up to 20 min, surface stickiness increased as the elapsed time between draining and measuring increased. As water was lost from the surface of the strands, they reasoned, lubrication was lost, and the surface became stickier. The precision of the stickiness measurement decreased as elapsed time increased. Therefore, the time for stickiness measurement was set at 10 min after draining. No stickiness values were reported after 20 min, even though stickiness should eventually decline because of excessive drying and loss of surface tack.

In addition to the mechanical methods of estimating surface stickiness in spaghetti, a chemical method has also been devised (D'Egidio et al 1982). Cooked strands were drained, rested, and stirred thrice in water at 25°C over a 12-min soaking period. After removal of strands, the total organic matter (TOM) in the rinse water was determined by chromate oxidation in strong acid. Using this method, Dexter et al (1985) started with 25 g of spaghetti and found that TOM was correlated negatively with cooking score ($r = -0.56$) and positively with stickiness ($r = 0.66$).

More recently, D'Egidio et al (1993) used sensory evaluation and the TOM method to analyze 118 spaghetti samples made with Italian durum wheat. In the sensory analysis (evaluation by sight and handling), stickiness was defined as the material adhering to the surface of cooked pasta; bulkiness was defined as the degree of adhesion between pasta strands; and firmness was defined as the resistance of cooked pasta to chewing with the teeth. Multiple correlation analysis showed that low-temperature drying (50°C) of spaghetti gave cooked strands with an eating quality mostly dependent upon stickiness and somewhat dependent on firmness, whereas high-temperature drying (90°C) decreased the relative weighting on stickiness and increased that on firmness. Overall, stickiness correlated well ($r = 0.83$) with bulkiness in sensory evaluation. The authors also presented a mechanical method of measuring stickiness using the viscoelastograph. Malcolmson et al (1993) presented a method to estimate surface stickiness using bulkiness.

In the last decade, a new generation of texture-measuring instruments—compact in size and capable of rapidly measuring force, distance, and time—were commercialized. One such instrument is the TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY). This computer-controlled instrument allows a compression-retraction measurement to be made on a strand in less than 1 min. The data are stored in memory and analyzed either on-line or off-line.

The objectives of the present investigation were: 1) to fabricate attachments to the texture analyzer that allowed the measurement of stickiness on spaghetti and noodle strands; and 2) to use the system to measure stickiness of cooked spaghetti or noodles over time as they are held under ambient conditions.

MATERIALS AND METHODS

Materials

Commercial durum wheat flour with 13.3% protein and 0.86% ash (14% mb) was purchased from ConAgra Grain Processing Co., Hastings, MN. Kansas hard white winter (HWW) wheat harvested in 1990 was milled to 72% extraction flour with 11.9% protein and 0.55% ash (14% mb) on the Buhler experimental mill in the Department of Grain Science at Kansas State Univer-

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sity. Five brands of spaghetti were purchased from a local supermarket.

Distilled water and artificially hard water were both used as cooking and cooling media. The artificially hard water contained sodium carbonate (100 mg/L), sodium bicarbonate (150 mg/L), potassium sulfate (30 mg/L), magnesium chloride (30 mg/L), and calcium chloride (90 mg/L) (Dexter et al 1985).

Spaghetti and Noodle Making

Commercial durum wheat flour or HWW wheat flour (1,170 g, 14% mb) was placed in the 4-qt bowl of a Hobart mixer fitted with a flat paddle agitator (Hobart Mfg. Co., Troy, OH). The agitator was set at low speed and run for 1 min. Water (optimum level) was added slowly over a period of 3 min. The agitator was then run at medium speed for 2 min. The mixing bowl was covered with a damp cloth, and the crumbly dough was allowed to rest at room temperature for 15 min. The optimum level of water was sufficient to hydrate all flour particles, as evidenced by the absence of white specks in the extruded strands, but it was low enough to give a free-flowing, noncohesive dough at the inlet of the extruder barrel. Optimum water level to prepare spaghetti and noodles was 33% for both flours, which equaled 28.3% absorption on a 14% mb.

Spaghetti and noodles were made using a small pasta press (Demaco model S-25, DeFrancisci Machine Co., Brooklyn, NY) fitted with different dies. Spaghetti was made using a die with 84 circular, teflon-lined holes, 1.8 mm diameter (D. Maldari & Sons, Inc., Brooklyn, NY). Noodles were made using a die with 24 rectangular, teflon-lined holes, 6 mm × 0.5 mm (Montoni Inc., Napa, CA). The dough was transferred to the holding chamber of the press, and the chamber was evacuated to a vacuum gauge reading of 17 in. (446 mm) of mercury. The barrel of the extruder was preheated and maintained at 35°C; the auger of the press was set at 30 rpm. Extruded strands were cut into lengths of 50–60 cm and hung on aluminum poles. The loaded poles were placed in a laboratory dryer (Standard Industries Inc., Fargo, ND) controlled by a Micristar Microprocessor (Research Inc., Minneapolis, MN). The products were dried at low temperature as follows: 15 min at 30°C and 90% rh; 4 hr each at 45°C and 85, 80, and 75% rh; and, finally, 15 min at 30°C and 75% rh. Dried products were equilibrated at ambient conditions for 24 hr and then packaged in polyethylene zip-lock bags. The bagged spaghetti and noodles were stored in a cabinet at room temperature for approximately one month before testing.

Apparatus to Measure Stickiness

A TA-XT2 texture analyzer was interfaced with an IBM computer (386DX-33). The system included a color monitor and was controlled by software (SMS1-Stable Microsystems, Texture Technologies Corp). The load cell was rated from 1 to 5,000 *g*-force. Detailed drawings of the apparatus used to measure stickiness by the compression-retraction method are given in a U.S. patent (Seib and Guan 1994). Drawings may be obtained from KSU Research Foundation, Kansas State University. Brief descriptions of the components are given here.

A supporting surface (Fig. 1A) for cooked strands was made from a polystyrene plate (240 × 140 × 12 mm) covered with Whatman No. 1 chromatography paper (0.15 mm thick). The paper was marked with five equally spaced lines (24 mm apart) running parallel to the long dimension of the plate. The paper also was marked along the length of the plate into 15-mm segments that demarcated measurement positions on a strand. Figure 1B shows one cooked strand in position for measurement.

A multifaced probe was built from polystyrene in the configuration of a turret that rotated on an axle spanning two support legs of a stainless steel mount (Fig. 2). The support legs extended from the head of the mount, which was bolted to the load cell attached to the arm of the texture analyzer. One support leg contained a small threaded hole through its edge to accommodate the set screw that held the axle in place. One support leg also had a second and enlarged threaded hole in its side to house a screw that was used to hold the turret in a fixed position.

The turret contained six radially extending probes; three of them were one-tip probes with a contact area of 14 × 4 mm; the other three were double-tip probes with two contact areas, each 14 × 4 mm. One-tip probes were used for noodles and double-tip probes were used for spaghetti. The probe surface used for most of the measurements reported herein was polished (600 A NAPA abrasive) polystyrene. Other contact surfaces were examined, such as a vinyl rubber film cut from vinyl gloves. The hub of the turret had a series of holes to accommodate the set screw on the support leg to hold the turret stationary.

The restraining unit, constructed mostly of stainless steel, is shown in Figure 1C. The unit was attached to the beam arm (Fig. 1D) of the texture analyzer by four mounts fitted with set screws (Fig. 3). Each of the four mounts was attached to one end of a support rod that carried a plate at its other end. The plate contained a large aperture in its center to allow free passage of the probe and also four holes near its periphery. Those four holes accommodated four spring-loaded suspension rods that supported the foot used to restrain a cooked strand. The foot was essentially a flat plate with a pair of apertures to allow passage of the tip of the probe. Rails of various thicknesses were positioned parallel to the direction of the cooked strand and were glued to the bottom of the foot. The rails prevented distortion of a sample by excessive compression when it was restrained. In the present investigation, the rails were 3 mm thick, 25 mm long, and either 0.45 or 2.3 mm high for cooked noodles or spaghetti, respectively.

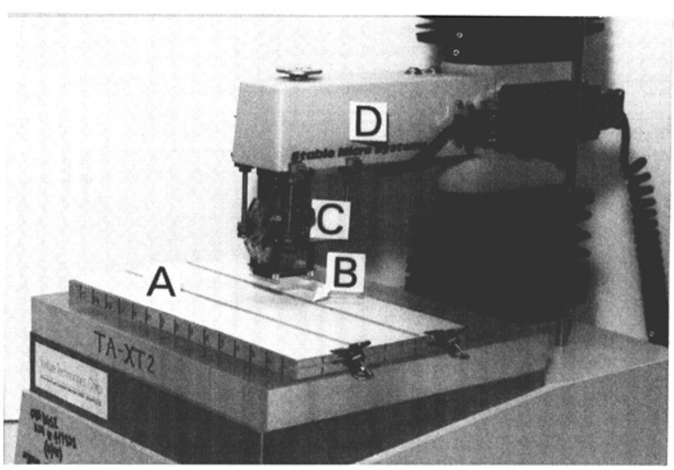

Fig. 1. Texture analyzer: sample holder (A); mounted sample strands (B); multifaced probe with sample-restraining device (C); and beam arm (D).

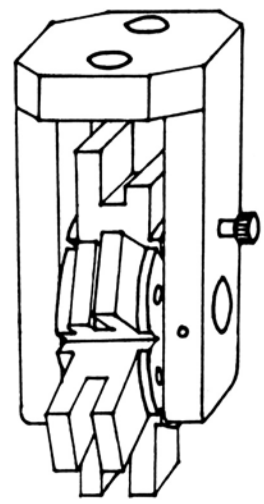

Fig. 2. Diagram of multifaced probe used to measure stickiness in the compression-retraction method.

Stickiness Measurement

One spaghetti strand (21 cm long) was added to boiling distilled water or artificially hardened water (2,000 ml). For all samples, each strand was cooked in gently boiling water for 11 min. Replicate samples, up to five strands, were cooked at 1-min intervals in separated zones inside the cooking pan. At the proper time, a strand was removed from the boiling medium and placed in water (300 ml) at room temperature for 2 min. The sample holder was tilted 80° to vertical, and the strands were mounted along the traced lines on the paper atop the sample holder. The loaded sample holder remained in that position under ambient conditions until all stickiness measurements were made. Relative humidity in the room was determined from the wet-bulb and dry-bulb temperatures measured by a sling psychrometer.

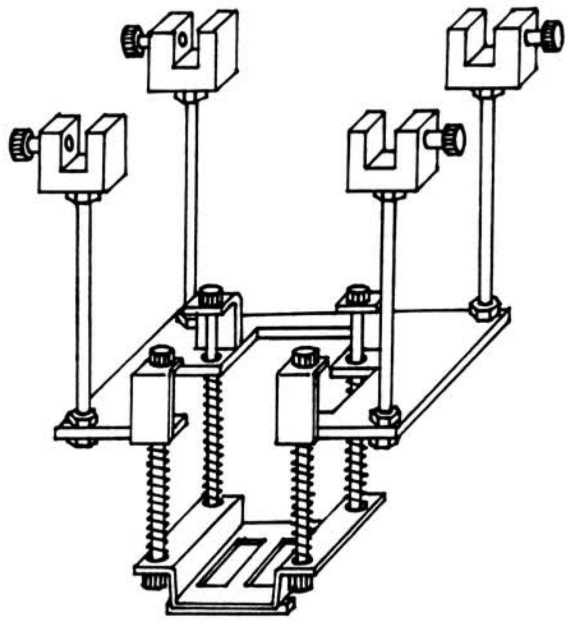

Fig. 3. Diagram of a sample-restraining unit used with the multifaced probe.

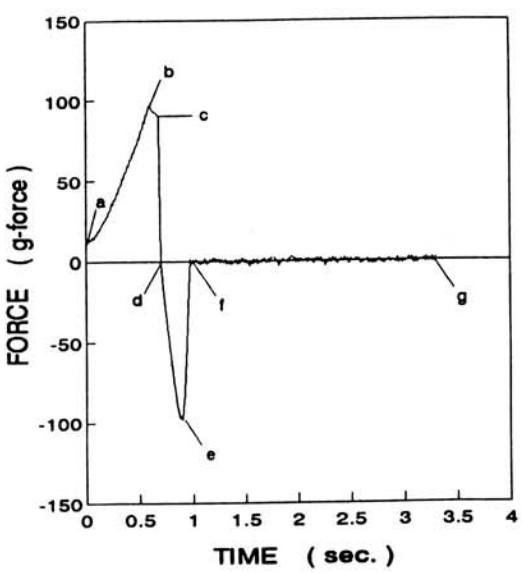

Fig. 4. Force-time curve generated by the compression-retraction method of measuring stickiness. The points on the curve were: a) the descending probe engaging the strand; b) maximum compression; c) force after a brief rest period (0.1 sec) and at the start of retraction of the probe; d) beginning of tensile force; e) peak tensile force due to stickiness; f) probe disengaging from surface; and g) probe returning to initial position. Probe speeds on curve: a–b, 0.1 mm/sec; b–c, 0 mm/sec; c–g, 3.0 mm/sec.

Noodle strands (21 cm long) were cooked and mounted in a similar manner, except cooking time was 2.5 min and cooling time in the water was 1.5 min.

Stickiness measurements were made on the texture analyzer using the software program called Hold Distance. The variable settings were: 1) arm speed prior to sensing a sample, 1.0 mm/sec; 2) trigger point, or the force indicating when the probe began to engage a strand's surface, 1.0 *g*-force; 3) arm speed during compression of strand, 0.1 mm/sec; 4) compression force at the end of compression, 100 *g*-force; 5) holding time at maximum compression, 0.1 sec; and 6) arm speed during retraction of arm and sensing of stickiness, 3.0 mm/sec. In some experiments, the compression force was varied between 50 and 150 *g*-force.

After an aging period of 10–150 min under ambient conditions, a strand was positioned under the restraining device, and the testing cycle of the texture analyzer was initiated. As the probe moved through its test cycle, a force-time curve was simultaneously displayed on the monitor. The negative area of the force-time curve was converted to a force-distance curve and integrated, then the area was stored in memory. The time required to measure one stickiness value, and to store the data in memory, was less than 1.0 min. Measurements were made at 1.0-min intervals on the other replicate strands. The stickiness value at any given holding time for a noodle or spaghetti sample was the mean of measurements on two to five replicate strands. Because each measurement required 1.5 cm of undisturbed length along a strand, 14 measurements were possible along a 21-cm strand. For most samples, multiple measurements were made along replicate strands until the maximum tensile force (work) was observed while holding the samples under ambient conditions.

RESULTS AND DISCUSSION

Probe Design

A probe was designed to attach to the load cell on the moving arm (Fig. 1D) of the texture analyzer. The probe was a multifaced turret that featured six possible surfaces (Fig. 2). A sample-restraining device and a sample holder also were designed to work along with the multifaced probe.

The sample holder (Fig. 1A) accommodated five individual strands in parallel fashion, and up to 14 stickiness measurements could be made along each strand. The advantage of measurements on a single strand is the small sample size. The disadvantage is that the replicate strands must be cooked separately at 1-min intervals so that moisture redistribution will be the same when stickiness measurements are made, also at 1-min intervals.

The sample-restraining device (Fig. 3) was designed for attachment to the perimeter of the arm on the texture analyzer. The concerted movement of the multifaced probe and the sample-restraining device allowed rapid intermittent measurement of adhesion between the probe and a single strand of cooked spaghetti or noodle. The adhesion portion of the force-time (distance) curve was retrieved and then stored in memory.

Stickiness Measurements

To develop the method to measure surface stickiness, all measurements, unless otherwise stated, were made on spaghetti that had been cooked 11 min and on noodle strands that had been cooked 2.5 min in distilled water and then cooled in water without agitation. Figure 4 shows a typical force-time curve measured by the instrument on a cooked spaghetti strand using the multifaced probe with its sample-restraining device. After the compression force reached the set value of 100 *g*-force, there was a stationary pause of 0.1 sec, which was observed on the curve as the slight relaxation of the compressed strand. The probe then was retracted at 30 times the speed of its compression stroke. Stickiness was recorded either as the peak tensile force or as the tensile work to separate the probe from the sample's surface. Tensile work was computed from a force-distance curve obtained by conversion from the force-time curve.

The highest speed of retraction on the instrument is 10 mm/sec, or 3.3 times faster than the speed used in this work. The higher the speed of retraction, the higher the maximum tensile force, and the lower the tensile area. All measurements reported in this work were done at a rate of retraction of 3 mm/sec to avoid vibrations that occurred at high speeds.

Within 1 min of elapsed time, it was possible to position a sample, record the force-time curve, retrieve the adhesion portion of the curve, and store the data. In this investigation, we measured up to five replicate strands at 1-min intervals. The curve shown in Figure 4 was reproduced with good precision. When five replicate strands were cooked at 1-min intervals, aged for 30 min, and then processed to measure stickiness at 1-min intervals, the coefficient of variation (CV) for the peak force of the tensile portion of the curve was 3.4%, whereas the CV for the tensile work was 8.6%.

Stickiness Measured by the Texture Analyzer

Stickiness of cooked and mounted noodle and spaghetti strands was compared with increased aging time up to 150 min at ambient conditions. Families of stickiness curves for the two samples of noodles aged up to 110 min are shown in Figure 5. The tensile work values and the maximum tensile force values were taken from the families of curves in Figure 5A and B. Those two parameters were used to construct the time-change curves shown in Figure 6A and B, respectively.

After being held for 30–40 min at ambient conditions, the noodles made from HWW flour were shown by either parameter in Figure 6 to be stickier than those made from durum flour. Thus, stickiness measurements made at any time between 40 and 110 min differentiated between those samples. Similar data were obtained on spaghetti strands made from the two flours (data not shown). Preliminary sensory data on surface differences indicate agreement with the instrumental data.

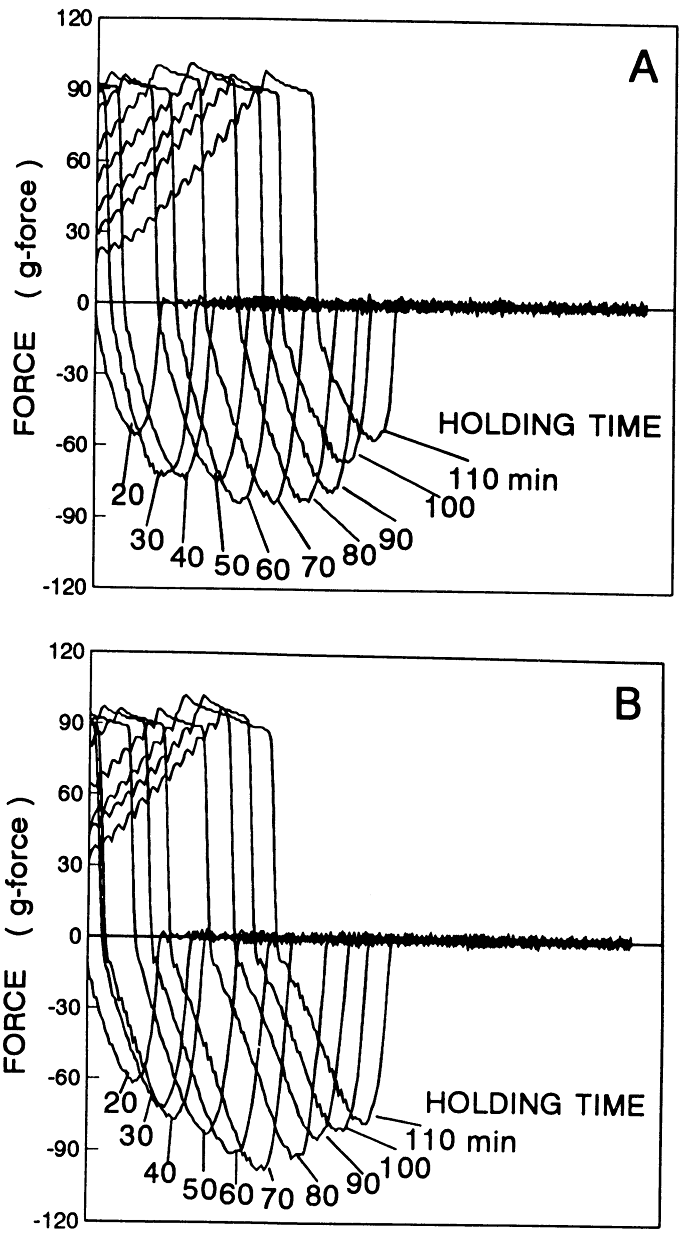

Fig. 5. Force-time curves on noodles after holding the cooked mounted strands for different times under ambient conditions (25°C and 61% rh). The noodles, made from durum (A) and HWW wheat flours (B), were cooked in boiling distilled water for 2.5 min, cooled in distilled water for 1.5 min at 25°C, then mounted.

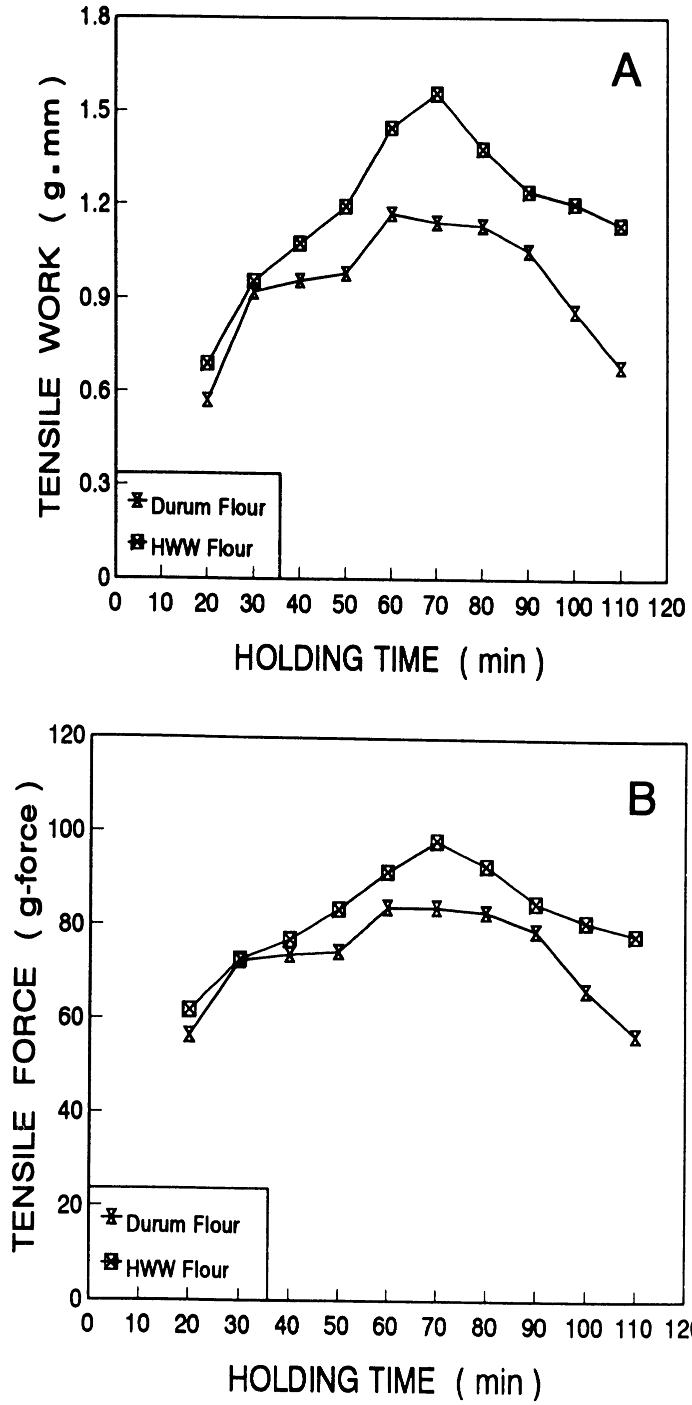

Fig. 6. Stickiness measured by tensile work (A) and peak tensile force (B) of cooked noodles aged simultaneously at 25°C and 61% rh.

Effect of Relative Humidity on Stickiness Measurement

Cooked spaghetti strands were made from durum and HWW flours, mounted, and aged for up to 150 min in the laboratory at 61 or 74% rh and 25°C. When stickiness was measured as peak tensile force, and when the peak tensile force was plotted against aging time, the plots all showed a rise followed by a decline in stickiness (Fig. 7). Spaghetti from durum wheat reached approximately the same maximum tensile force with time at the two relative humidities, but spaghetti from HWW reached slightly different peak values. The maximum tensile force was reached in approximately one-half the holding time at 61 vs. 74%, for both HWW and durum spaghetti (Fig. 7A and B). The data on tensile work versus aging time of mounted spaghetti (Fig. 8) showed the same trend.

In spite of the changing ambient conditions in our laboratory during the summer and fall months, stickiness of noodles measured as maximum tensile force during aging under ambient conditions showed CV of 5.1–6.0% (Table I). That precision for maximum tensile force (stickiness) compared favorably with CV previously measured: 6.3% by Dexter et al (1983a) and 6.4–22.9% by Voisey et al (1978). Stickiness measured in terms of maximum tensile work versus aging time showed CV that ranged from 8.8 to 13.0% (Table II). The tensile work may include forces that not only to overcome the adhesion between the probe and the surface of a strand, but also overcome cohesion within a strand.

When the spaghetti and noodles were cooked in artificially hard water, the precision of measuring stickiness by either parameter was somewhat improved. The CV for maximum tensile force

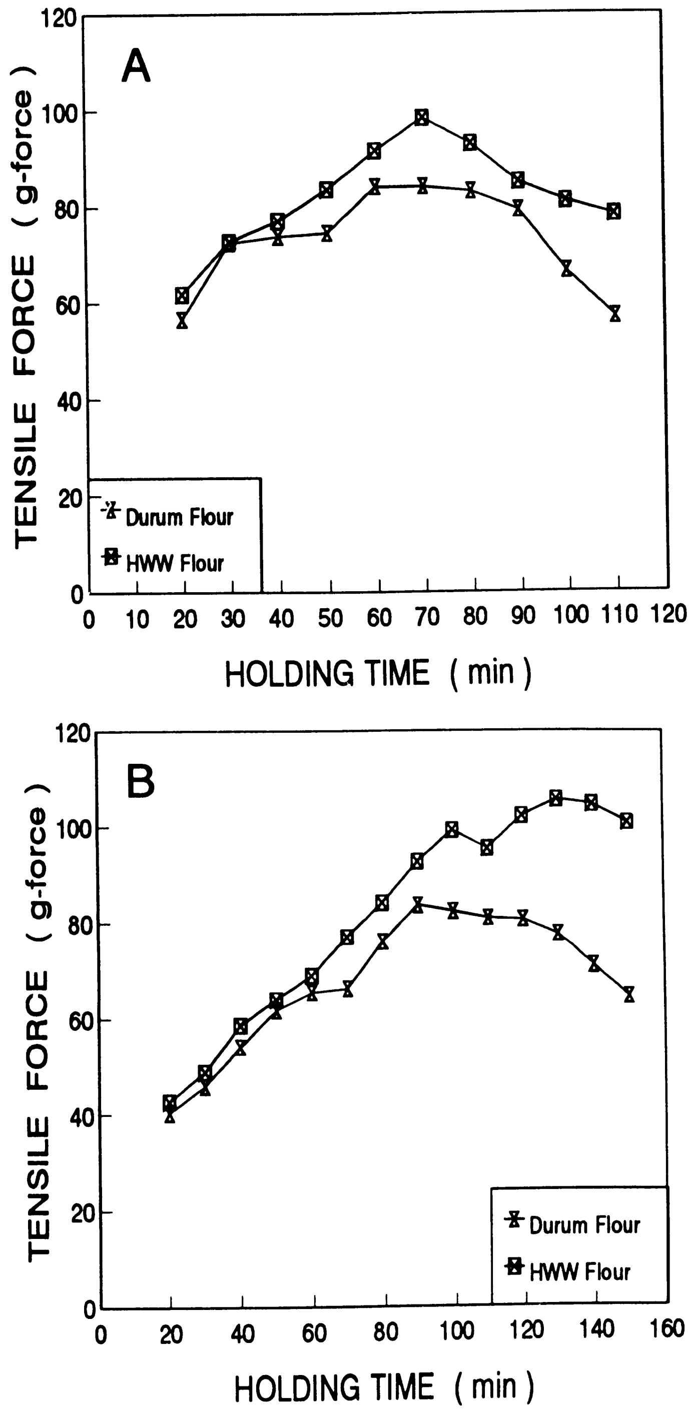

Fig. 7. Stickiness (peak tensile force) of cooked noodles aged simultaneously under two conditions: **A,** 25°C, 61% rh; **B,** 25°C, 74% rh.

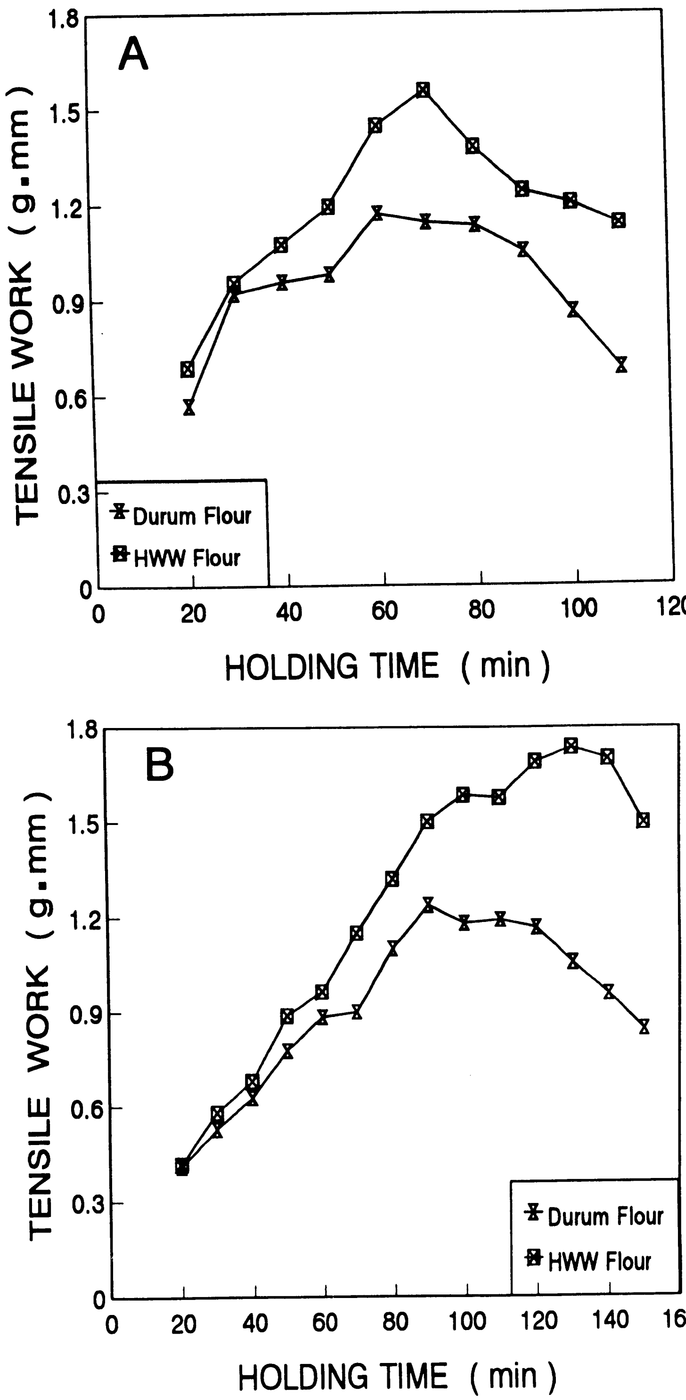

Fig. 8. Stickiness (tensile work) of cooked noodles aged simultaneously under two conditions: **A,** 25°C, 61% rh; **B,** 25°C, 74% rh.

ranged from 4.3 to 5.3% (Table III), and the CV for maximum tensile work ranged from 8.9 to 10.9% (Table IV).

When ambient conditions did not change during aging of the strands, the precision of measuring stickiness by either parameter (maximum tensile force or maximum tensile work) was excellent; the CV ranged from 2.3 to 3.8%. Obviously, measuring the stickiness simultaneously on strands from two samples, one of which could be a reference standard, would yield precise data.

Other Factors Affecting Stickiness Measurements

Two samples of spaghetti, one made from durum wheat flour and the other made from HWW wheat flour, and two samples of noodles made in the same way, were tested for stickiness while the maximum compression force was varied. Figure 9A shows that when the maximum applied force was between 75 and 125 *g*-force, the tensile portion of the force-time curve was practically constant for cooked durum spaghetti. Figure 9B shows the same result for cooked HWW spaghetti. Moreover, cooked noodles made from the durum and HWW wheat flours gave the same tensile curves for 75–125 *g*-force and 75–100 *g*-force, respectively (data not shown). Earlier investigators (Voisey et al 1978, Dexter et al 1983a), who measured stickiness as the maximum tensile force in a compression-tension method, demonstrated the independence of stickiness values over a range of compression forces. In this work, a maximum compression of 100 *g*-force was chosen for all samples.

The multifaced probe was designed so that both the surface area and surface smoothness were variable. The rotating turret contained six probes, three of which had dual-probe ends that were used on spaghetti strands because of their curved surface; a single-probe end was used on noodles.

In one experiment, the surface of one pair of probe ends was covered with vinyl rubber film; the polished polystyrene surface of another pair was left uncovered. These two pairs of probes were used to measure peak tensile force versus aging time for cooked spaghetti (Fig. 10). The surface covered with rubber film gave increased stickiness values compared to those given by the uncovered polystyrene surface, but it gave the same variance (data not given).

Cleaning the surfaces of the rubber-covered and the uncovered polystyrene probes was not necessary. The stickiness values were not statistically different, whether or not the probe surfaces were wiped with a damp cloth between measurements on cooked noodles or spaghetti (data not given). No residue was observed visually on the probe's tip. Those results indicate that the force recorded on the probe was predominantly that required to overcome surface adhesion rather than cohesiveness of the cooked spaghetti or noodle.

As expected from the work of Dexter et al (1983b, 1985), cooking spaghetti in artificially hard versus distilled water increased

TABLE I
Stickiness of Spaghetti and Noodles[a] Measured by Maximum Tensile Force During Aging of Cooked Strands

Spaghetti				Noodles			
Ambient Conditions		Tensile Force (*g*-force)		Ambient Conditions		Tensile Force (*g*-force)	
% rh	°C	Durum Flour	HWW[b] Flour	% rh	°C	Durum Flour	HWW Flour
50	26	54.3	64.8	67	24	86.3	99.2
50	26	53.0	66.3	69	25	85.5	102.3
50	26	58.0	69.9	70	24	79.6	89.6
61	22	58.8	62.5	74	23	93.0	105.8
74	24	59.6	72.6	74	23	83.6	100.3
Mean		56.8	67.2			85.3	99.2
SD[c]		2.9	4.0			4.4	5.4
CV[d], %		5.1	6.0			5.2	5.5

[a]Cooked in distilled water and stored under ambient conditions for 60–100 min.
[b]Hard white winter wheat.
[c]Standard deviation.
[d]Coefficient of variation.

TABLE II
Stickiness of Spaghetti and Noodles[a] Measured by Maximum Tensile Work During Aging of Cooked Strands

Spaghetti				Noodles			
Ambient Conditions		Tensile Work (g·mm)		Ambient Conditions		Tensile Work (g·mm)	
% rh	°C	Durum Flour	HWW[b] Flour	% rh	°C	Durum Flour	HWW Flour
50	26	0.90	1.27	67	24	1.33	1.59
50	26	0.85	1.28	69	25	1.26	1.79
50	26	0.99	1.50	70	24	1.07	1.32
61	22	1.15	1.52	74	23	1.36	1.74
74	24	1.05	1.72	74	23	1.24	1.54
Mean		0.99	1.46			1.25	1.60
SD[c]		0.12	0.19			0.11	0.19
CV[d], %		12.1	13.0			8.8	11.9

[a]Cooked in distilled water and stored under ambient conditions for 60–100 min.
[b]Hard white winter wheat.
[c]Standard deviation.
[d]Coefficient of variation.

TABLE III
Stickiness of Spaghetti and Noodles[a] Measured by Maximum Tensile Force During Aging of Strands after Cooking in Artificially Hard Water

Spaghetti				Noodles			
Ambient Conditions		Max. Tensile Force (*g*-force)		Ambient Conditions		Max. Tensile Force (*g*-force)	
% rh	°C	Durum Flour	HWW[b] Flour	% rh	°C	Durum Flour	HWW Flour
61	23	72.7	64.1	60	23	67.0	76.0
62	23	71.7	56.9	60	23	68.6	72.9
62	23	68.0	57.8	62	23	63.6	77.4
63	23	69.9	56.8	62	24	67.0	77.0
65	22	78.0	59.3	65	24	73.0	82.0
Mean		72.1	59.0			67.8	77.6
SD[c]		3.8	3.0			3.4	3.3
CV[d], %		5.3	5.1			5.0	4.3

[a]Cooked in artificially hard water and stored under ambient conditions for 60–100 min.
[b]Hard white winter wheat.
[c]Standard deviation.
[d]Coefficient of variation.

TABLE IV
Stickiness of Spaghetti and Noodles[a] Measured by Maximum Tensile Work During Aging of Strands After Cooking in Artificially Hard Water

Spaghetti				Noodles			
Ambient Conditions		Tensile Work (g·mm)		Ambient Conditions		Tensile Work (g·mm)	
% rh	°C	Durum Flour	HWW[b] Flour	% rh	°C	Durum Flour	HWW Flour
61	23	1.81	1.49	60	23	0.91	1.15
62	23	1.68	1.16	60	23	0.69	1.01
62	23	1.42	1.16	62	23	0.87	1.26
63	23	1.69	1.35	62	24	0.84	1.03
65	22	1.80	1.31	65	24	0.89	1.16
Mean		1.68	1.29			0.84	1.12
SD[c]		0.16	0.14			0.09	0.10
CV[d], %		9.5	10.9			10.7	8.9

[a]Cooked in artificially hard water and stored under ambient conditions for 60–100 min.
[b]Hard white winter wheat.
[c]Standard deviation.
[d]Coefficient of variation.

stickiness for the durum samples. The average maximum tensile force upon aging under ambient conditions was 56.8 ± 2.9 *g*-force for durum spaghetti cooked in distilled water (Table I), and 72.1 ± 3.8 *g*-force for that cooked in artificially hard water (Table III). However, stickiness for the HWW samples cooked in distilled water decreased from 67.2 ± 4.0 *g*-force (Table I), to 59.0 ± 3.0 *g*-force when cooked in artificially hard water (Table III). Overcooking appears to eventually cause erosion of starch from a strand's surface. The starch on the surface of HWW spaghetti apparently was overcooked and sloughed off (Dexter et al 1985). The loss of surface starch from cooked spaghetti from HWW probably exposed denatured gluten protein that reduced stickiness.

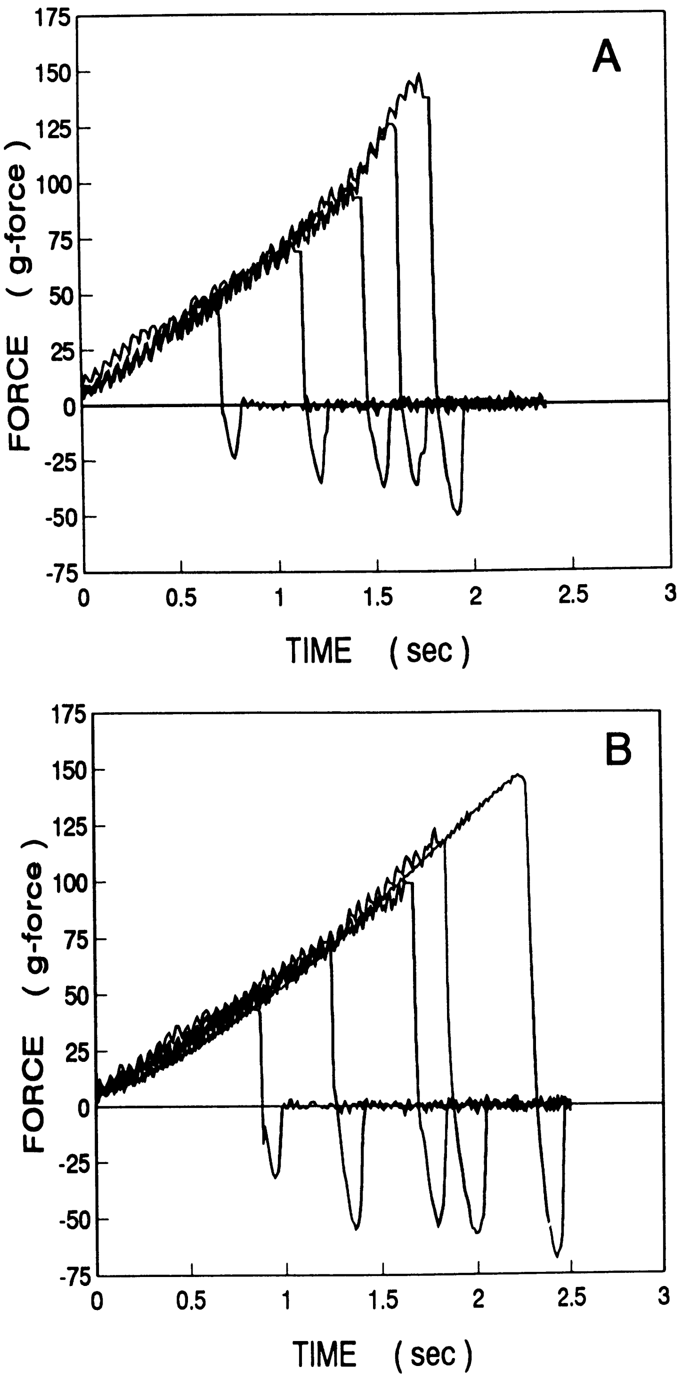

Fig. 9. Force-time curves of cooked spaghetti made from durum wheat (**A**) and HWW wheat (**B**). The samples were cooked for 11 min in boiling water, cooled for 2 min in cold water, mounted, held for 60 min under ambient conditions, and then subjected to a maximum compression of 50–150 *g*-force.

Stickiness of Commercial Samples of Spaghetti

Of the five brands of commercial spaghetti tested, spaghetti samples 1 and 2 were significantly stickier than were the other three samples (Table V). The three less sticky samples were produced from 100% durum flour and semolina. The two more sticky samples were from flour that probably contained some common hard wheat flour.

CONCLUSIONS

A commercial texture analyzer can be fitted with a sample-restraining device and a multifaced probe so that surface stickiness of five strands of cooked spaghetti or noodles can be measured

TABLE V
Stickiness of Cooked Commercial Spaghetti Measured by Maximum Tensile Force During Aging of Cooked Strands[a]

	Commercial Spaghetti Samples				
Variable	1	2	3	4	5
Main ingredient	Flour	Flour	100% Durum	100% Durum	100% Durum
Tensile force (*g*-force)	46.9	46.0	39.4	40.9	41.8
	46.3	43.0	42.9	45.0	40.5
	46.1	46.2	44.8	44.9	41.8
	45.1	48.1	43.4	42.2	41.8
	46.5	47.1	44.5	39.7	38.7
Mean	46.2	46.1	43.0	42.5	40.8
SD	0.67	1.91	2.16	2.37	1.29
CV, %	1.46	4.15	5.02	5.57	3.16
Statistical difference[b]	A	A	B	B	B

[a] Cooked in distilled water and stored under ambient conditions for 60–100 min.
[b] LSD = 2.36; $\alpha = 0.05$.

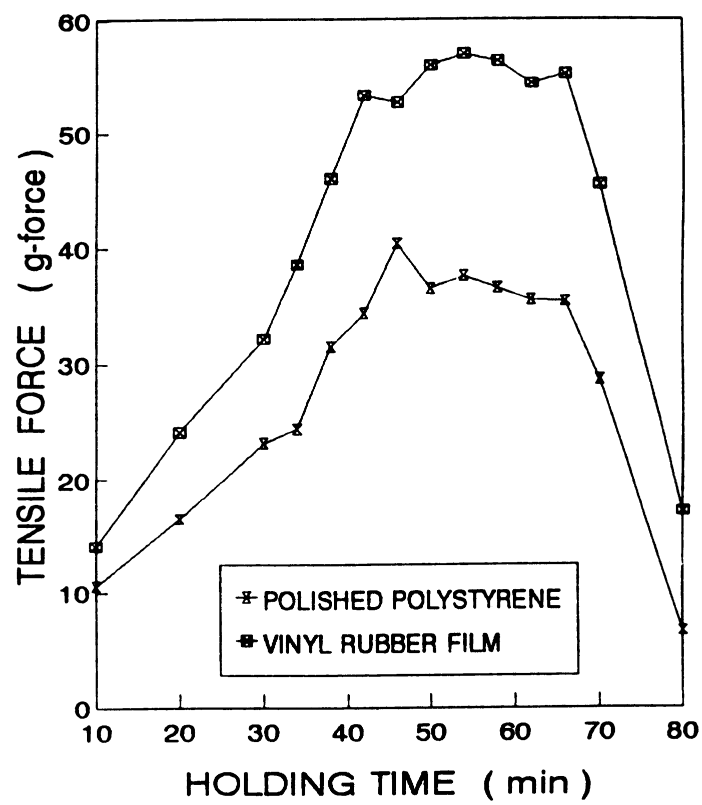

Fig. 10. Stickiness of cooked spaghetti (one strand each) measured as peak tensile force while the strands were aged simultaneously at 25°C and 67% rh. Stickiness was measured with a probe with dual tips of polished polystyrene with or without a covering of vinyl rubber film.

and recorded in 5 min. When cooked spaghetti or noodle strands are aged at 25°C under ambient relative humidity, stickiness measured as peak tensile force increases to a maximum value in 40–130 min, then it declines. Variations between 50 and 74% rh at 25°C cause insignificant differences in stickiness values measured as maximum tensile force upon aging. However, when ambient conditions vary excessively, we recommend that absolute values of stickiness not be measured. Instead, stickiness of a test sample can be compared to that of a reference standard.

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