

The Ultimate Tensile Strength of Spaghetti

Explore Engineering Innovation

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Abstract

Tensile forces are applied to spaghetti and three other sizes of solid, cylindrical pasta using a tabletop lever apparatus. One side of the lever holds a bucket that is filled with successively larger amounts of steel shot. The other side is attached to a chain that pulls on the pasta sample along its length. The diameter of the pasta sample and the mass of the bucket and steel shot are measured directly. The force and stress at failure are calculated. The maximum tensile force is found to increase as the diameter of the pasta increases. The ultimate tensile strength averaged over three samples each of angel hair, vermicelli, and spaghetti is found to be 7.31 ± 1.83 MPa.

Introduction

Structures, both man-made and biological, are constantly subjected to forces that push, pull, bend, and twist them. The strength of those structures depends on both the type of material and the size of the structural components. For example, engineered spider silk can be several times stronger than a steel wire of similar size, but steel wire is usually stronger because it is thicker. Understanding material properties is essential when designing and building a structure.

Pasta is not commonly considered a building material, but knowledge of its material properties can be useful for two reasons. First, knowledge of the material properties can assist quality control during manufacture. Dry pasta is a foodstuff commonly made of durum wheat and water that is mixed, shaped, then dried. The conditions within which it is manufactured, such as ambient humidity and drying temperature, affect the product. Some factories use material property tests to monitor the quality of their product. Breaking strength from a bending test, for instance, helps predict whether the pasta is likely to break in transit (Cole, 2007).

A second reason to be interested in material properties of spaghetti, and one that is more broadly applicable, is that pasta serves as a readily available and cost-effective building material for educational purposes. Spaghetti acts as a good model for truss members, which are usually slender and theoretically experience only tensile or compressive forces. To design a truss, it is important to know the ultimate tensile strength, which determines maximum tensile forces, and the Young's modulus, which partially determine the maximum compressive forces.

The tensile force required to pull a material apart depends on two things: the inherent strength of the material and the cross-sectional area of the sample. A larger cross-section requires a larger force to pull it apart because there are more atomic bonds to pull apart. Engineers often consider **stress**, which is a measure of force concentration—how much force is applied per unit area.

Tension tests are one of the most common mechanical property tests. Pulling on both ends of a rod with an increasing amount of force, making sure to apply the force only along the length of the rod, will cause it to break. The stress in the rod when it fractures is an estimate of the **ultimate tensile strength** for the

material. Knowledge of the ultimate tensile strength allows engineers to predict how much force a truss member in tension can withstand without breaking. A prior study (Guinea, Rojo, & Elices, 2004) used an Instron 4111 universal testing machine to test Barilla spaghetti in tension and reports ultimate tensile strength in the range 26-33 MPa (see Figures 3 and 5 in the reference). The current study serves to provide additional experimental data to the literature and proposes a new method that is simple and low-cost that may be of use for future studies that test the tensile strength of spaghetti or other solid, cylindrical pasta.

Methods

Sample Preparation

Three sizes of solid, cylindrical pasta are used for this experiment: angel hair, vermicelli, and spaghetti. This order is from smallest to largest diameter. The brand of pasta is San Giorgio. All samples are from boxes of mostly unbroken pasta purchased from a grocery store and stored indoors. Four samples of each pasta type are tested to failure. Digital calipers are used to measure the diameter of each pasta sample before the test begins. The precision of the digital calipers is ± 0.1 mm.

Ribbons are epoxied to each end of the pasta as shown in Figure 1. The 5-minute, two-part epoxy cures for more than six hours. The length of pasta between the ribbons is 6 ± 1 cm. The distance between the ends of the ribbons is 13 ± 0.2 cm. The loop created by each ribbon fits an S-hook that is attached to a chain on the testing apparatus shown in Figure 2. The loose fit between the ribbon and s-hook reduces torsional forces so that most of the force on the pasta is directed along its length (i.e., a tensile force).

Force Application

Force is applied to each pasta sample using the testing apparatus shown in Figure 2. The top bar acts as a lever that balances the weight of the bucket on the left with the tension in the chain on the right. The pasta sample, as shown in Figure 1, is connected to the chain on top and a pin on the bottom using two S-hooks. The top bar should be roughly level, so the chain is perpendicular to the bar.

Once the pasta sample is mounted in the apparatus, steel shot is slowly added to the bucket until the pasta breaks. If the location of the fracture along the pasta's length is adjacent to the epoxy, then another sample should be prepared and tested; this may be a sign that the sample experienced bending or torsional forces. A scale is used to measure the mass of the bucket and steel shot that caused the pasta to break. The precision of the scale is ± 1 g.

Data Analysis

On the left-hand side of the lever, the bucket and steel shot create a downward force equal to

$$W = mg, \tag{1}$$

where W is the weight of the bucket and steel shot, m is the mass of the bucket and steel shot, and g is the acceleration due to gravity.

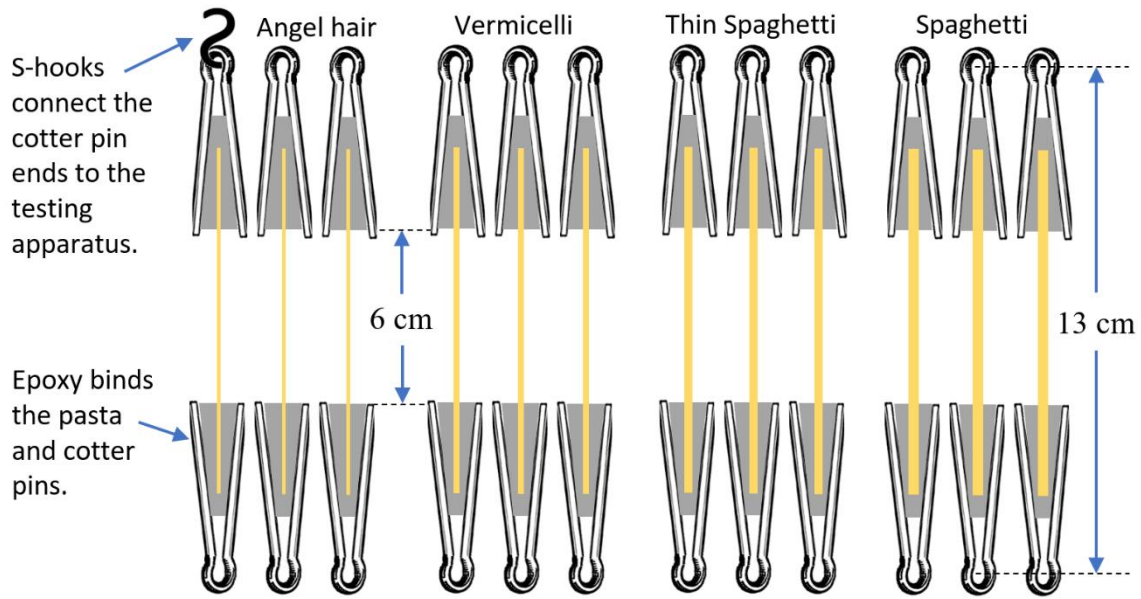


Figure 1: Pasta samples are epoxied to ribbons so they can be attached to the testing apparatus shown in Figure 2.

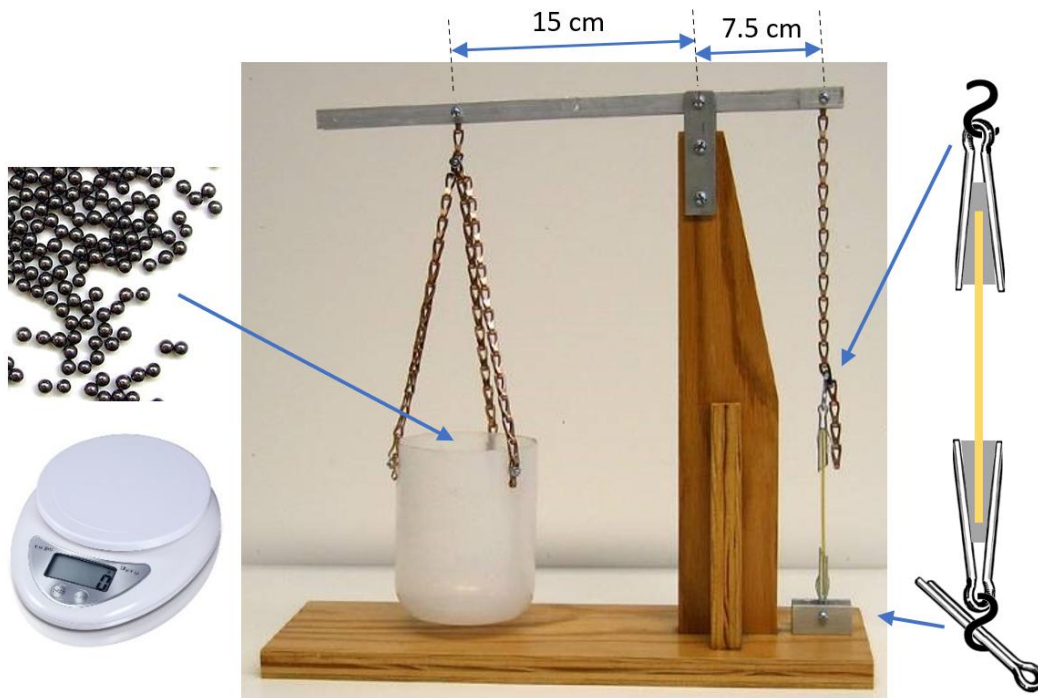


Figure 2: The tension testing system consists of a lever with a bucket to hold the steel shot (left) and a mechanism to connect the spaghetti sample using ribbons and S-hooks (right).

Before the pasta breaks, the system is stationary, which indicates that all forces and moments are balanced. The moment caused by the bucket and shot is balanced by the chain and pasta on the right-hand side. The distance between the bucket connection and the lever pivot is 15.0 ± 0.1 cm. The

distance between the lever pivot and the right-hand side chain is 7.5 ± 0.1 cm. The force in the chain—which is also the tensile force in the spaghetti sample—is therefore

$$F = 2W \quad (2)$$

where F is the force acting on the pasta sample and W is the weight of the bucket and steel shot.

The diameter of each pasta sample is measured using digital calipers. The cross-sectional area of the sample is then calculated from the diameter using

$$A = \frac{\pi}{4} d^2 \quad (3)$$

where A is the cross-sectional area and d is the diameter. The stress in the pasta sample can then be calculated using the force from Equation (2) and the cross-sectional area from Equation (3) as

$$\sigma = \frac{F}{A} = \frac{2W}{\frac{\pi}{4} d^2} \quad (4)$$

The value of σ calculated from the force that caused the pasta to break is an estimate of the ultimate tensile strength for this material. If the ultimate tensile strength, σ_{ut} , is the same for all diameters of pasta tested in this experiment, then the relationship between the force at failure, F_f , and the pasta diameter, d , would be

$$F_f = \sigma_{ut} \frac{\pi}{4} d^2 \quad (5)$$

Results

Direct Measurements

Four samples each of angel hair, vermicelli, and spaghetti were tested to failure. The diameter of each sample and the mass of the bucket and steel shot at the time of failure are shown in Table 1.

Stress Calculation

The weight of the bucket and steel shot is calculated from its mass using Equation (1). The force applied to the pasta during failure is calculated from the weight of the bucket and steel shot using Equation (2). The cross-sectional area of each sample is determined from the diameter using Equation (3). These values are all shown in Table 2.

The force on the spaghetti and the cross-sectional area are used to calculate the stress in the spaghetti at fracture using Equation (4). This is the estimate of the ultimate tensile strength for spaghetti-type pasta. The stress for each sample and the average for each type of pasta are shown in Table 3. The average stress over all samples is 7.31 MPa and the standard deviation is 1.83 MPa.

Table 1: The diameter of each sample was measured with a digital caliper. The bucket filled with steel shot was weighed on a scale after the pasta sample failed.

Sample number	1	2	3	4	5	6
Pasta type	Angel Hair	Angel Hair	Angel Hair	Angel Hair	Vermicelli	Vermicelli
Diameter (mm)	1.28	1.31	1.27	1.29	1.51	1.53
Bucket & shot mass (g)	607	393	492	503	657	337

Sample number	7	8	9	10	11	12
Pasta type	Vermicelli	Vermicelli	Spaghetti	Spaghetti	Spaghetti	Spaghetti
Diameter (mm)	1.48	1.57	1.78	1.81	1.76	1.74
Bucket & shot mass (g)	597	617	1474	980	915	894

Table 2: Cross-sectional area of each sample and force on each side of the apparatus' lever are calculated from the data in Table 1.

Sample number	1	2	3	4	5	6
Area (m ²)	1.29E-06	1.35E-06	1.27E-06	1.31E-06	1.79E-06	1.84E-06
Area (m ² x 10 ⁻⁶)	1.29	1.35	1.27	1.31	1.79	1.84
Bucket & shot weight (N)	5.95	3.85	4.82	4.93	6.44	3.30
Force on pasta (N)	11.90	7.70	9.64	9.86	12.88	6.61

Sample number	7	8	9	10	11	12
Area (m ²)	1.72E-06	1.94E-06	2.49E-06	2.57E-06	2.43E-06	2.38E-06
Area (m ² * 10 ⁻⁶)	1.72	1.94	2.49	2.57	2.43	2.38
Bucket & shot weight (N)	5.85	6.05	14.45	9.60	8.97	8.76
Force on pasta (N)	11.70	12.09	28.89	19.21	17.93	17.52

Table 3: Stress is calculated based on cross-sectional area and force at failure for each sample, as given in Table 2.

Sample number	1	2	3	4	5	6
Pasta type	Angel Hair	Angel Hair	Angel Hair	Angel Hair	Vermicelli	Vermicelli
Stress in pasta (MPa)	9.25	5.71	7.61	7.54	7.19	3.59

Sample number	7	8	9	10	11	12
Pasta type	Vermicelli	Vermicelli	Spaghetti	Spaghetti	Spaghetti	Spaghetti
Stress in pasta (MPa)	6.80	6.25	11.61	7.47	7.37	7.37

Relationship Between Force and Diameter

Figure 3 plots the force needed to break the pasta sample as a function of its diameter—data included in Table 2. The results show that force increases with sample diameter.

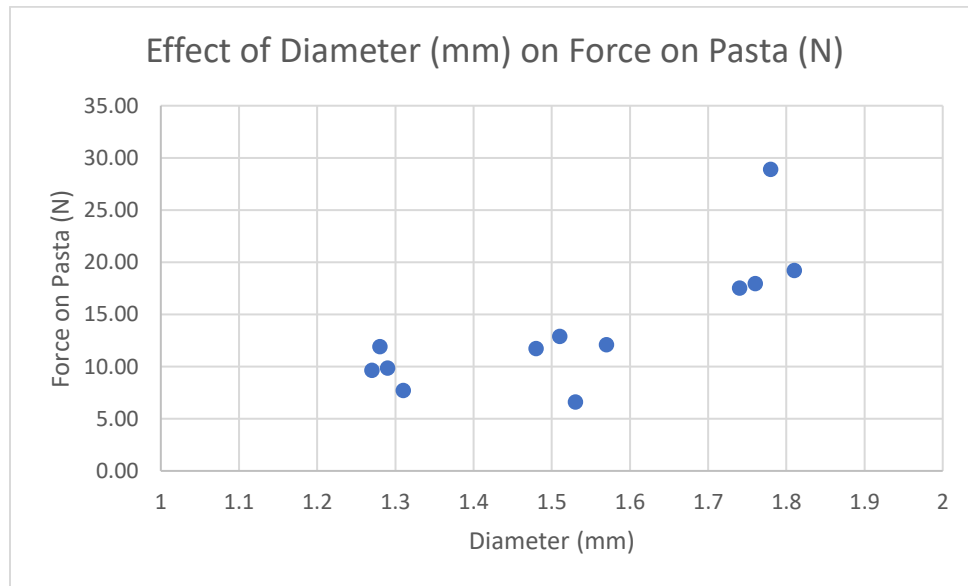


Figure 3: This is a plot of the force needed to break the pasta sample as a function of the pasta diameter for all 12 samples.

Figure 4 is a log-log plot of the data shown in Figure 3, which plots the force needed to break the pasta vs the pasta diameter. The line of best fit for the data in Figure 4 is

$$\log F = 2.2583 \log d + 0.6982. \quad (6)$$

Rearranging Equation (6), to solve for force:

$$\log F = \log d^{2.2583} + \log 5.003,$$

$$\log F = \log(5.003 \cdot d^{2.2583}),$$

$$F = 5.003 \cdot d^{2.2583}$$

$$F = 6.37 \cdot \frac{\pi}{4} d^{2.2583} \quad (7)$$

Equation (7) is a power-law fit to the force and diameter data presented in Table 1 and Table 2, respectively.

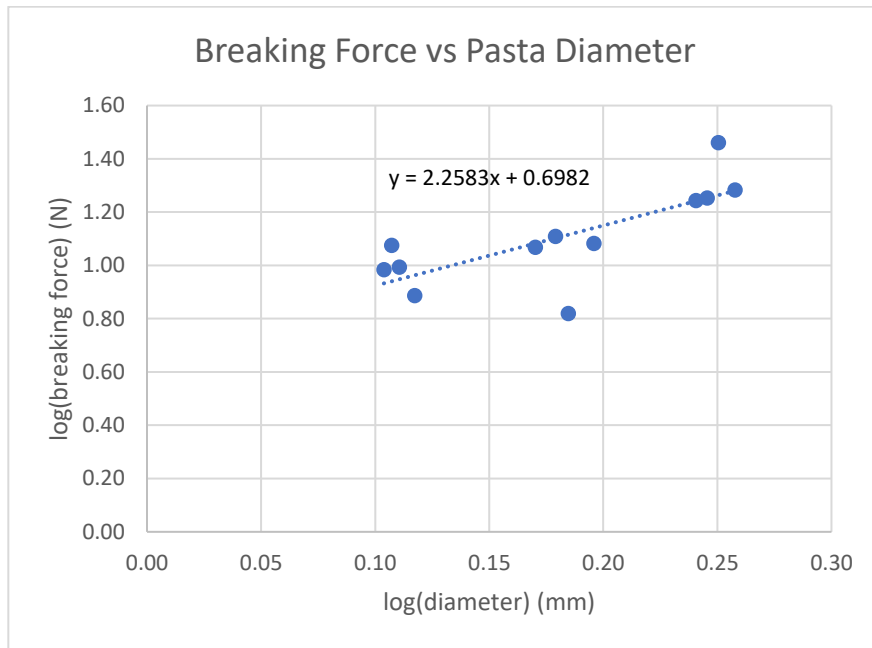


*Figure 4: This is a plot of **log(force)** vs **log(diameter)** for all 12 samples. Equation (6) is the line of best fit for this data.*

Discussion

The calculated values for ultimate tensile strength vary among the three pasta samples. The angel hair samples have a spread of 5.71 to 9.25 MPa, vermicelli has a spread of 3.59 to 6.80 MPa, while spaghetti has a spread of 7.37 to 11.61. Since all the samples from one type of pasta are assumed to be made from the same materials and in the same manufacturing conditions, the ultimate tensile strength should be relatively similar and consistent. However, the observed variation in the tensile strength shows that there were most likely some inaccuracies or errors in the experiment. There are not any trends in our data that would suggest inaccuracies, but for both angel hair and vermicelli, the longest diameter pasta had the lowest tensile strength, which suggests that the diameter was probably over-measured and caused the cross-area to be overestimated.

Equation (7) and theoretical Equation (5) should be similar, since they represent the relationship between diameter and force of failure of the same group of samples. However, in our case the exponent is 2.2583, which is slightly above the expected 2. Ideally, if the material was perfectly consistent and only diameter influenced strength, the force should scale with diameter squared. A higher exponent suggests that inconsistencies were made during the experiment. Not all samples may have experienced pure tensile force straight down the center, and inaccuracies in epoxy bonding or placing the pasta straight may have affected the actual transmitted force. These results suggest room for improvement in the precision of the setup and consistency in sample preparation. In the end, in the actual experiment, 6.37 MPa of stress is obtained, instead of 7.31 MPa of theoretical stress.

Percentage of error of the coefficient can be calculated with

$$\text{Percentage of Error} = \frac{\text{Error}}{\text{True Value}} = \frac{|6.37\text{MPa} - 7.31\text{MPa}|}{7.31\text{MPa}} \cdot 100\% = 12.9\%.$$

Percentage of error of the exponent can be calculated with

$$\text{Percentage of Error} = \frac{\text{Error}}{\text{True Value}} = \frac{2.2583 - 2}{2} \cdot 100\% = 12.9\%.$$

Some possible sources of error in this experiment are: First, the pasta diameter is tiny, so small errors with the measurement can change the area of the cross-section a lot, therefore affecting stress. Second, since it's difficult to predict when the pasta will break, so there is often an excess amount of steel shots added after the force of failure has reached due to human reaction time, causing the measure of force of failure to become bigger than the actual value. Another possible error is if the pasta isn't aligned perfectly straight up or if the force isn't applied directly along its length, the pasta will bend and cause it to break faster, which will undermine the tensile strength. Lastly, the pasta might also have cracks or chips on it, which will cause failure faster and will also undermine tensile strength.

Conclusion

Four samples each of angel hair, vermicelli, and spaghetti were tested in tension using a tabletop lever. The ultimate tensile strength of spaghetti was found to be 7.31 ± 1.83 MPa. Future studies should include a larger number of samples to improve accuracy and precision.

The brand of pasta used for this experiment was San Giorgio. Other brands may use different ingredients or recipes to manufacture their pasta, so it is unclear how broadly these results apply. Additionally, it would be interesting to study the effect of temperature and humidity on material properties.

References

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