

Allowable Vacuum for Wood Turning

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Woodturning crafters desire a device that allows a smooth finish on the bottom of the item. A vacuum chuck device allows the crafted item to be held without marring the finished surface, thus allowing a smooth finish to be applied. The different types of wood, the variations in grains, and the size of the vacuum chuck however, require careful control of the vacuum to prevent fracturing of the finished piece. This paper calculates the allowable vacuum on specific woods.

It should be noted that wood material can have great variation in grain, moisture content, and voids. Worm or insect holes may exist that could greatly weaken any wood material. The analysis and results provided here assume that the wood material is of uniform and average consistency, 3/16" uniform thickness, no voids and with 12% moisture content.

The calculated fracture stresses depend greatly on whether the pressure is applied across the grain or with the grain.



Wood is decidedly weaker under conditions where pressure is applied with the grain. Because most cases of wood turning use with-grain conditions, we will calculate the allowable stress using the with-grain condition. We will also use a factor of safety of two to compensate for 1) weak spots, 2) low moisture content, 3) wood material variations, and 4) poor vacuum gauge calibration. In most cases, a safety factor of two will be sufficient but if you feel the unknowns are great then use a higher number by multiplying the allowable vacuum (Table 2) value by the ratio of 2/higher FS to get a lower allowable, or, a smaller chuck will serve the same purpose.

The calculations assume circular flat plates of constant thickness t with a uniform loading pressure w . The basic formula for determining the allowable pressure on a round object is:

Edges supported with uniform load over entire surface.

$$S = k \times \frac{w \times r^2}{t^2 \times FS}$$

S = stress in psi
 r = radius in inches
 w = vacuum pressure in psi
 t = plate thickness in inches = 3/16"
 k = coefficient for circular plates = 1.24 for this case
 FS = Factor of Safety

Source: Marks Standard Handbook for Mechanical Engineers, 8th edition pg 5-52

We know the values for S of various wood types from engineering tables (see Table 1). For our calculation we will use the values of shear strength parallel to grain since that is the typical condition during wood turning and is probably worst case.

It should be noted that the inside of bowls will usually have a spherical shape and will thus be stronger than a flat plate under vacuum, but I will ignore that condition to simplify the analysis. It is difficult to determine the different spherical configurations possible and the allowable vacuum would be higher anyway. Note also that this analysis is performed for near sea-level atmosphere of 14.7 psi or 29.9 in hg. Should the operation be performed at altitude such as Denver, the differential pressure will be less than the normal 29.9 in hg, therefore a somewhat higher vacuum can be utilized. To estimate, use the ratio of 29.9/atmospheric pressure (in hg). To convert lbs/in² to in hg, multiply lbs/in² by 2.036¹.

Table 1 - Strength properties of woods at 12 % moisture content.²

Wood Type	Shear Strength parallel to grain – lb/in²
<u>HARDWOODS</u>	
Ash, white	1950
Basswood	990
Beach	2010
Birch, yellow	1880
Cherry, black	1700
Cottonwood, eastern	930
Elm, american	1510
Elm, rock	1920
Sweetgum	1600
Hickory, shagbark	2430
Mahogany, Cent American	1230
Maple, sugar	2330
Oak, red northern	1780
Oak, white	2000
Poplar, yellow	1190
Tupelo, black	1340
Walnut, black	1370
<u>SOFTWOODS</u>	
Cedar, western red	860
Cypress	1000
Douglas Fir, coast	1160
Hemlock, eastern	1060
Hemlock, western	1250
Larch, western	1360
Pine, red	1210
Pine, ponderosa	1130
Pine, eastern white	900
Pine, western white	1040
Pine, shortleaf	1390
Redwood	940
Spruce, sitka	1150
Spruce, white	1080

¹ Marks Handbook for Mechanical Engineers, 8th Edition, pg 1-49

² Ibid, pg 6-124, table 2

Notice that some hardwoods are much weaker than some softwoods so be careful in your assumptions when using a vacuum chuck.

Now we will determine the allowable vacuum for various size vacuum chucks; 2", 4", 5", and 8" for each type of wood using the aforementioned formula and Table 1 properties.

Wood Type	Shear (S) (psi)	Allowable vacuum – in hg, 3/16" thick plate			
		2" Chuck (in hg)	4" Chuck (in hg)	6" Chuck (in hg)	8" Chuck (in hg)
HARDWOODS					
Ash, white	1950	29.9	29.9	24.9	14.0
Basswood	990	29.9	28.4	12.6	7.1
Beach	2010	29.9	29.9	25.7	14.4
Birch, yellow	1880	29.9	29.9	24.0	13.5
Cherry, black	1700	29.9	29.9	21.7	12.2
Cottonwood, eastern	930	29.9	26.7	11.9	6.7
Elm, american	1510	29.9	29.9	19.3	10.8
Elm, rock	1920	29.9	29.9	24.5	13.8
Sweetgum	1600	29.9	29.9	20.4	11.5
Hickory, shagbark	2430	29.9	29.9	29.9	17.5
Mahogany, Cent American	1230	29.9	29.9	15.7	8.8
Maple, sugar	2330	29.9	29.9	29.8	16.7
Oak, red northern	1780	29.9	29.9	22.7	12.8
Oak, white	2000	29.9	29.9	25.5	14.4
Poplar, yellow	1190	29.9	29.9	15.2	8.5
Tupelo, black	1340	29.9	29.9	17.1	9.6
Walnut, black	1370	29.9	29.9	17.5	9.8
SOFTWOODS					
Cedar, western red	860	29.9	14.7	11.0	6.1
Cypress	1000	29.9	28.7	12.8	7.2
Douglas Fir, coast	1160	29.9	29.9	14.8	8.3
Hemlock, eastern	1060	29.9	29.9	13.5	7.6
Hemlock, western	1250	29.9	29.9	16.0	8.9
Larch, western	1360	29.9	29.9	17.4	9.8
Pine, red	1210	29.9	29.9	15.4	8.7
Pine, ponderosa	1130	29.9	29.9	14.4	8.1
Pine, eastern white	900	29.9	25.9	11.5	6.5
Pine, western white	1040	29.9	29.9	13.3	7.5
Pine, shortleaf	1390	29.9	29.9	17.8	10.0
Redwood	940	29.9	27.0	12.0	6.8
Spruce, sitka	1150	29.9	29.9	14.7	8.3
Spruce, white	1080	29.9	29.9	13.8	7.8

Note: All wood Shear values for 2" chuck exceed the max vacuum attainable, therefore the max vacuum of 29.9 in hg is used. Shear values greater than 1040 psi for 4" chuck calculate to greater than the maximum vacuum, therefore the max vacuum of 29.9 in hg will be used.

Vacuum Gauge. A potential error factor in determining the allowable vacuum for wood turning is the gauge. If the gauge scale is small such that you cannot easily determine whether the reading is 14 or 14.1 in hg for example, then a reading error is introduced. It is desirable to use the largest scale you can obtain. Another error is introduced if the gauge is not properly calibrated. You should have your gauge calibrated periodically, about every 6 months or so.

Biography: Mr. Marx, is not experienced in wood working, and has produced this analysis for information only. He is an Author and an Engineer. Mr. Marx received a BS (Math) from Washington University-St. Louis and performed graduate work at the University of Missouri-St. Louis. He worked as an engineer for Boeing for 32 years before retiring in 1992 and has written a book called "Nickel And Dime Millionaire" (<http://www.nickelanddime.com>). He owned and operated a web design and hosting company and developed numerous commercial software programs, notably a contracts program used by the St. Louis Association of Realtors and the St. Charles Board of Realtors.

The source to this document can be found at <http://www.twistedturner.com/vacuumchuck.htm>